Agriculture intensification population growth and cropland expansion: evidence from post-Green Revolution Andhra Pradesh

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Abstract

Increasing food demand due to rising population and urban growth may distort earth's natural landscape unless technology driven intensification helps to spare land for alternative activities. Technological intervention in agriculture has not only increased agricultural yield which reflects land saving aspect of technology but it has also reduced fallow period substantially to increase effective supply of land which mirrors land augmenting aspect of technology. Here, we examine the impact of these two aspects of technology on cropland expansion for Andhra Pradesh using district level data over the period 1970-2009. Along with it, we also investigate the impact of growth in population, urban population and literate population on cropland expansion. We use a regression model based on the IPAT framework to measure the relative impact of affluence, population and technology on resource use. Results reject land sparing hypothesis in the state since the inception of new technology. However, population pressure on cropland seem to have declined. Other important result highlights the negative impact of urban growth on cropland expansion which implies that loss of prime cropland due to urban expansion cannot be refuted.

***Keywords*:** Land sparing, Land augmentation, Land saving, Jevons' Paradox.

1. Introduction

Population driven cropland expansion has been a major driver of land use change both at global as well as regional level (Ramankutty *et al.* 2002). Population-cropland debate goes back to Malthus (1798) who predicted that carrying capacity of earth is limited to satiate food demand of increasing human population.[3] While Malthusian prediction has not been materialized yet; questions regarding feeding more and wealthier people using limited land resource are still

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[3] Studies by Meadows et al. (1970); Ehlrich and Holdren (1971) also support Malthusian hypothesis in its spirit; however, these studies generalize Malthusian idea to a much broader context which not only includes land but other natural resources also which are fundamental to economic growth.

fundamental to sustainability debate. Past century has witnessed unprecedented growth in cropland across the world which came mostly at the cost of forests and pastures (Ramankutty *et al.* 2002; Barbier 2003; Waggoner and Ausubel 2001). Additionally, industrialization led urban population further complicates the cropland expansion phenomenon by increasing competition for land (Smith *et al.* 2010). *Land sparing* or minimizing the environmental footprints of agriculture, thus, is an important sustainability criterion.[4] Land use transition can be regarded as sustainable if technology led intensification relieves enough land to accommodate urban expansion and ecological resilience.

While claims regarding the land sparing potential of technology doesn't seem invalid, empirical evidences suggest otherwise. In fact, increased efficiency of land use sometimes encourages cropland expansion by increasing the profitability agricultural operations (Lambin and Meyfroidt 2011; Rudel *et al.* 2009). This phenomenon is popularly known as *Jevons paradox* or *rebound effect* (see Alcott, 2005) in literature. William Stanley Jevons (1865) while examining the impact of increased coal use efficiency on consumption of coal observed that as the efficiency of coal use improved, thereby allowing for the production of more goods per unit of coal, total coal consumption also increased. At least two potentially complementary explanations can be provided to explain this paradox (we explain it for land). First, as the efficiency of land use increases, price of agriculture commodities decreases. Decreased commodity prices shoots up the demand of commodities (assuming that demand is price elastic) which, in turn, increases the demand of land. Second, the drive to increase profits leads producers to try to both reduce costs by reducing land use per unit of production (i.e., improving efficiency) and increase revenues by expanding the production of agricultural commodities, thus encouraging the expansion of resource consumption.

Furthermore, forest and wildlife conservation has been the major focus of land sparing studies (see, Angelsen and Kaimowitz, 2001; Tilman *et al.* 2002; Barbier 2003; Balmford *et al.* 2005; Ewers *et al.* 2009); however, cropland expansion-deforestation nexus is not a universal phenomenon. For instance, India (for Andhra Pradesh see, figure 1) has witnessed an increase both in its agricultural as well as forest land in post-independence period (Waggoner and Ausubel 2001; Singh and Narayanan 2013). In fact, many countries have witnessed rapid

[4] Technology enables to produce more food from equal amount of land which is expected to minimize environmental footprints of agriculture. This phenomenon is described as land sparing in the literature.

industrialization and urban growth in past decades which has intensified the competition for land. Indirect effect of urbanization can be discussed in terms of increasing emissions emanating from urban production-consumption activities which fuels demand for conservation. Relatively higher literacy plays an important role in creating awareness regarding environment in urban societies (Dasgupta *et al*. 2002). Since urbanization and agriculture are competitive activities from a land use perspective, it is required to enquire what role technology had played in moderating land use transition.

While land sparing has been examined at global (Balmford *et al.* 2005; Ewers *et al.* 2009) as well as national (Singh and Narayanan 2013) scales; evidences regarding land sparing at sub national scale are missing. Available empirical literature also lacks theoretical linkage to back the econometric model chosen for examining land sparing hypothesis. Recently, few researchers have used $I=PAT$ equation (Ehrlich and Holdren, 1971) to identify drivers of agricultural expansion (see, Waggoner and Ausubel 2001; Ausubel *et al.* 2012). Present study uses a variant of $I=PAT$ equation to examine the impact of technology and population on cropland expansion in Andhra Pradesh, India to draw conclusion regarding drivers of land use change in the state.

A state in India is the federal unit which determines policies regarding land use; therefore, it is a relevant scale for examining land sparing hypothesis. Rest of the study is organized as follows. Section 2 gives a brief background. Section 3 discusses the variant of $I=PAT$ equation which is used as a background for econometric study. Section 4 explains data sources, variables and econometric model. Section 5 deals with the data analysis and discussion. Section 6 concludes the main findings of the study.

2. Background and a brief review of literature

Population and affluence driven increase in consumption of primary products exerts considerable pressure on land. Early population theorists, more importantly Malthus (1798), proposed that scarcity of land with high agro-ecological suitability acts as a constraint on population growth i.e. there exists a one way causality between population and productive land and direction of this causality runs from land to population. However, early theories explaining population driven cropland expansion overlooked technological changes that might occur with increasing demand for food and other primary products with increasing population. Boserup

(1965) was the first to contend that population pressure urges farmers to adopt more intensive land use practices to increase food production. Boserup (1965) and others (Darity 1980; Robinson and Schutjer 1984) argued that agricultural intensification driven by population growth and land scarcity induces technological and institutional changes in order to increase the agricultural output from given land supply. Validity of Boserup (1965) hypothesis is confirmed by the large amount of evidences from the broad agrarian change history.

However, population and affluence are not the only factors to explain demand for agricultural land and economic instruments chosen for technology diffusion also contribute to explain cropland expansion. Seed water fertilizer technology which is rightly credited for unprecedented increase in food production in last century is a composition of various induced innovations which took place in US and Japan at the beginning of 20th century (Ruttan and Hayami 1970). Most of the countries had adopted these innovations by manipulating their agriculture systems using economic tools among which subsiding supply of technological inputs and assuring remunerative prices for new varieties have major implications on land use. Subsidies and ensured profit act as incentives to bring new lands into agriculture (Barbier and Burgess 1992). In short run, improved land use efficiency increases the profitability of agricultural operations and shoots up the cropland expansion especially when demand is price and income elastic (Lambin and Meyfroidt 2011; Rudel *et al.* 2009). This phenomenon is more probable in low income countries where income elasticity of primary products is high (Singh and Narayanan, 2013) and/or export opportunities are increasing due to trade opening (Barbier 2003; Lambin and Meyfroidt 2011).

Moreover, process and nature of economic development also affects cropland expansion. Failure of industrial sector to absorb surplus labor relieved from agriculture is a factor behind cropland expansion (Angelsen and Kaimowitz 1998; Matson and Vitousek 2006). However, this phenomenon can be reversed if labor intensive farming creates better employment opportunities drawing people into highly intensive farming (Shively and Pagiola 2004). In addition, changing complementarities between agriculture and livestock operations due to increased mechanization of agriculture also contributes to cropland expansion (Repatto 1987).

However, cropland expansion on marginal land cannot continue as any resource cannot be used beyond a limit after which its marginal productivity becomes negative (Antle and Heidebrink, 1995). In this connection, a growing body of research intends to investigate the impact of political, institutional and governance factors on land use change. Boserup (1976) calls these factors as administrative technology. Institutional and governance factors are major barriers as far as proper adoption of technology is concerned. Appropriate institutional structure reduces uncertainty in exchange, reduces transaction costs and improves allocative efficiency which in turn help to optimize cropland expansion (Culas 2007). However, Ceddila *et al.* (2013) observe contrary results in a sample of Latin American countries to conclude that better governance may sometime induce cropland expansion.

Agricultural sector in India is still heavily controlled and both union as well as state governments can manipulate land use in agriculture by changing agricultural policies. Gradual but substantive changes have taken place in policies related with the agricultural investment and subsidies since 1980. Major shifts in irrigation policy and restructuring of other input subsidies in post liberalization period have implications for cropland expansion. The importance of subsidies on cropland expansion has been highlighted in a number of studies concerning the process of regional and global land use changes (Ewers *et al*. 2009; Singh and Narayanan, 2013). Farmers in rice and wheat growing regions of India have been the biggest beneficiary of these subsidies.

3. Approach

While the impact of anthropogenic factors on agriculture and its related environment has been a well-researched issue in economic literature; it is relatively recent that researchers began examining factors that contribute to cropland expansion (see, Waggoner and Ausubel 2001; Barbier 2003). An equally important issue from policy perspective is to know the relative contribution of these factors on cropland expansion. *I=PAT* equation (Ehrlich and Holdren 1971) is a widely used tool to determine relative contribution of factors in explaining environmental impact. *I=PAT* equation states that interaction of population (*P*), affluence (*A*) and Technology (*T*) determines environmental impact. Matching dimensionality of impact and drivers side is a major issue associated with the use of any variant of *I=PAT* equation; therefore, we use a back substitution to write:

$$L = \frac{L}{P} \times \frac{P}{C} \times \frac{C}{N} \times N \quad (1)$$

In which C and P, stands, respectively, for total consumption and total production of agricultural commodities. Similarly, N and L represent population and cropland respectively. Equation (1) implies that demand for cropland (L) i.e. impact (I) is determined by the interaction of per capita consumption $\left(\frac{C}{N}\right)$ and production-consumption ratio $\left(\frac{P}{C}\right)$ or extent of net agriculture trade, both represent level of affluence (A), population (N) and (reciprocal) per hectare productivity $\left(\frac{L}{P}\right)$ i.e. technology (T).

Technology has two-fold impact on demand for land for food production. Use of HYV (high yielding variety) seeds increases land productivity (yield or per hectare production) which is *land saving* aspect of technology. Similarly, external nutrient supplements such as chemical fertilizers and irrigation ensures multiple use of land in a calendar year which is *land augmenting* aspect of modern agriculture technology.[5] Equation 1 is further decomposed to separate land saving aspect of technology from land augmentation aspect of technology. This decomposition results in equation 2 in which land saving is represented by $\frac{P}{L^A}$ and land augmenting is captured by $\frac{L}{L^A}$; where L^A is extent of augmented land or effective land.

$$L = \left(\frac{L}{L^A} \times \frac{L^A}{P}\right) \times \frac{P}{C} \times \frac{C}{N} \times N \qquad (2)$$

While equation (2) is a well suited variant of $I=PAT$ equation, variable of our interest is not crop land but change in it. Therefore, we take log of equation 2 and difference the logged equation over time to reach at an equation in which all variables are expressed in terms of annual change. In result, we get:

$$\Delta L = \Delta N + \Delta\left(\frac{C}{N}\right) + \Delta\left(\frac{P}{C}\right) - \Delta\left(\frac{L^A}{L}\right) - \Delta\left(\frac{P}{L^A}\right) \qquad (4)$$

[5] Soil productivity depletes rapidly due to multiple use of land, therefore, long fallow period is required to replenish lost soil productivity. Fertilizers and micronutrient work as external supplement to keep soil productivity intact and allow farmers to use same land for multiple times in a year. This phenomenon is termed as resource augmenting technological change in literature.

Dietz and Rosa (1997) employ *I=PAT* equation in a stochastic framework in which relative contribution of factors can be empirically investigated using econometric methods. Stochastic version of equation (3) can be represented as:

$$\Delta L_{it} = \alpha_i + \beta_1(\Delta N)_{it} + \beta_2\left(\Delta \frac{C}{N}\right)_{it} + \beta_3\left(\Delta \frac{P}{C}\right)_{it} + \beta_4\left(\Delta \frac{L^A}{L}\right)_{it} + \beta_5\left(\Delta \frac{P}{L^A}\right) + \varepsilon_{it} \qquad (4)$$

Where subscripts i and t represent geographical entity (country, state, districts) and time respectively. α_i and β's are the parameters to be estimated. Stochastic model reduced to mathematical identity given in equation (2) when all α and β's equal to 1 and equation is in level form. Equation (4) is a clear modification over existing methodologies as it separates land augmentation from land saving; both of which contribute to land use efficiency.

4. Data, Variables and Econometric Model

Data for empirical enquiry is borrowed from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) which provides district level data on area and production (crop-wise), irrigation, land use, census (human population) and road infrastructure for a fairly long period (1966-67 to 2009-10). Data for all 20 districts (district boundaries in the dataset are adjusted according to the 1965-66 status) in the state is used for empirical analysis.[6] Gaps in census data which is available only at decadal intervals are interpolated using linear interpolation technique. A balanced sample is constructed using data for all 20 districts for 40 year (1970-2009) period. 1970 is chosen as the initial year of analysis to avoid the anomalies in data which may occur in the early years of implementation of HYV technology in the state.

Researchers have considered various measures of cropland depending on the nature of hypothesis to examine land sparing hypothesis. Barbier (2003) who examined determining factors of agricultural expansion considered entire rural land as cropland. However, a broad definition as used in Barbier (2004) is useful only when agricultural expansion takes place at the cost of forests. Evers *et al.* (2009) use three different measures of cropland which are acreage under crops used to measure energy yield (kilocalorie per hectare), acreage under crops other

[6] District boundaries in apportioned data base of ICRISAT are managed according to the 1966 status. Data for all variables in newly formed districts were given back to the parent districts. This adjustment leaves only 20 district in the state instead of current 23 districts. 3 newly formed districts are Rangareddy, Vijiyanagaram and Prakasam.

than those which are included to measure yield and total acreage which is the sum of first two to test land sparing hypothesis. Other global scale studies also use either arable or agricultural land as a measure of cropland with an objective to link cropland expansion with deforestation.[7] Singh and Narayanan (2013) use net cultivated (sown) area as a measure of cropland as they find no sign of deforestation in the case of India.

Indian land use classification is based on a Nine-fold classification system which offers additional flexibility while choosing a measure of cropland.[8] For the present study, we consider acreage associated with the crops considered for yield measurement and net cultivated area as two measure of cropland. Cropland expansion measure, based on net cultivated area, explains horizontal expansion; however, acreage based measure of cropland doesn't differentiate between horizontal and vertical expansion.[9] Therefore, net cultivated area is a better measure to draw conclusions regarding land sparing.

To obtain yield, we use data on crop production (harvested mass in tonnes) and the acreage (hectares) of crops with specific focus on energy providing staple crops (rather than non-food crops).[10] Physical production of crops is converted into its energy equivalent (kilocalorie) using modified Merrill and Watt (1973) conversion table provided by the Food and Agriculture Organization (FAO). This conversion is required to bring different crop yields in one dimension to get energy yield (see, Balmford *et al.* 2005; Ewers *et al.* 2009).[11] Energy produce of agricultural system is divided by the acreage under staple crops to obtain energy yield.[12]

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[7] Barbier (2003) and other studies on the issue use World Bank or Food and Agricultural Organization (FAO) data for his study. World Bank provides country level data on agricultural and arable land. For definitions of agricultural land and arable land see, http://faostat.fao.org/site/379/DesktopDefault.aspx?PageID=379

[8] See, http://mospi.nic.in/mospi_new/upload/COMPENDIUM_ENVIRONMENT_STATISTICS_INDIA_18mar11/_Appendix%208.pdf

[9] Net cultivated area represents the total area sown with crops and orchards. Area sown more than once in the same year is counted only once. Therefore, any change in net cultivated area shows geographical expansion or contraction in agriculture. We term it as horizontal expansion. While acreage based measure of cropland includes land which may be sown multiple times.

[10] These crops include cereals, pulses, oil-seeds and sugarcane. These crops currently account for more than 75 percent of the cropland area in the state. Major omissions are cotton, fruits, vegetables and spices for which production data is not reported in the data set.

[11] There are studies (for example, Ceddia *et al*. 2013) which have used price instead of calorie as a weight to measure composite yield.

[12] Term 'staple crops', in the rest of the text, refers to the crops used for measuring energy yield.

We use equation 4 as basic framework for econometric analysis; however, certain modifications in the equation due to data constraints are needed. For example, annual data on per capita consumption of food is not available at the district level and we also fail to find any proxy (per capita GDP) at district level; therefore, we cannot estimate impact of affluence on cropland expansion.[13] Similarly, inter-district exchange of food has not been controlled.[14] To overcome the problem, we add a linear time trend as a regressor assuming that it will capture the affluence impact.[15]

Extent of cropland expansion also depends on per capita food supply and cropland expansion may reverse in regions where per capita food supply is in excess of what is needed to feed local population. However, we are engaged in a sub national analysis and possibility of inter-district exchange of food cannot be refuted. If this is the case, it is difficult to claim that districts with high per capita food supply will show a negative relationship with cropland expansion. To examine which of these cases hold true, we add per capita food supply (production) as an explanatory variable in regression models. Cropland expansion is also limited by the availability of land mass and regions in which landmass dedicated to agriculture is historically high in proportion may find it difficult to expand agriculture operations. To examine this relationship, we include share of cropland in district as an explanatory variable in econometric models for both the dependent variables.

To examine the role of technology in moderating relationship between cropland expansion and urban growth, we use urban population growth as an explanatory variable. Similarly, improvement in literacy, defined as the annual change in literate population, is included as additional explanatory variable to examine the secondary effects of economic development on cropland expansion. We find that these variables are highly correlated mutually and also with the population growth; therefore, we run separate regressions to determine impact of urbanization and improvement in literacy on cropland expansion.[16] Sustained infrastructure development is vital for sustainable agriculture intensification (Byerlee, Stevenson and Villoria, 2014). Physical connectivity facilitated by expanding road network, however, sometimes contributes to cropland

[13] District GDP data is available only from 1993 onwards.
[14] Since India is a big producer of agricultural products; we see no harm in assuming that consumption-production ratio at the district level will be almost unity.
[15] We assume a positive relationship between growth in affluence and cropland expansion.
[16] Tables of variable construction, summary statistics and correlation are given in appendix.

expansion simply by increasing the size of the market which farmers face (Lambin and Mayfroidt, 2011). To assess the impact of market expansion on cropland expansion, we add road expansion as an explanatory variable in the regression model.

$$AGEXP_{it} = \alpha_i + \beta_1(PG)_{it} + \beta_2(YLD)_{it} + \beta_3(CI)_{it} + \beta_4(RDEXP)_{it} + \beta_5(PCFS)_{it} + \beta_6(SHARE)_{it} + \beta_7(TREND) + u_{it} \quad (5)$$

$$AGEXP_{it} = \alpha_i + \beta_1(UREXP)_{it} + \beta_2(YLD)_{it} + \beta_3(CI)_{it} + \beta_4(RDEXP)_{it} + \beta_5(PCFS)_{it} + \beta_6(SHARE)_{it} + \beta_7(TREND) + u_{it} \quad (6)$$

$$AGEXP_{it} = \alpha_i + \beta_1(EDUEXP)_{it} + \beta_2(YLD)_{it} + \beta_3(CI)_{it} + \beta_4(RDEXP)_{it} + \beta_5(PCFS)_{it} + \beta_6(SHARE)_{it} + \beta_7(TREND) + u_{it} \quad (7)$$

Empirical Analysis

4.1. An examination of cropland expansion and technology at aggregate level

We begin our analysis by examining the dynamics between technology and cropland expansion at aggregate level. In this connection, we take 5 year moving average of district level data before aggregating it to attain state level aggregate values.

Figure 1 plots movement of various land use categories in the state. Plot depicting cropland (net cultivated area) shows a declining trend; however, it cannot be considered as conclusive evidence to support land sparing.[17] In fact, we see no change in land notified as forests which is contrary to experience of Latin American countries which have witnessed large scale deforestation due to export driven agricultural expansion (see, Barbier 2003). Additionally, a declining trend of pasture and an increasing trend in land under non agriculture land use category is observed. Since non-agricultural land includes all lands occupied by buildings, roads, railways or under water, e.g. rivers and canals, and other land put to uses other than agriculture; it gives an approximation regarding extent of urban pressure. Observing trends of various land use categories, the possibility of urbanization at the cost of agricultural land cannot be ruled out in the state and demands further enquiry.

[17] Except analysis depicted in figure 4, net cultivated area is considered as a measure of cropland everywhere in this section.

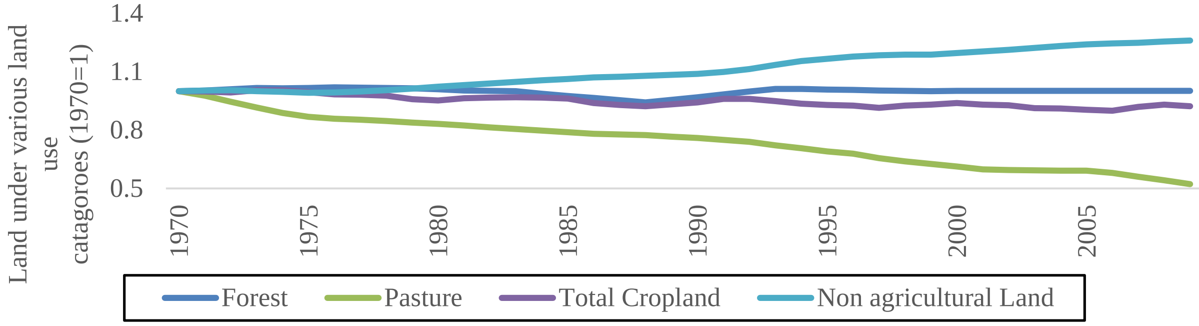

Figure 1: Land use change in Andhra Pradesh

After analyzing land use trends in the state, we perform a comparative analysis to examine how cropland expansion is associated with the changes in yield and cropping intensity in the districts of Andhra Pradesh. We have plotted relationship between change in cropland (net cultivated area) against change in yield (figure 2) and cropping intensity (figure 3) in districts.[18] It can be observed that yield and cropping intensity has increased and cropland has declined in majority of districts since the inception of technology. It seems that districts which have witnessed relatively sharp rise in yield have also witnessed a negative change in cropland. On the contrary, districts which have experienced relatively sharp rise in cropping intensity seem to have added more land to farming (figure 3). Most of the districts that have experienced a moderate intensification have behaved ambiguously as far as cropland expansion is concerned. Still, a comparative analysis like this ignores annual fluctuations in variables; therefore, an exercise at more disaggregated level seems useful to draw any conclusion regarding land sparing.

[18] Change is defined as the log difference of values at the beginning (1970) and at the end (2009) of study period.

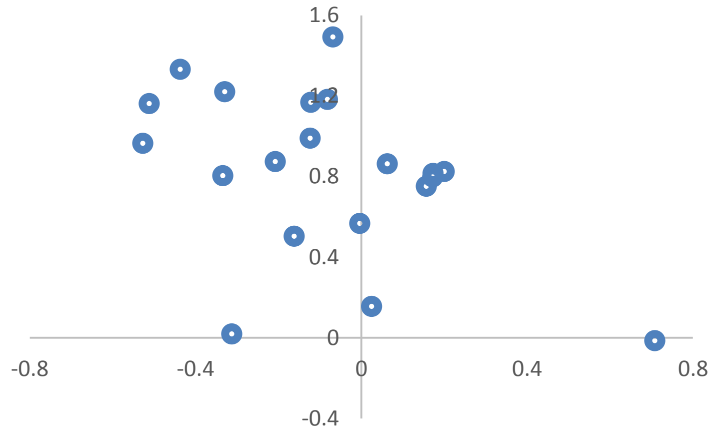

Figure 2: Change in the cropland (on horizontal axis) during the period 1970-2009 in relation to the change in energy yield during the same period

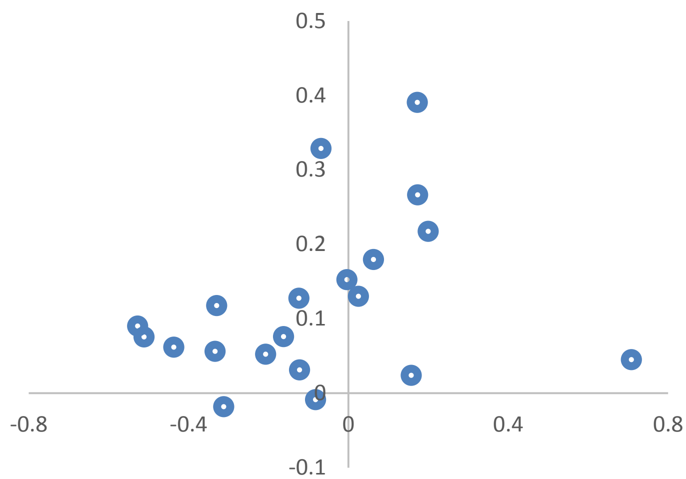

Figure 3: Change in the cropland during the period 1970-2009 in relation to the change in cropping intensity during the same period.

A fair judgment regarding the impact of technology on land use cannot be made unless we know what would have happened if technological intervention would not have taken place. Figure 4 depicts result of a counterfactual analysis in which we have kept energy yield constant at 1970 level and computed the land required to produce actual energy output produced every year since 1970. This counterfactual amount of cropland (depicted by the line plot) is plotted against the actual cropland (area plot) used in the production. From the figure, it can be observed that cropland required to produce output equivalent to the 2009 output is three times of the cropland which was actually employed in production.

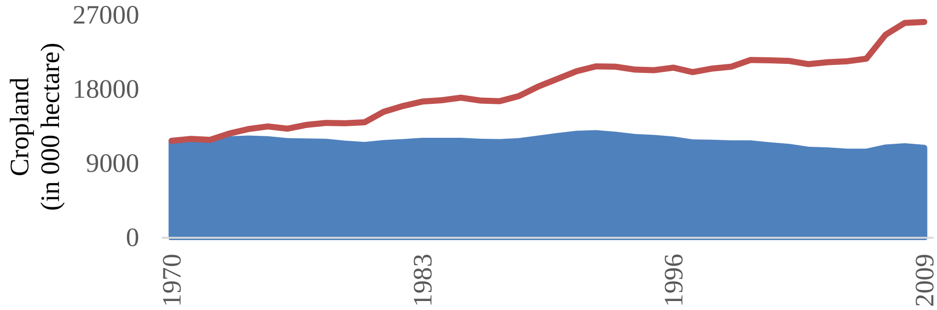

Figure 4: Actual and potential cropland required for energy (in kilocalorie) production, Andhra Pradesh

4.2. Econometric Methods and Results

Before examining the relationship between technology and cropland expansion, we perform unit root test for examining possible non-stationarity of variables used in the econometric analysis. Aggregated time series data normally trends and inferences drawn from such data may turn spurious. We use panel unit root test developed by Im-Pesaran-Shin (Im *et al.* 2003) to draw conclusions regarding stationarity of the variables. Im-Pesaran-Shin (2003) unit root test has the advantage of not imposing a common autoregressive parameter restriction on the panels (districts here) and is based on a set of Augmented Dickey-Fuller regressions to estimate the t-statistic. Unit root test results, reported in table 1, suggests that in case of all variables except population growth, we can reject the null hypothesis of non-stationarity. Unit root from population growth variable is removed by differencing the variables.

Table 1: Unit root test results

Variable	Fixed N exact T		Fixed T, Asymptotic N		Asymptotic T and N	
	No trend	With trend	No trend	With trend	No trend	Trend
	t_{bar}	t_{bar}	$Z_{t\text{-tilde-bar}}$	$Z_{t\text{-tilde-bar}}$	$W_{t\text{-bar}}$	$W_{t\text{-bar}}$
Cropland expansion(net cultivated area)	-7.82	-7.77	-18.63	-18.70	-21.28	-19.50
Cropland expansion(staple crops)	-8.88	-8.80	-20.08	-20.09	-23.45	-21.50
Yield gain	-9.88	-9.77	-21.00	-21.00	-27.00	-25.16
Change in cropping intensity	-8.71	-8.69	-19.83	-19.89	-21.32	-19.53
Population growth	-0.96*	-3.17	3.30*	-7.24	3.59*	-8.53
Urban population growth	-2.01	-2.67	-2.18	-5.21	-1.87	-3.79
Growth in number of literates	-2.16	-2.74	-2.99	-5.61	-2.12	-2.79
Cropland share	-3.70	-4.43	-9.17	-11.96	-6.02	-6.50
Energy production per capita	-3.83	-4.75	-9.77	-13.01	-5.60	-6.91
Road expansion	-16.75	-16.07	-23.68	-22.71	-18.29	-15.96

Note: t-bar calculated under fixed T and N follows a t-distribution and represents average of the panel-level t-statistics obtained through Augmented Dickey-Fuller regressions. Z-t tilde-bar calculated under fixed T and asymptotic N follows a standard normal distribution. The corresponding p-values are reported in the adjacent column. W-t-bar are calculated under sequentially asymptotic T and N has an asymptotically standard normal distribution. W-t-bar statistics is appropriate under serial correlation, where the ADF regressions were carried out including appropriate number of lags which minimized the Bayesian Information Criterion (BIC). Fixed N critical values without time trend for 1 percent, 5 percent and 10 percent are -1.73, -1.67, and -1.64 respectively. Fixed N critical values with trend for 1 percent, 5 percent and 10 percent are -2.36, -2.31, and -2.28 respectively. * indicates not significant at least 5 percent level of significance.

We start the regression analysis by estimating fixed effects (FE) and random effects (RE) model and preferred model between the FE and RE is chosen by using Hausman specification test (Hausman 1978). Estimated values of Hausman test statistic across the models suggest that only coefficients of model specified with fixed effects (FE) give consistent estimates irrespective of the choice of dependent variable. Recent advances in panel data analysis suggest that efficiency of FE model estimates is compromised when regression errors violate OLS assumptions (Greene 2012). For efficient estimation of FE model, regression errors must be group-wise homoskedastic as well as cross sectionally and temporally uncorrelated. Presence of autocorrelation in fixed effects model is tested using Wooldridge (2002) procedure. Based on the significance of Wooldridge's test statistic, we reject the null that regression errors are independent across the models. Similarly, modified Wald test (Baum 2001; Greene 2012) statistic turns statistically significant at 1 percent level of significance across the models, indicating presence of group-wise heteroskedasticity. FE model results are further tested for the presence of cross sectional dependence using test developed by Pesaran (2007) and we fail to reject the null hypothesis of no cross sectional dependence for all models.

In order to resolve issues related with serial and cross sectional correlation and panel heteroskedasticity in FE results, we employ Driscoll and Kraay's (1998) covariance matrix estimator which produces efficient estimates in presence of heteroskedasticity, cross sectional dependence and serial correlation. This estimator applies Newey and West (1987) type correction to the covariance matrix to generate efficient estimates. Among its attractive features which make it superior in its class of estimators (panel corrected standard error (PCSE) and feasible generalized least squares (FGLS)) is that it is consistent for the unknown form of correlation (Hoschle 2007). Regression results for staple cropland model and net cultivated area model are reported in table 2 and table 3 respectively.

Table 2: Regression results of staple cropland model

VARIABLES	Model 1	Model 2	Model 3
YLD	-0.0141	-0.0107	-0.0109
	(0.0974)	(0.0938)	(0.0936)
CI	1.016***	1.013***	1.015***
	(0.159)	(0.160)	(0.160)
PG	-0.164***	-	-
	(0.0436)		
UREXP	-	-0.0411	-
		(0.0661)	
EDUEXP	-	-	-0.0519**
			(0.0220)
RDEXP	0.066	0.011	0.011
	(0.089)	(0.019)	(0.019)
SHARE	0.381***	0.380***	0.380***
	(0.0435)	(0.0419)	(0.0428)
PCFS	0.109**	0.105**	0.105**
	(0.0427)	(0.0405)	(0.0408)
TREND	0.000510	0.000548	0.000539
	(0.000719)	(0.000742)	(0.000712)
Constant	-0.710*	-0.696	-0.690
	(0.387)	(0.422)	(0.416)
Observations	780	800	800
Number of groups	20	20	20
Within R square	0.30	0.30	0.30
Hausman test	137.22 (7)***	137.79 (7)***	137.84 (7)***
Modified Wald test for groupwise heteroskedasticity in FE model	500.34 (20)***	520.29 (20)***	526.08 (20)***
Pesaran's test of cross sectional independence	22.97***	23.26***	23.55***
Wooldridge test for autocorrelation in panel data	1.71 (1, 19)	1.76 (1, 19)	1,75 (1, 19)

Note: Fixed effect model is estimated using Driscoll-Kraay method which produces efficient estimates when errors are non-spherical. Standard errors of estimates are in parentheses. *, **, *** refers to significance at 10, 5 and 1 percent level. In case of diagnosis tests, figures reported in parentheses are degrees of freedom.

Except technology related variables, all explanatory variables show identical relationship with cropland expansion in terms of sign across the models. As far as technology effect is concerned, change in energy yield shows a positive impact on cropland expansion when we consider net cultivated area as a measure of cropland. Results indicate that a one percent increase in energy yield increases net cultivated area by 0.10 percent. On the other hand, when we consider area under staple crops as a measure of cropland; we find that it is only the change in cropping intensity which has a significant and positive impact on cropland expansion. A one percent increase in cropping intensity increases cropland by more than 1 percent. It is evident from the results that technology driven intensification, instead of sparing cropland, has contributed to expand cropland irrespective of the measure of cropland chosen in the study.[19]

Table 4: Regression results of net cultivated area model

VARIABLES	Model 1	Model 2	Model 3
YLD	0.108***	0.108***	0.108***
	(0.0241)	(0.0229)	(0.0227)
CI	-0.137	-0.136	-0.136
	(0.108)	(0.107)	(0.107)
PG	-0.124***		
	(0.0258)		
UREXP		-0.0691*	
		(0.0379)	
EDUEXP			-0.0487**
			(0.0185)
RDEXP	0.0340	0.00614	0.00617
	(0.0754)	(0.0144)	(0.0147)
SHARE	0.396***	0.394***	0.394***
	(0.0415)	(0.0409)	(0.0414)
PCFS	0.0238*	0.0225*	0.0228*
	(0.0129)	(0.0123)	(0.0125)
TREND	0.00106***	0.00104***	0.00105***
	(0.000356)	(0.000374)	(0.000364)
Constant	-0.241*	-0.223	-0.230
	(0.140)	(0.162)	(0.161)
Observations	780	800	800
Number of groups	20	20	20
Within R square	0.30		
Hausman test	189.16 (7)***	192.32 (7)***	192.08 (7)***
Modified Wald test for groupwise heteroskedasticity in FE model	331.01 (20)***	321.14 (20)***	392.42 (20)***
Pesaran's test of cross sectional independence	18.79***	19.15***	19.005***
Wooldridge test for autocorrelation in panel data	74.58 (1, 19)***	76.23 (1, 19)***	75.511 (1, 19)***

Note: Fixed effect model is estimated using Driscoll-Kraay method which produces efficient estimates when errors are non-spherical. Standard errors of estimates are in parentheses. *, **, *** refers to significance at 10, 5 and 1 percent level. In case of diagnosis tests, figures reported in parentheses are degrees of freedom.

Growth in cropping intensity which measures improvement in land augmentation (or vertical land expansion) induces cropland expansion by equal amount when we consider acreage

[19] We have also used agricultural land as a measure of cropland to construct dependent variable. Surprisingly, we observe a significant negative relationship between growth in cropping intensity and cropland expansion (see appendix). Additionally, we have also explored possible nonlinearity between dependent and independent variables representing intensification (yield and cropping intensity); however, results refuted any nonlinearity among the variables.

under staple crops as a measure of cropland. These results can be interpreted in terms of input supply policies of the government. Increasing consumption of fertilizers, other soil nutrients and ensured supply of irrigation are prerequisite for land augmentation. Irrigation expansion in the state during the later phases of green revolution is achieved by subsidizing groundwater irrigation (see, figure 5). Groundwater irrigation is cost effective only when distance between destination and source of irrigation is kept at a minimum.[20] It is therefore wise for farmers to use plots nearby the irrigation source more intensively to reap benefits of economies of scale which arise due to minimization of water transportation costs. Horizontal expansion of cropland to cultivate staple crops not only faces land constraint but is also constrained by the accessibility to irrigation sources. Therefore, it is profitable for farmers to prefer vertical expansion by using most fertile land many times in a year for production of staple crops. Additionally, coefficient value of the CI is 1.016(=1) in the staple cropland model which indicates that augmented land goes to increase cropland under staple crops only.

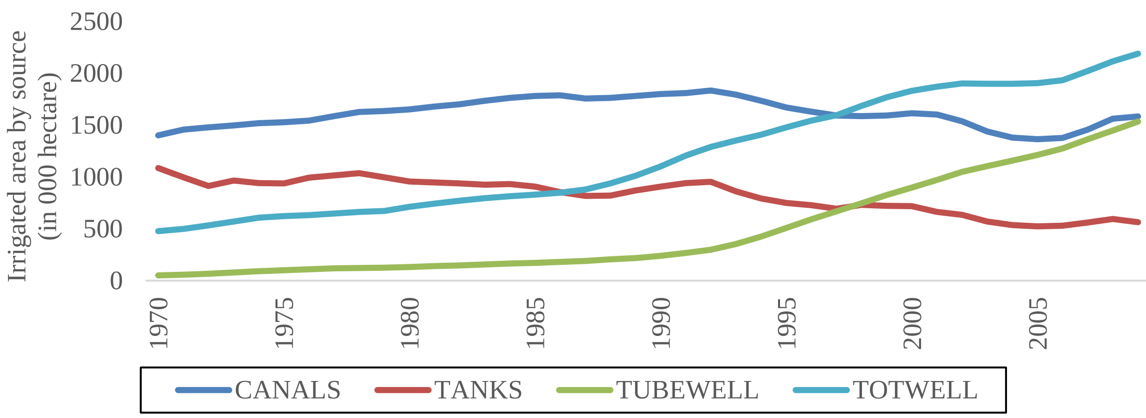

Figure 5: Change in irrigation pattern in Andhra Pradesh

On the other hand, growth in per hectare energy production shows a significant positive impact on expansion of net cultivated area (table 3). However, land augmentation doesn't seem to have any significant impact on expansion of net cultivated area. Varying results for two measures of cropland imply that validation of land sparing hypothesis is sensitive to the measure of the cropland (also see, Appendix).

[20] In most of the cases, drains meant to transport groundwater are public in nature. If these drains are not maintained in an efficient way massive wastage of water cannot be ruled out. Wastage of water creates problem of waterlogging in adjacent fields and reduces productivity, increases cost of irrigation and makes entire operation environmentally and economically unsustainable. On the other hand, increasing density of groundwater resources, which can reduce wastage of precious groundwater, is unsustainable in long run.

Results found in this study, thus, refute land sparing hypothesis. Previously, land sparing hypothesis has been questioned in the case of India (Singh and Narayanan 2013), Latin American countries (Ceddia *et al.* 2013), Brazilian Amazon (Ruf 2001) and Tanzania (Angelsen *et al.* 1999). Evidences from few Global studies (Ewers *et al*. 2009; Bamford *et al.* 2005) also fail to provide any conclusive evidence regarding land sparing. Additionally, we find no evidence of deforestation in the state which indicates that cropland expansion in districts has taken place mostly at the cost of fallows and pastures available at the margins of the cropland (net cultivated area). Since fixed cost associated with the conversion of these lands is lesser than the conversion of forest lands; it is easier for farmers to encroach pastures and fallows for expanding agricultural operations.[21]

Except technology, all other variables behave identically against cropland expansion irrespective of the measure of cropland chosen in the study. Population elasticity of cropland is negative irrespective of the cropland measure. There may be multiple explanations to justify the results. The simplest explanation which can be given is based on the theory of demographic transition. As population growth slows with demographic transition, land required to feed additional persons will also decrease; therefore, negative sign is on expected lines (Ausubel *et al*. 2012). However, impact of population dynamics on cropland expansion is supposed to be more complex. A significant negative relationship between cropland expansion and urban population growth infers that urban growth at the cost of prime cropland cannot be refuted in the state. Land is an essential input to sustain growing urban population as more homes, hospitals and parks are required to manage increasing population. It is not possible without acquiring land from other activities. This is an outcome of competition for land among competing activities where activity in which price of land (rent) is low shrinks geographically. Another demographic attribute, growth in number of literate persons, is used as a proxy for examining impact of improvement in awareness on cropland expansion. Sustainable development requires virtuous use of scarce resources. Increasing literacy helps to create awareness regarding environment and lubricates effective exchange of information and knowledge among various stakeholders (Dasgupta *et al.* 2002; Dinda, 2004). Additionally, increasing literacy ensures mobility of population from agriculture to industry and services which helps to relieve pressure from cropland. Econometric

[21] We have also estimated a model where annual change in forest land is considered as dependent variable to examine relationship between deforestation and technology and we find no significant relationship (see appendix).

result in this study supports the view that growing literacy helps to spare land from agricultural operations.

Two additional variables which are considered important in other studies to explain land use change dynamics are cropland share (see, Barbier, 2003) and domestic food supply (see, Ewers *et al.*, 2009). It was expected that cropland expansion will be negative in districts with high cropland share as marginal benefits from land conversion will be lesser in these districts. Similarly, districts with higher per capita production of staple crops were expected to relieve pressure from the land for food production. However, in this study, both variables show a significant positive relationship with cropland expansion. We suspect that districts with high cropland share possess good agricultural infrastructure under centralized planning since independence and emerged as food production centers in the state.[22] Availability of infrastructure and reserve lands (fallows and pasture) together may cause cropland expansion in districts with high cropland share and high per capita production. For example, irrigation penetration is very low in southern Andhra Pradesh due to its geographical location and flawed irrigation policies of the government. On the other hand, other districts in the state have developed relatively good irrigation network and cropping intensity and yields are higher in these districts compared to southern districts.

4.3. Discussion

Results found here are useful to understand the dynamics between technology, population and cropland expansion and can be used to draw useful policy insight for managing land use in the state in a sustainable manner. In summary, two observations can be made out of the analysis which we think are important from policy perspective.

First, a positive relationship has been found between technology driven intensification and cropland expansion (net cultivated area) which resembles with the phenomenon of Jevons' paradox. Possible reasons behind occurrence of Jevons' paradox in case of Andhra Pradesh may be the low fixed costs associated with the conversion of marginal lands (pastures and fallows) and supply of subsidized irrigation. Andhra Pradesh is one of the leading states in India with

[22] At national level also, preferential infrastructure development can be seen to support agriculture sector in states like Punjab, Haryana, Western Uttar Pradesh and Andhra Pradesh itself.

respect to irrigation subsidies. Major part of irrigation subsidies in the state goes for the provision of free electricity and for expanding groundwater irrigation in the regions where canal irrigation is not possible. The level of irrigation subsidies in the state has increased from INR (Indian National Rupee) 428 million (US$9.56 million) in 1980–81 to INR 8402 million (US$187.75 million) in 1999–2000 (Reddy 2003). Deviating from earlier strategy to promote micro irrigation, the Government of Andhra Pradesh (GoAP) launched the Jalayagnam Program (Water Infrastructure Development Program) from 2004 onward, prioritizing the development of medium and large irrigation infrastructure. The aim was to create a new command area of 4.45 million hectare by investing INR1662630 million (US$37,153.74 million) by the year 2014 (Palanisami *et al.* 2011). However, complete deviation from groundwater based micro irrigation is not possible in near future considering the long gestation period which medium and large irrigation projects take.

While subsidizing groundwater irrigation has helped to increase land productivity; it has also led to rapid depletion of groundwater in the state (Mukherji *et al.* 2013). Therefore, there is a need to identify and develop irrigation systems which suits to the local conditions. For example, canal based irrigation is not a cost effective option in this region due to complex geography of the inland southern Andhra Pradesh.[23] Therefore, development and management of tank irrigation which is a time tested method of irrigation in this region is fundamental to agricultural sustainability and land sparing (Sakthivadivel *et al.* 2004; Palanisami *et al.* 2010).

Second, horizontal expansion of cropland at the cost of pasture and permanent fallows is counterproductive in long run. Pastures and land which are left as fallows since long are precious for preserving biodiversity in rural areas. Additionally, evidences regarding land sparing must be seen in the light of negative relationship between urban growth and cropland expansion. Urbanization is not counterproductive when land can be relieved from the agriculture due to technology driven intensification. At the same time, if technology fails to spare land from farm activities then urban expansion at the cost of cropland may cause social tension and can also intensify poverty and inequality. What we infer from regression results, here, is that urban expansion is coexisting with technology driven cropland expansion in Andhra Pradesh. There is

[23] National Sample Survey Organization (NSSO) includes Anantpur, Cudappa, Prakasam (not in the dataset), Kurnool, and Chittoor in inland southern Andhra Pradesh. These districts are among the most drought prone districts in the state.

a fair possibility that urban expansion, in the state, has taken place at the cost of prime cropland and loss of prime cropland has been compensated by brining marginal lands into cultivation. Augmenting marginal lands for multiple cropping is more cost intensive and sometimes it is not even possible to use marginal lands for multiple cropping. Therefore, the amount of marginal land needed to compensate the loss of prime cropland will always be higher than the amount of land lost which forms a vicious cycle of land use transition.

5. Conclusion

We have conducted an econometric to examine land sparing hypothesis at a sub national scale. We have adopted Dietz and Rosa (1997) formulation as a theoretical framework and exploit annual variation in data for hypothesis testing. Unlike earlier studies which regress per hectare production on cropland expansion to draw conclusions regarding land sparing, we have separated impact of land augmentation from land productivity which is helpful to understand intervention options available to government. We find evidence which refute land sparing hypothesis and support Jevons' paradox. Additionally, we confirm a negative and significant impact of urban population growth on cropland expansion which may increase tension among different stakeholders.

Appendix

Table A1: Variable description

Variable	Abbreviations	Definition
Cropland expansion	EXP	$(ln\ A_{it}\text{-}ln\ A_{i(t-1)})$ Where, A is net cultivated area or acreage under staple crops
Yield gain	YLD	$(ln\ Y_{it}\text{-}ln\ Y_{i(t-1)})$ Where, Y is the energy yield.
Change in cropping intensity	CI	$(ln\ I_{it}\text{-}ln\ I_{i(t-1)})$ Where, I is the ratio between gross cultivated are and net cultivated area.
Population growth	PG	$(ln\ P_{it}\text{-}ln\ P_{i(t-1)})$ Where, P is the population.
Urban population growth	UREXP	$(ln\ U_{it}\text{-}ln\ U_{i(t-1)})$ Whare, U is the urban population.
Growth in number of literates	EDUEXP	$(ln\ E_{it}\text{-}ln\ E_{i(t-1)})$ Where, E is the number of literate persons.
Cropland share	SHARE	Share of net cultivated area in total geographical area.
Energy supply per capita	PCFS	Per capita production of agricultural output in terms of energy equivalent.
Road expansion	RDEXP	$(ln\ R_{it}\text{-}ln\ R_{i(t-1)})$ Where, R is the length of road network.

Table A2: Correlation matrix

	YLD	CI	PG	UREXP	EDUEXP	RDEXP	SHARE	PCFS
YLD	1.00							
CI	0.21	1.00						
PG	-0.03	0.01	1.00					
UREXP	-0.03	0.02	0.89	1.00				
EDUEXP	-0.03	0.02	0.91	0.88	1.00			
RDEXP	0.01	-0.01	0.01	-0.02	-0.03	1.00		
SHARE	0.04	0.02	-0.02	-0.09	-0.07	0.06	1.00	
PCFS	0.20	0.11	-0.12	-0.07	-0.04	0.01	0.31	1.00

Table A3: Summary statistics of variables

Variable	Observations	Mean	Std. Dev.	Min	Max
EXP (Net Cultivated Area)	800	-0.004	0.082	-0.382	0.429
EXP (Staple crops)	800	-0.0058	0.122	-0.838	1.011
YLD	800	0.018	0.197	-1.285	1.367
CI	800	0.0028	0.036	-0.169	0.201
PG	800	0.016	0.019	-0.441	0.066
UREXP	800	0.028	0.039	-0.984	0.107
EDUEXP	800	0.039	0.059	-1.577	0.122
RDEXP	800	0.054	0.237	-1.086	1.775
SHARE	800	0.39	1.28	0.20	0.60
PCFS	800	2682.27	1.63	328.42	7786.85

Table A4: Impact of urbanization and technology driven agricultural intensification on agricultural land expansion and deforestation

	Dependent variable: Agricultural land expansion	Dependent variable: Deforestation
YLD	0.014	0.009
	(-0.010)	(-0.009)
CI	-0.106	-0.034
	(0.023)***	(-0.039)
UREXP	0.003	-0.003
	(-0.006)	(-0.013)
Constant	-0.00075	0.0003
	(-0.001)	(-0.002)

Note: Agricultural land includes net cultivated area, fallows and pastures. Fixed effect model is estimated using Driscoll-Kraay method which produces efficient estimates when errors are non-spherical. Standard errors of estimates are in parentheses. *, **, *** refers to significance at 10, 5 and 1 percent level.

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