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Inter-district variation and convergence in agricultural productivity in India

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Abstract Using district-level data for the 1971–2010 period, we examine the convergence in agricultural productivity. We find significant spatial variation in agricultural productivity and growth in the past four decades at different levels of spatial aggregation, and we find evidence of both absolute and conditional convergence. The state-wise convergence suggests that the districts of most states are converging towards the steady-state. At the regional level there is strong convergence for all the four regions. Conditional convergence suggests that districts with better initial conditions are growing at a higher rate.

Keywords Agricultural productivity, convergence, regional disparities

JEL codes C33, Q10, O13, Q18

The green revolution technologies were introduced to the agricultural sector in India more than 50 years ago, but variations in growth persist. Some studies examine regional disparities in Indian agriculture, but most of them rely on state-level data (Bajpai and Sachs 1996; Cashin and Sahay 1997; Rao et al. 1999; Mukherjee and Kuroda 2003; Ghosh 2006; Nayyar 2008; Poudel et al. 2011; Birthal et al. 2011; Chand and Parappurathu 2012; Balaji and Pal 2014; Kumar et al. 2014; Banerjee and Kuri 2015; Binswanger and D'Souza 2015; Chatterjee 2017). The states differ significantly in size, however, and intra-state variations are wide. State-level statistics cannot appropriately capture these variations. Disaggregated district-level data possesses greater variability, and it is better suited for understanding the spatial dimensions of agricultural performance and intra-state variability—the policy environment in a state applies equally to all its districts; therefore, studying disaggregated district-level data can tell us why performance differs, but the attempts made to analyse regional variation at the district level are few (Bhalla and Alagh 1979; Bhalla and Tyagi 1989; Bhalla and Singh 2001; Bhalla and Singh 2009; Singh et al. 2014). In this paper, we examine convergence in agricultural productivity using district-level data for the period from 1971 to 2010 at three levels of spatial disaggregation: all-India,[1] state, and region. Each level has a distinct environment (social, economic, and institutional) and agroclimatic conditions, and the implications differ when convergence is examined at the different levels of spatial aggregation.

Methodology

Convergence can be classified into beta and sigma; beta convergence occurs when poorer economies grow faster than richer economies and tend to catch up (Barro 1991; Barro and Sala-i-Martin 1991, 1992, 1992a), and sigma convergence looks into cross-sectional variation—convergence occurs if the dispersion, measured by standard deviation or coefficient of variation, declines over time.

[1] For our purpose the national-level estimates represent all the included states.

The systematic formulation of β-convergence owes to the seminal work of Solow (1956), which describes a mechanism through which regions reach steady-state equilibrium. Solow's model leads to two conclusions: regions converge to a common steady state if the growth rate of technology, investment, and labour force is identical across regions; and farther the region from its steady-state, the faster this region will grow, leading to the general prediction that poorer regions will grow faster than richer. The movements of factors across regions in search of higher returns would make this happen. "Convergence is more likely across regions of same country rather than between the countries because the structural differences are likely to be smaller across regions of the same country (Sala-i-Martin 1995). β-convergence can be absolute or conditional. Absolute convergence signifies that poorer regions tend to grow faster and catch up with the richer ones. Following Sala-i-Martin (1995) it can be expressed as

$$\frac{1}{T}\ln\left[\frac{y_{it}}{y_{i0}}\right] = \alpha - \left[\frac{\left(1-e^{-\beta T}\right)}{T}\right]\ln y_{i0} + \varepsilon_{i,0,t} \qquad \ldots(1)$$

where y_{it} represents the current value of output and y_{i0} its initial value. The dependent variable is average growth rate regressed on initial output. The coefficient of the initial output $\ln y_{i0}$ can be written as

$$-\frac{1}{T}\left(1-\frac{1}{e^{\beta T}}\right)$$

for a given time period T when $\beta>0$, $e^{\beta T}>1$, $\frac{1}{e^{\beta T}}<1$, $\left(1-\frac{1}{e^{\beta T}}\right)>0$. Consequently $\frac{1}{T}\left(1-\frac{1}{e^{\beta T}}\right)>0$ and hence $-\frac{1}{T}\left(1-\frac{1}{e^{\beta T}}\right)<0$. This establishes a negative relationship between productivity growth $\frac{1}{T}\ln\left[\frac{y_{it}}{y_{i0}}\right]$ and initial productivity $\ln y_{i0}$. A positive value of β suggests that poorer regions are growing faster than richer ones, leading to convergence.[2]

The main limitation of absolute convergence is that it assumes that there are no structural differences in the units of observations, which of course is a strict assumption. The conditional convergence takes into consideration such differences. Then, Equation 1 can be modified as:

$$\frac{1}{T}\ln\left[\frac{y_{it}}{y_{i0}}\right] = \alpha - \left[\frac{\left(1-e^{-\beta T}\right)}{T}\right]\ln y_{i0} + \sum_{j=1}^{k}\gamma_j \ln x_j + \varepsilon_{i0,t} \qquad \ldots(2)$$

There are k control variables that account for differences in regional growth rates. Both the absolute and conditional equations can be estimated using panel data or cross-sectional frameworks. The steady-state can be controlled implicitly through fixed effects if panel data is used, and that is its advantage over cross-sectional data, but one potential problem is that the dependent variable—the annual or short-term growth rate—tends to capture short-term adjustments around the trend rather than the long-term convergence. This study relies on the nonlinear method for estimating β coefficients in Equation 1. The nonlinear least-squares method of estimation is better suited for subperiod comparisons (Barro and Sala-i-Martin 1992; Cashin and Sahay 1997; Yin et al. 2003), and it enables us to interpret the estimated beta coefficients as the speed of convergence.

Data

The Village Dynamics in South Asia project of the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) maintains a data set of area and production figures by crop for 19 major crops (rice, wheat, sorghum, pearl millet, maize, finger millet, barley, chickpea, pigeon pea, groundnut, sesame, rapeseed and mustard, safflower, castor, linseed, sunflower, soybean, sugarcane, and cotton) for 305 districts in 19 states[3] at their 1966 level. The empirics

[2] To avoid the complexity of the nonlinear estimator, most studies used the linear version of Equation 1: $\frac{1}{T}\ln\left[\frac{y_{it}}{y_{i0}}\right] = \alpha + \beta\ln y_{i0} + \varepsilon_{i0,t}$. This formulation is easy to estimate by applying the OLS method. In this case β<0 signifies convergence by establishing an inverse relation between growth $\frac{1}{T}\ln\left[\frac{y_{it}}{y_{i0}}\right]$ and initial output $\ln y_{i0}$.

Table 1 Productivity and average growth (1971–2010)

State	Output 1971 per hectare (INR)	Output 2010 per hectare (INR)	Average growth (%) (1971–2010)	Average growth (%) (1971–1991)	Average growth (%) (1991–2001)	Average growth (%) (2001–2010)
Haryana	20,484	60,960	2.8	3.22	1.42	3.38
Punjab	30,203	65,459	1.98	2.77	1.54	0.73
Rajasthan	8,572	26,615	2.9	2.43	2.81	4.08
Uttar Pradesh	22,184	50,892	2.13	3.21	1.46	0.48
Northern region	*18,844*	*46,130*	2.3	3.1	1.73	1.12
Assam	16,867	33,878	1.79	1.36	1.63	2.91
Bihar	20,212	26,803	0.72	0.85	1.98	–0.97
Jharkhand	13,061	30,819	2.2	0.14	8.36	–0.07
Chhattisgarh	14,389	28,294	1.73	1.77	0.94	2.54
Odisha	15,230	30,800	1.81	2.96	0.13	1.1
West Bengal	18,251	46,679	2.41	3.44	1.66	0.95
Eastern region	*16,992*	*33,568*	1.75	2.18	1.7	0.84
Gujarat	16,815	43,435	2.43	0.62	5.73	2.8
Maharashtra	10,298	33,488	3.02	2.62	2.91	4.05
Madhya Pradesh	13,215	23,217	1.45	1.2	2.33	1.01
Western region	*12,904*	*32,780*	2.39	1.55	3.54	2.99
Andhra Pradesh	21,255	42,007	1.75	2.34	1.42	0.79
Karnataka	18,241	40,340	2.04	2.23	1.08	2.67
Kerala	27,279	42,421	1.13	1.03	1.23	1.24
Tamil Nadu	33,249	77,380	2.17	2.76	1.96	1.07
Southern region	*23,317*	*46,417*	1.77	2.3	1.32	1.08
All India	*17,670*	*40,098*	2.1	2.45	1.95	1.48

Source Authors' calculation based on ICRISAT data

presented in this paper are obtained using district-level data from this data set. Many observations are missing for Uttarakhand, Himachal Pradesh, and Jammu & Kashmir, and we dropped these three states. To estimate agricultural productivity, we converted the physical output of crops into their monetary equivalent by multiplying these by their respective wholesale prices in 2010–11 and dividing the aggregate output value by the aggregate area.

Spatial and temporal variations in level and growth of productivity

Initially productivity was low in most states except Tamil Nadu and Punjab; over time productivity improved in all states significantly, though differentially across time, and it increased fastest during the period of the green revolution (1971–91). From 1971 to 2010, on the whole, agricultural productivity grew at 2.1% annually (Table 1).

The northern states rode the technological gains of the green revolution—quite apparent in Haryana, Punjab, and Uttar Pradesh between 1971 and 1991—although the growth momentum dampened subsequently. Growth in the western region was the highest in the period after the green revolution—3.54% annually from 1991 to 2001 and 2.99% annually from 2001 to 2010. Productivity started from a low base in Rajasthan and increased at 4% annually from 2001 to 2010. The only state in this region that has lagged behind is Madhya Pradesh.

Growth has been high in West Bengal, but in the rest

[3] Three new states were formed in the year 2000: Chhattisgarh (from Madhya Pradesh), Jharkhand (from Bihar), and Uttarakhand (from Uttar Pradesh). The districts formed before 2000 are included in their parent states; those formed later are listed in the 'New districts formed' column.

of the eastern region productivity and productivity growth have always been lower than the national average. Bihar experienced negative growth between 2001 and 2010. With less than 1% productivity growth, Bihar is the worst performing state.

Productivity in the southern region was the highest throughout the period from 1971 to 2010; Tamil Nadu was at the forefront. Starting from high base productivity, all the states in this region except Kerala registered high growth rates, although with considerable variation over the subperiods. Productivity growth was higher in Andhra Pradesh and Tamil Nadu during the green revolution period; in Karnataka growth was rapid during the period from 2001 to 2010. Productivity growth in Kerala is low but stable.

Over the subperiods both productivity (Figure 1) and growth (Figure 2) varied by district. In 1971, productivity was high in only a few districts, but by 2010, it was high in most, and the districts in the northern and southern regions performed better. Productivity growth, too, varied widely by district and period. The districts in the western region experienced sustained growth was; only the districts in the eastern region lagged behind.

The analysis of productivity growth shows a shift in the distributional symmetry of districts over time.

Convergence Analysis

We econometrically assess whether the growth has been converging at three levels of spatial aggregation—all-India, regions, and states—and present the estimated coefficients of variation in productivity at different points of time (Table 2).

At the all-India level, taking all the districts together, the value of the coefficients of variation first increased, then slowed down. Productivity growth was the highest in the initial phase of the green revolution at the national level and for all regions except the southern region, where the value of the coefficients of variation first increased, then began to taper off. In the southern

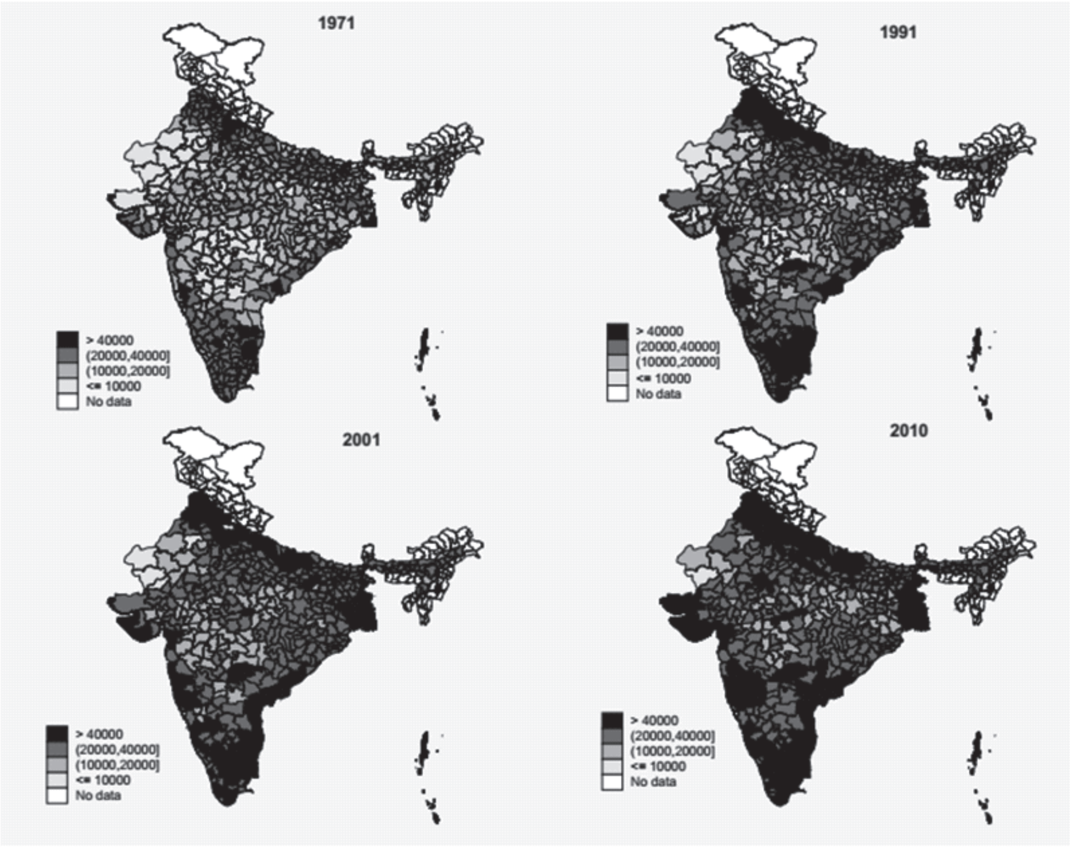

Figure 1 Agricultural productivity, variation by district (INR)

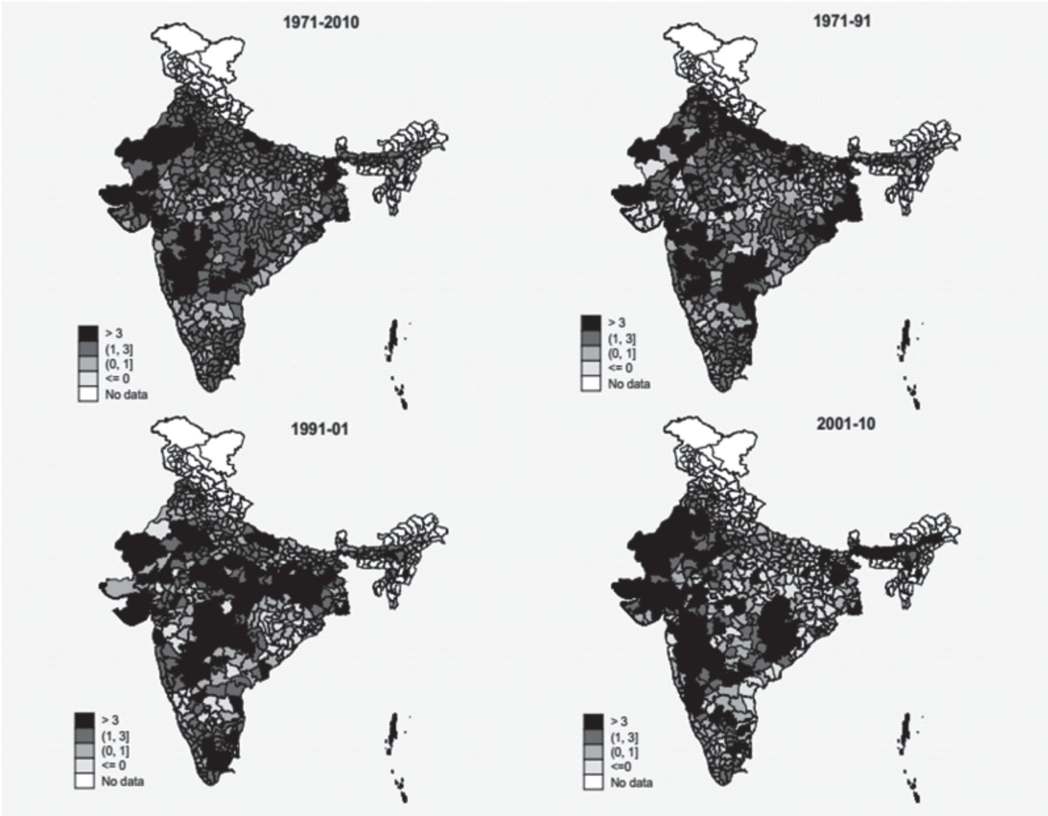

Figure 2 Productivity growth over subperiods by district
Source Authors' calculation, based on ICRISAT data.

region, the inter-district variation in productivity peaked in 2001. The value of the coefficients of variation declined in most states except Jharkhand, Chhattisgarh, Odisha, Madhya Pradesh, Karnataka, and Tamil Nadu, where it increased.

In 2010 the inter-district variation was lower in Assam, Kerala, and Punjab than in Maharashtra, Uttar Pradesh, and Karnataka. The inter-district variability declined continually in all the northern states, but Uttar Pradesh has the highest inter-district variability. That is a matter of concern. The value of the coefficients of variation increased in the eastern region in Jharkhand, Chhattisgarh, and Odisha but declined in Assam and Bihar.

Absolute beta convergence

Nonlinear least-squares estimates are better suited for subperiod comparison (Sala-i-Martin 1995); therefore, we present the estimates of the nonlinear form of the convergence equation. To account for district heterogeneity and likely heteroscedasticity we rely on robust standard errors. We present the estimates of absolute beta convergence equation in Table 3. For the state (region) level results we estimated all the coefficients by using state (region) dummies in a single regression. While running the regression for states (regions) we omitted the intercept term and included all the states (regions) in the model. The results are analogous to running a regression separately for each state.

At the national level there was absolute convergence; the convergence speed during the 1971–2010 period was 1.7%, meaning that the productivity growth across districts was unconditionally converging towards the steady-state. An analysis by subperiods suggests that the speed of convergence during the early phase of the green revolution was slow. In the latter two periods we find evidence of strong convergence; the speed of convergence being 3.1% for 1991–2001 and 2.4% for 2001–2010. This is compatible with our earlier findings

Table 2 Coefficient of variation in productivity (by state and region)

States	Coefficient of variation			
	1971	1991	2001	2010
Haryana	0.489	0.345	0.300	0.187
Punjab	0.151	0.135	0.119	0.093
Rajasthan	0.523	0.498	0.394	0.278
Uttar Pradesh	0.529	0.515	0.471	0.435
Assam	0.171	0.158	0.212	0.089
Bihar	0.451	0.206	0.221	0.152
Jharkhand	0.183	0.096	0.126	0.574
Chhattisgarh	0.125	0.146	0.091	0.198
Odisha	0.199	0.162	0.175	0.217
West Bengal	0.189	0.208	0.188	0.155
Gujarat	0.472	0.786	0.608	0.373
Maharashtra	0.834	0.728	0.642	0.558
Madhya Pradesh	0.260	0.367	0.332	0.353
Andhra Pradesh	0.500	0.341	0.362	0.292
Karnataka	0.391	0.385	0.466	0.433
Kerala	0.187	0.121	0.077	0.090
Tamil Nadu	0.249	0.230	0.271	0.262
Northern region	0.564	0.610	0.545	0.445
Eastern region	0.373	0.404	0.359	0.373
Western region	0.504	0.607	0.537	0.493
Southern region	0.379	0.366	0.428	0.379
All states	0.501	0.583	0.535	0.473

Source Authors' calculation based on ICRISAT data

of sigma convergence.

At the national level our analysis suggests weak β-convergence during the green revolution period, which was marked with high growth and variability. The regional-level results are in conformity with the national-level results. The speed of convergence was the highest for the eastern region. The speed of convergence in the northern region was similar to that at the all-India level. The productivity growth converged at the speed of 1.9%. An analysis by subperiods shows that the early green revolution triggered asymmetric growth in some districts in the northern region, but with the gradual spread of new technologies, the speed of convergence increased to 3.2%.

The western region attained a speed of convergence of 1.5% in the 1971–2010 period. Inequalities increased during the green revolution period in the northern region, accompanied by high growth and the absence of absolute convergence. Productivity growth improved from 1991 to 2001 except in the southern region, where productivity growth had been converging at a slower rate.

While explaining convergence estimates at the state level, the sample size must be considered. We report the convergence estimates for all the states, but we limit our discussion to the states where the sample size is large enough (with at least 10 districts). Convergence was high in the districts of Punjab during the past decade. The findings must be seen together with our earlier finding that in Punjab the average growth from 2001 to 2010 was negligible. Punjab is one obvious exception, as both the growth rate and convergence were high. The results for Rajasthan are noticeable; the convergence for all the subperiods was high.

Uttar Pradesh, with the largest number of districts, does not show any sign of convergence as evidenced by the estimated value of beta convergence. Given the size of the state, in terms of both share in agricultural output and the population dependent upon it, the persistence of inter-district variability is a matter of serious concern.

In the eastern region, Jharkhand and Chhattisgarh have fewer districts. The condition of nonlinear least squares beta estimate is not fulfilled for these states. Assam and Bihar experienced high rate convergence in agricultural productivity, especially during the past decade, when the speed of convergence was more than 10%. The productivity growth across districts in Odisha and West Bengal have been converging unconditionally towards their steady states. Our analysis shows that Assam and West Bengal have been achieving inter-district convergence with fairly robust growth in agricultural productivity. The convergence in Bihar is due to the extremely slow growth in agricultural productivity.

In the western zone, in Gujarat, the convergence coefficient is insignificant for the initial subperiods, although the evidence of convergence is strong for all the subperiods. Agricultural productivity has been growing and converging at a very high speed in the districts of Gujarat during the past two decades. In Maharashtra, between 1971 and 1991, there was an absence of convergence, but the speed of convergence grew in the past two decades, and for the overall period the speed of convergence was around 2%. There is no

Table 3 Estimates of speed of convergence

State/Region	1971–2010		1971–1991		1991–2001		2001–2010	
	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*
				State level				
Haryana	0.035**	*0.02*	0.013**	0.02	0.020***	0.00	0.103	0.12
Punjab	0.038**	*0.01*	0.024**	0.04	0.018	0.23	0.061**	0.01
Rajasthan	0.036***	*0.00*	0.029*	0.07	0.045***	0.00	0.036***	0.00
Uttar Pradesh	0.003	*0.38*	–0.008*	0.08	0.020***	0.00	0.008*	0.07
Assam	0.047**	*0.01*	0.024	0.24	0.007	0.75	0.107***	0.00
Bihar	0.075**	*0.04*	0.105**	0.01	0.019	0.42	0.139**	0.04
Jharkhand			0.119***	0.00	0.016	0.81	–0.064	0.44
Chhattisgarh	0.002	*0.90*	–0.002	0.93	0.185**	0.03	–0.092**	0.03
Odisha	0.030	*0.32*	0.055	0.15	0.012	0.38	0.019	0.67
West Bengal			0.140	0.59	0.046	0.10	0.098**	0.01
Gujarat	0.019***	*0.00*	0.064	0.36	0.106	0.11	0.043***	0.00
Maharashtra	0.013**	*0.01*	0.008**	0.03	0.024**	0.02	0.019*	0.08
Madhya Pradesh	0.005	*0.47*	–0.005	0.58	0.047***	0.00	0.013	0.37
Andhra Pradesh	0.022***	*0.00*	0.016	0.17	0.036	0.13	0.031**	0.03
Karnataka	0.019*	*0.07*	0.011	0.17	0.009	0.63	0.039**	0.01
Kerala	0.035***	*0.00*	0.048***	0.00	0.080***	0.00	0.007	0.81
Tamil Nadu	0.015	*0.14*	0.014	0.51	0.021	0.22	0.060	0.18
R2	0.685		0.728		0.733		0.608	
				Region level				
Northern	0.019***	0.00	0.008	0.34	0.025***	0.00	0.032***	0.00
Eastern	0.040**	0.04	0.056**	0.03	0.064***	0.00	0.036**	0.03
Western	0.015***	0.00	0.022*	0.06	0.056**	0.01	0.012*	0.07
Southern	0.016***	0.00	0.011*	0.05	0.011	0.41	0.031***	0.00
R2	0.867		0.618		0.614		0.426	
				All India				
All states	0.017***	*0.00*	0.010*	*0.05*	0.031***	*0.00*	0.024***	*0.00*
R2	0.385		0.066		0.324		0.171	
N	292		292		292		*292*	

Source Authors' calculation based on ICRISAT data.
Notes 1. Standard errors reported are clustered at the district level.
2. * depicts significance at 10%, ** at 5%, and *** at 1%
3. For Jharkhand and West Bengal numerical condition of non"linear estimation has not been fulfilled.

evidence of convergence in Madhya Pradesh between 1971 and 1991.

Conditional convergence

The idea of conditional convergence is based on the premise that factors apart from initial conditions are responsible for convergence. Conditional growth regression can be used to explain the determinants of long-run growth with initial output as one of the determinants. Table 4 describes the control variables used in Equation 2. Table 5 provides the estimates of the conditional regression model as specified by Equation 2.

The model is estimated using the nonlinear least-squares method. Two sets of estimates are provided. In one model we added regional dummies with the northern region to accommodate the region-specific factors. The standard errors reported are clustered at the district level. Both the models suggest convergence. The positive value of the 'initial productivity level' indicates convergence. These results can be used to understand the determinants of long-run

Table 4 Control variables

Variable	Description
Agricultural implements	Diesel pump set, electric pump set, power tiller, and tractor (number per hectare)
Fertilizer	Nitrogen (N), phosphorus (P), and potassium (K), or NPK (kg per hectare of net cropped area)
Livestock	includes cattle, horses, and camels (number per hectare)
Road length	Road length (meter per hectare)
Labour	Cultivators and agricultural labourers (number per hectare)
Literacy	Rural literacy rate (%)
Irrigation	Net crop area irrigated (%)

Table 5 Conditional convergence: determinants of growth

Variables	Coefficient	.Standard deviation	P>t	Coefficient	Std.	P>t
Initial output	0.033***	*0.007*	*0.00*	0.033***	0.007	0.00
Irrigated area	0.010**	*0.004*	*0.02*	0.004	0.004	0.31
Ln (NPK)	0.002**	*0.001*	*0.03*	0.002***	0.001	0.00
Livestock	0.003*	*0.002*	*0.08*	0.000	0.002	0.97
Ln (road length)	0.002*	*0.001*	*0.04*	0.003**	0.001	0.01
Rural literacy rate	0.005	*0.006*	*0.37*	0.006	0.006	0.29
Labour	–0.004**	*0.002*	*0.01*	–0.004**	0.002	0.02
LN(agricultural implements)	0.001**	*0.000*	*0.04*	0.000	0.001	0.43
Constant	0.191***	*0.018*	*0.00*	0.197***	0.018	0.00
Eastern region				–0.006**	0.002	0.02
Western region				–0.008***	0.002	0.00
Southern region				–0.005**	0.002	0.03
R”square	0.512			0.557		
N	289			289		

Source Authors’ calculation based on ICRISAT data.
Note * depicts significance at 10%, ** at 5%, and *** at 1%.

productivity growth.

The model that includes regional dummies provides a better fit. All the regional dummies are negative and significant, implying that the region-specific differences in productivity are considerable and that productivity was the highest in the northern region.

Our results suggest that factors other than initial output differences influence long-run growth considerably. Most of the variables have positive and significant coefficients. The growth in agricultural productivity is positively related with irrigation, fertiliser use (NPK), livestock numbers, greater mechanization, and better roads.

Conclusions

The states in India are large, and intra-state variations are significantly wide. The state-level statistics cannot help us explore the variations; therefore, district-level output data for the 1971–2010 period is used to test the agricultural productivity convergence hypothesis. To understand whether poorer regions can catch up with well-off regions, we followed both exploratory approaches (growth analysis with the help of summary statistics and mapping) and confirmatory approaches (formal tests: sigma and beta convergence). To capture the differential effects of changes in the economic environment, we conducted subperiod analysis.

Over the past four decades all-India and regional average productivity increased; the national-level productivity growth rate declined continually, with regional variations. Our study suggests both sigma and beta convergence, and absolute convergence at the national level with the convergence parameter of 1.7% over the 1971–2010 period.

The speed of convergence was meager early during the green revolution, the subperiod analysis suggests. The absence of unconditional beta convergence in this period is evidenced by the hike in variability. During the two later sub-periods, there is evidence of strong convergence; the speed of convergence coefficient is 3.1% for 1991–2001 and 2.4% for 2001–2010. This is confirmed with sigma convergence.

Our analysis suggests no beta convergence at the national level during the high-growth pre-reforms period but high convergence in the two later decades with low average growth. Conditional convergence analysis suggests that initial conditions matter for subsequent growth. It is found that districts with better irrigation, fertilizers, livestock, road length, and agricultural implements are growing at a higher rate.

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