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Understanding the Geographic Pattern of Diffusion of Modern Crop Varieties in India

A Multilevel Modeling Approach

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Abstract

In this paper, we seek to quantify the relative importance of various geographical and administrative factors affecting the diffusion process of modern crop varieties in India. Our study relies on a multilevel modeling approach and uses pan-Indian, household-level data on the adoption of different varieties of rice, wheat and maize. Findings indicate that household-level differences explain larger variation in the adoption of modern crop varieties, but the contextual effects of state actions also play an important role in the diffusion process. These contextual effects are larger for commercial crops than for subsistence crops. Although level-specific recommendations are beyond the scope of this paper, our findings imply a need for strengthening linkages between research and extension systems, and better coordination of programs and strategies across different geographical levels for dissemination of modern crop varieties.

Keywords: diffusion of modern varieties, cereals, multilevel modeling, India

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INTRODUCTION

In the latter half of the twentieth century, technological change supported by massive investments in irrigation, infrastructure and agricultural institutions along with the introduction of incentives – in the form of input subsidies and output price support – propelled India and several other Asian countries towards food self-sufficiency. Though the nation endured acute food scarcity throughout the 1960s and 1970s, India's food grain production increased from 108 million tons in 1970-71 to 276 million tons in 2017-18.

Nonetheless, the need to produce more food remains as urgent today as it was in the past. By 2033, India's demand for food grains is predicted to increase to 333 million tons (GoI, 2018), and new challenges stand in the way of meeting that demand. Indian agriculture is now threatened by several biotic and abiotic factors, such as quantitative and qualitative deterioration of natural resources (i.e., land and water), increasing frequency of extreme climatic events (i.e., droughts, heat waves and floods), and deceleration in technological gains achieved during the bio-chemical technology boom of 1970s. Moreover, the yield growth of important staple cereal crops, viz., rice and wheat, has decelerated considerably. Rice yields, which had been growing at an annual rate of 2.3% from 1970-71 to 1990-91, decelerated to 1.3% growth during 1991-92 to 2016-17. During that same time span, the yield growth of wheat slowed from 3.5% to 1.2%. This is a matter of serious concern. The country's net-cropped area has been stagnating around 142 million hectares for the past four decades, and the prospects of its intensification via multiple cropping are constrained by the increasing scarcity of water and energy for irrigation. Any increases in food grain production must, therefore, come from a continuous introduction of improved technologies, including high-yielding crop varieties, and their large-scale diffusion.

Studies from the developing world show that adoption of agricultural technologies, including modern crop varieties, is constrained by several socio-demographic, economic, institutional and policy factors (Feder et al., 1985; Foster and Rosenzweig, 1995; Asfaw et al., 2011; Simtowe et al., 2011; Mottaleb et al., 2014; Birthal et al., 2015; Paltasing and Goyari, 2018). This paper aims to understand the diffusion patterns of modern varieties of rice, wheat and maize in India at multiple geographical and administrative levels. While most studies on the adoption of modern technologies are focused on household-level determinants, ignoring the higher geographical or administrative levels, we believe that understanding the relative importance of different geographical and administrative levels is essential for appropriate targeting of technologies and ensuring their diffusion in a way that leads to efficient and sustainable increase in food grain production.

The rest of the paper is organized as follows. Section 2 discusses sampling and data. A conceptual framework is discussed in section 3. Section 4 provides descriptive statistics. Section 5 provides the estimation procedure and is followed by a discussion of key findings in section 6. Concluding remarks are made in the last section.

DATA

Our data on the adoption of modern crop varieties comes from a nationally representative survey of farm households, conducted by the International Food Policy Research Institute (IFPRI) during 2017-2018. The primary aim of this survey was to generate information on the adoption of modern varieties of important crops in major Indian states and the factors underlying farmers' adoption behavior. A total of 30,540 farm-households were surveyed. Of the total sample, 19,877 households were paddy cultivators, 9,467 households were wheat growers, and 2,681 households were maize cultivators. Some of the sample households cultivated more than one crop.

This survey has used a multistage sampling procedure. The state is the first-stage sampling unit and the household is the ultimate sampling unit. The survey covers most Indian states, but to account for contiguity of states, sizes of their agricultural sectors and similarities or dissimilarities in their agro-climatic and socio-economic conditions, some smaller states were merged, and larger states divided. With the exception of Assam, all states in the northeastern region (i.e., Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Sikkim) were merged to form a single unit for first-stage sampling, considering their adjacent boundaries, small agricultural sectors and similar agro-ecological and socio-economic conditions. On the other hand, Uttar Pradesh, one of the largest states in India, was divided into two: eastern Uttar Pradesh and western Uttar Pradesh. This approach accounts for the considerable spatial heterogeneity in its agro-climatic and socio-economic conditions. Uttarakhand, a part of western Uttar Pradesh until 2000, was merged with its parent state. Likewise, Telangana was given back to its parent state, Andhra Pradesh.

For our sampling of spatial or administrative units below the state level, a list of districts from each state, blocks from each district and villages from each block was compiled from the Census of India 2011. The districts in each state were ranked in ascending order of their combined share of five major crops in the state's total cropped area. Accordingly, 13 districts representing different agro-climatic conditions of the state were selected for sampling of blocks, villages and households. Three blocks from each district and two villages from each block were randomly selected. Finally, a sample of around 20 farm households from each village was drawn at random.

Information was collected from selected households on: (a) farm and household characteristics, such as landholding size, soil types, irrigation sources, acreage allocations to crops and their varieties, sources of seeds, crop yields, sources of information on agricultural technologies and households' access to institutional credit; and (b) socio-demographic characteristics, such as family size, religion, caste and age, gender, education and agricultural experience of the household heads.

Since we use plot-level data in this analysis, each observation pertains to one plot. This study, therefore, comprises a total of 37,041 observations. Of the total sample observations, 23,772 observations pertain to paddy, 10,588 observations relate to wheat and 2,681 belong to maize. Table A1 in the appendix provides state-wise distribution of sample observations pertaining to these crops.

CONCEPTUAL FRAMEWORK

The process of technology diffusion is influenced by several factors, including farm and farmer characteristics, resource endowments, local environments, governance structures, availability of infrastructure (e.g., roads, electricity and banking), markets, incentives, extension and policy support. Putting it differently, the diffusion of technologies is an outcome of an interactive process, operating at multiple geographical and/or administrative levels. This complexity underscores the need to understand the relative importance of different geographical and administrative levels in explaining the variation in the diffusion pattern of agricultural technologies.

To understand the geographical pattern of technology diffusion we follow a multilevel modeling approach. This approach is widely used in social science research to analyze the mutually reinforcing and reciprocal relationships between people (compositional effects) and places (contextual effects). To the best of our knowledge, only a few studies have applied multilevel models to research in agriculture and rural development (Overmarks et al., 2006; Su and Xiao, 2013; Xiao et al., 2015; Su et al., 2016; Thapa et al, 2018; Zhang et al., 2018; Birthal et al., 2019, 2020). There are three principal advantages of a multilevel modeling approach (Goldstein, 2003; Raudenbush and Bryk, 2002; Kim et al., 2016):

1.This approach unlike a single-level approach, is capable of capturing spatial heterogeneity in climatic conditions, infrastructures, institutions, and socio-demographic and economic factors that matter in technology diffusion.

2. The observational units at a single level may show greater homogeneity of socio-economic and agronomic factors, but these factors are correlated due to a common effect, meaning decisions about technology adoption are confounded by compositional effects. For instance, the adoption rate of a particular technology could be higher in some districts because of the clustering of more skilled, better-endowed and innovative farm households. If this is the case, then between-district variation in rate of adoption gets reduced on controlling for farm and household characteristics. If the variation in adoption

rate still remains high, it indicates the true contextual effect of districts on the diffusion of technology. Therefore, it is essential to disentangle the contextual effects from the compositional effects, and this is possible through a multilevel approach.

3. Technology diffusion can be influenced by some factors simultaneously at more than one level; hence, their relative influence on technology adoption can be assessed only if multiple levels are considered simultaneously.

The sampling design of the IFPRI survey is inherently hierarchical. This allows us to build a multilevel model of the adoption of modern crop varieties. We construct a five-level geographical hierarchy without any prior assumptions regarding the relevance of different geographical levels in technology adoption decisions. At the top of the hierarchy are the states. Agriculture is a state subject in India, and priorities and policies for agricultural development differ across states. At the next level, we have the districts. The district administration is responsible for the provision of infrastructural, institutional, financial and market support for technology diffusion. Blocks comprise the next geographical or administrative level. A block is more homogeneous in agro-climatic conditions than a district, and block administration based on agro-climatic conditions facilitates the transfer of technologies to farm households within its administrative jurisdiction. Thus, the villages nested in blocks and the households nested in villages are the next hierarchical levels. The levels towards the bottom of the geographical hierarchy are more homogeneous in several socio-economic, agronomic, institutional and infrastructural aspects, as compared to the higher levels.

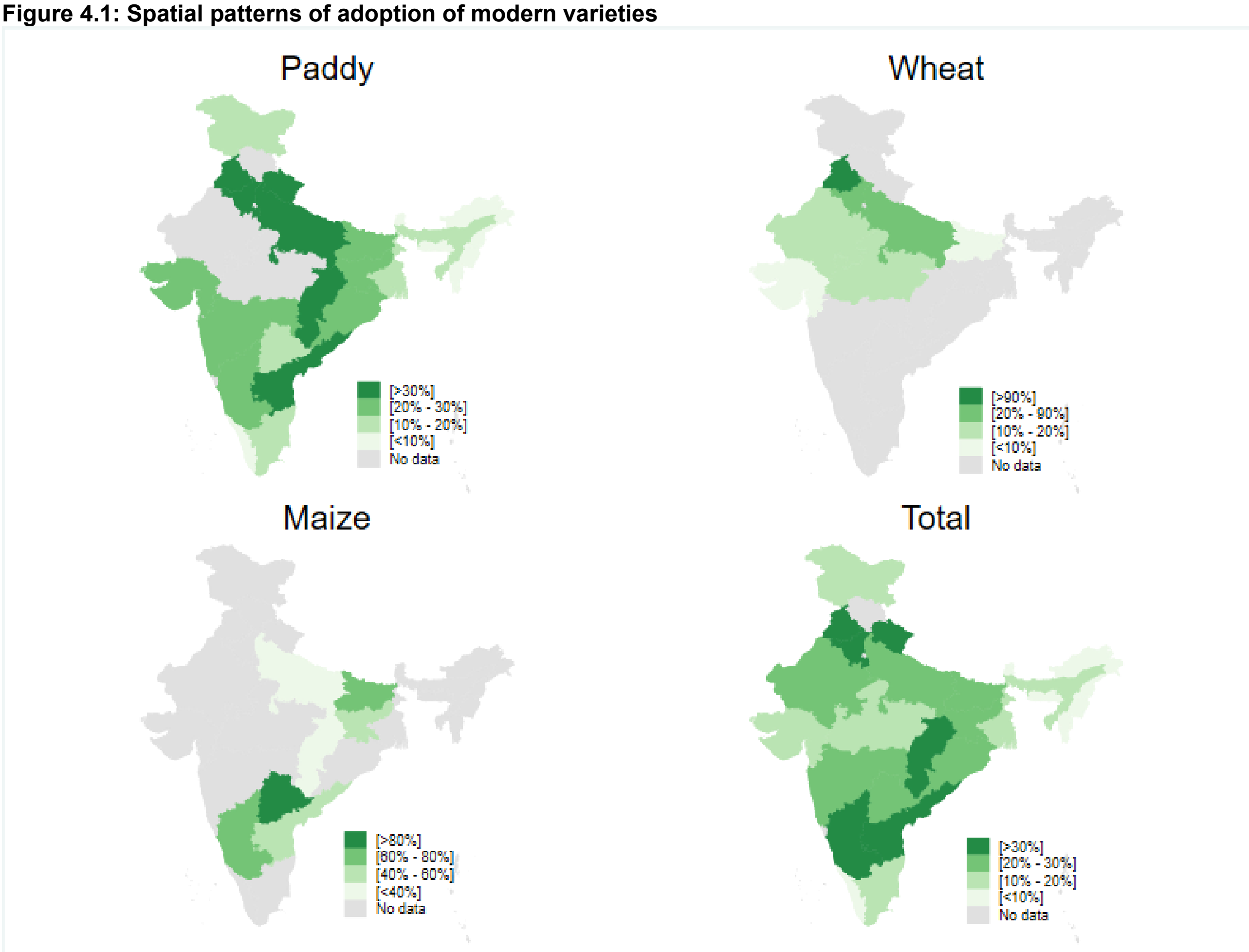
DESCRIPTIVE STATISTICS

The IFPRI survey collected information on different varieties of rice, wheat and maize grown by the sample households. Based on their age or year of release for commercial cultivation by government agencies (viz., Central or State Variety Release Committee), these varieties were classified as old or modern. Generally, a variety of 15 years of age or more is not included in the seed chain by the public-sector agencies, i.e., State

Department of Agriculture. Thus, we consider a variety to be modern if it was less than 15 years of age at the time of survey.

Figure 4.1 shows the spatial pattern of the diffusion of modern varieties of paddy, wheat and maize. The grey shades show the regions not covered by the survey, because of the smaller area under these crops. Paddy is widely cultivated, while the cultivation of wheat is restricted to the northwestern states. Maize cultivation is confined to some southern and eastern states. Even within their niche production regions, there is significant geographical variation in the diffusion of modern varieties of the selected crops.

Figure 4.1: Spatial patterns of adoption of modern varieties



Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Table 4.1 shows the percentage of total area under modern varieties of rice, wheat and paddy attributable to each farm-size class. On average, 37% of the total area under paddy cultivation is under modern varieties. The adoption rate of modern varieties of wheat and maize is higher. Close to 73% of the maize varieties and 62% of the wheat varieties are modern varieties/hybrids.

There is little variation in the proportion of area under modern varieties of maize across farm-size classes. On the other hand, the adoption rate of modern varieties of paddy and wheat is positively associated with landholding size. For example, on large farms about 55% of the paddy area and 72% of the wheat area is occupied by modern varieties as compared to 25% and 43%, respectively, on marginal farms.

Table 4.1: Percent area under modern crop varieties by farm-size class

	Paddy	Wheat	Maize	All
Marginal (<1ha)	25.3	43.0	71.8	29.8
Small (1-2ha)	29.8	49.7	75.2	36.9
Medium (2-4ha)	40.2	63.5	76.9	50.6
Large (>4ha)	54.8	72.0	65.4	63.8
All	37.3	61.6	73.1	47.3

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

There could be several reasons for the variation in adoption rate of modern varieties across crops and landholding classes. We consider households' access to information on modern technologies and practices to be an important factor in their decisions about whether or not to adopt modern seed varieties. Table 4.2 shows the distribution of households based on their sources of information on modern varieties. On the whole, about 64%, 26% and 31% of paddy, wheat and maize farmers, respectively, have access to information on modern varieties from at least one source. The information sources, however, vary across crops. Most of the paddy and wheat farmers rely on their fellow farmers for information on modern varieties, while maize farmers depend largely on local input dealers. Input dealers are also an important source of information for paddy and wheat farmers. Information from public extension systems and mass media are sourced by only a small proportion of households.

Table 4.2: Distribution of sources of information on modern seed varieties (%)

Sources	Paddy	Wheat	Maize	All
Other farmers	49.1	68.2	31.6	51.8
	[2,817]	[2,098]	[540]	[5,455]
Extension agent	7.6	4.6	5.0	6.3
	[438]	[141]	[85]	[664]
Mass media	10.2	5.8	17.5	10.1
	[587]	[179]	[299]	[1,065]
Input dealers	24.3	19.3	45.1	26.2
	[1,397]	[594]	[770]	[2,761]
Others	8.8	2.0	0.9	5.5
	[504]	[63]	[15]	[582]
Total	100.0	100.0	100.0	100.0
	[5,743]	[3,075]	[1,709]	[10,527]
From any source	63.7	26.2	30.8	47.4

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.
Note: Number of observations in brackets.

Table 4.3 presents the distribution of farm households by their main source of seeds of modern varieties of these crops. There are significant differences in seed sources for modern varieties of selected crops. Most of the paddy farmers source seeds from the government-approved seed dealers, and directly from the public-sector agencies, including research and extension systems. For over one-fifth of households, the private seed companies comprise a source of modern paddy seeds.

Among wheat farmers, private seed companies are the main source of modern seeds for 42%, followed by government-approved seed dealers (21%) and fellow farmers (13%). On the other hand, maize seeds are sourced mainly from the private seed companies (57%), local input dealers (17%) and government-approved seed dealers (14%).

Farmers' greater reliance on private seed companies for maize and paddy is related to the availability of their hybrids. Hybrid seed business in India is largely the domain of the private sector.

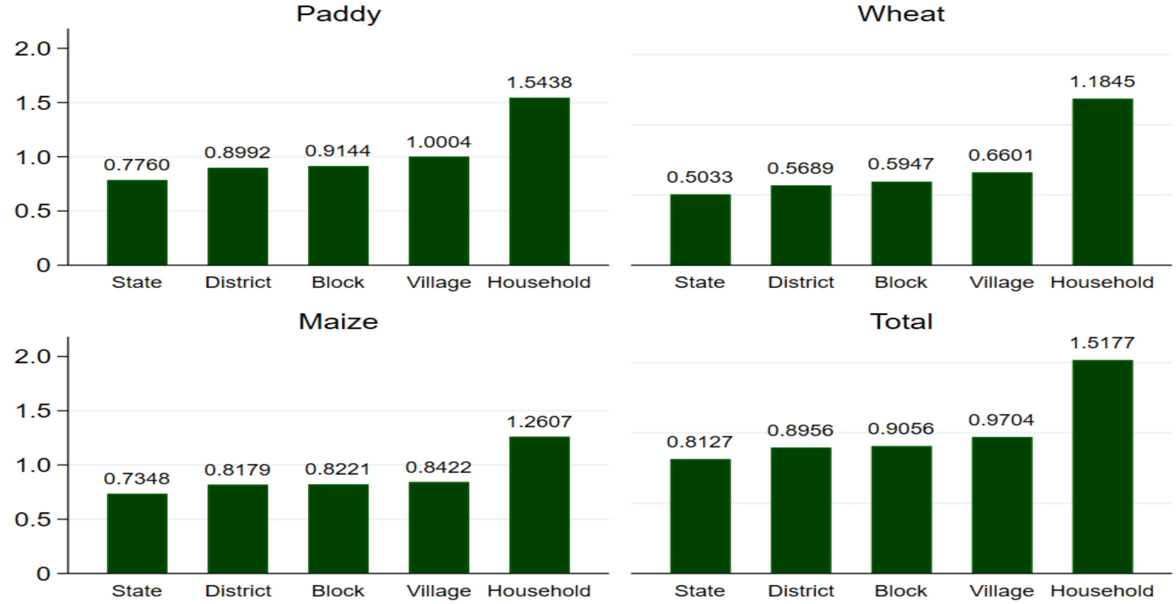
Table 4.3: Sources of modern seed varieties

Sources	Paddy	Wheat	Maize	Total
Local inputs dealer	0.6	10.6	16.3	6.1
	[36]	[325]	[278]	[639]
Government agencies	17.4	11.8	8.7	14.4
	[1,000]	[362]	[149]	[1,511]
Government-approved seed dealers	46.0	20.7	13.6	33.4
	[2,641]	[638]	[233]	[3,512]
Private seed companies	22.3	41.9	56.6	33.6
	[1,277]	[1,288]	[968]	[3,533]
Other farmers	13.1	12.6	4.7	11.6
	[750]	[388]	[81]	[1,219]
Own saved seeds	0.6	2.4	-	1.0
	[35]	[74]		[109]
Total	100.0	100.0	100.0	100.0
	[5,739]	[3,075]	[1,709]	[10,523]

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.
Note: Number of observations in brackets.

The differential patterns in farm households' access to information and sources of seeds indicate that there are differences in institutions, infrastructure and agricultural development priorities across different geographical levels, that give rise to differences in the adoption rates of modern varieties. In other words, area allocation to modern varieties will vary both within and across geographical or administrative levels. To illustrate this, in Figure 4.2 we present a coefficient of variation (CV) in area under modern varieties at different geographical levels. The variation in area under modern varieties is higher at the household-level for all crops. The coefficient of variation in area under modern crop varieties at other geographical levels is, by and large, similar. This is an early indication of the presence of both compositional effects (between households) and contextual effects (between population) on the diffusion patterns of modern crop varieties.

Figure 4.2: Coefficient of variation in adoption of modern varieties at different geographical levels



Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

ESTIMATION PROCEDURE

We begin by constructing a five-level random intercept model (RIM) with households nested within villages, villages within blocks, blocks within districts and districts within states.

$$\mathrm{MV}_{ivbds} = \beta_0 + (\delta_s + +\nu_{ds} + \gamma_{bds} + \eta_{vbds} + u_{ivbds}) \quad (1)$$

where, MV_{ivbds} represents area under modern varieties. β_0 is an intercept term and ϵ_i is an error term distributed normally with zero mean and finite variance. The random terms enclosed within the parentheses are the residual differentials that summarize variation in the dependent variable at the state (δ_s), district (ν_{ds}), block (γ_{vds}), village (η_{vbds}) and household (u_{ivbds}) levels. These random variances provide the between-individual (household) and between-population (village, block, district and state) variation in the dependent variable, and are assumed to be independent and normally distributed with zero means and the respective variances of σ^2_δ, $\sigma^2_\nu, \sigma^2_\gamma, \sigma^2_\eta$ and σ^2_u.

Eq. (1) captures only the geographical pattern of diffusion of modern varieties. It is, however, possible that the variation in diffusion of a variety at higher geographical levels could be an artifact of the compositional factors operational at lower levels. For instance, some villages may have clusters of households with similar characteristics (i.e., skills) that motivate them to adopt modern varieties. Therefore, we introduce fixed-effects covariates in Eq. (1) and re-write it as:

$$\mathrm{MV}_{ivbds} = \beta_0 + \beta_1 \boldsymbol{X}'_{ivbds} + (\delta_s + +\nu_{ds} + \gamma_{bds} + \eta_{vbds} + u_{ivbds}) \quad (2)$$

The vector $\mathbf{X}'$ in Eq. (2) is a deterministic component that captures compositional effects at the lowest level, i.e., household, and β_1 is a vector of their corresponding regression coefficients. The random terms in Eq. (2) provide the variance in area under modern varieties at different geographical levels, controlling for the fixed-effects covariates. The fixed effects are analogous as in a standard regression equation, and can be estimated directly; the random effects, the terms in parentheses, cannot be estimated directly, and are summarized based on their estimated variances and covariances.

The variation in area under modern varieties at any geographical level, known as the variance partitioning coefficient (VPC), can be calculated by dividing the variance at that level by the total variance for all levels (Goldstein et al., 2003. For instance, the proportion of variation in area under modern varieties at the village level can be estimated as:

$$\mathrm{VPC_s} = \frac{\sigma_\eta^2}{(\sigma_\delta^2 + \sigma_\nu^2 + \sigma_\gamma^2 + \sigma_\eta^2 + \sigma_u^2)} \quad (3)$$

The larger the value of VPC at a level, the greater is the scope for interventions at that level. The extent of variation in the adoption of modern varieties explained by the compositional factors at each geographical level can be estimated as the proportional difference in variance (PVC) between the variance of the conditional model (Eq. 2) and the variance of the unconditional model (Eq.1), i.e.,

$$PVC = \left(\frac{\sigma^2_{\mathrm{Unconditional}} - \sigma^2_{\mathrm{Conditional}}}{\sigma^2_{\mathrm{Unconditional}}}\right) * 100 \quad (4)$$

The PVC provides the variation in area under modern varieties accounted for by the compositional effects, i.e., the covariates in vector X, and the geographical differences, i.e., contextual effects. A larger PVC value suggests relevance of the compositional factors in varietal diffusion. Conversely, a smaller value of PVC implies the greater importance of geographical differences in explaining the variation in adoption rates of modern varieties.

RESULTS AND DISCUSSION

In this section, to clarify the relative importance of key determinants of adoption of modern varieties, we discuss results of the multilevel model, first estimated jointly for all crops and, subsequently, for the individual crops. The descriptive statistics of the variables used in multilevel regressions are provided in Table A2 in the appendix.

The households cultivating different crops differ in some of their socio-demographic, economic and institutional characteristics, and these differences influence their adoption of modern varieties. Landholding size of paddy farmers is much smaller than that of wheat and maize farmers. They, however, do not differ much in their labor endowment. Contrary to our expectation, maize farmers have better access to irrigation, especially surface irrigation. Tube-well irrigation is more prominent in wheat. Most of the household heads, irrespective of the crop they cultivate, are males. Household heads are relatively homogenous in terms of age and agricultural experience. Illiteracy is higher among maize farmers. Social status of the households may impact crop choice and the adoption of modern varieties. Maize and wheat are more prominent among upper-caste households, while paddy cultivation is more prevalent among lower-caste households. Maize and wheat farmers also have better access to institutional credit.

Estimates for aggregates of crops

Table 6.1 presents estimates of different specifications of our multilevel variety adoption model. Model 1 is an unconditional model that does not include any fixed-effects covariates. We build upon this by introducing successive fixed-effects covariates for households, farms and institutions so as to understand their relative importance in the adoption of modern crop varieties.

In model 2, most of the household-level fixed-effects covariates are significant. Adoption of modern varieties is positively associated with education. This is expected as farmers who have higher education have greater awareness and ability to process information for newer technologies suitable for their production environments than those who are less educated. Unexpectedly, the household size is inversely related with adoption of new varieties.

Interestingly, adoption is higher among lower-caste households, i.e., scheduled tribes, scheduled castes and other backward castes, than among the upper castes. This is in contrast to the observations of Batte and Arnholt (2003), and Ali (2012) that report that early adopters of innovations usually come from the upper strata of society. Further, the adoption of modern varieties is positively influenced by household heads' experience in cultivation, but negatively influenced by their age. In other words, the probability of adoption of modern varieties is higher among the younger but experienced household heads. Family size, a proxy for labor endowment, also has a positive and significant influence on the adoption of modern varieties.

Once the farm-level fixed-effects covariates (model 3) are incorporated, some of the household-level covariates, especially education and caste, cease to influence the adoption of modern varieties. Narayanmoorthy (2000) finds no significant association between education and the adoption of new varieties, while Paltasingh and Goyari (2018) find that a minimum threshold level of education is essential for adoption.

Farm size and land quality emerge as significant determinants of adoption. Farm size has a positive influence, a finding consistent with that reported in several other studies in India and elsewhere (Feder et al., 1985; Paltasingh and Goyari, 2018). Furthermore, soil quality also influences the adoption of modern varieties; generally, good-quality or fertile soils are preferred for cultivating modern crop varieties. Irrigation has a positive but not significant influence on their adoption.

Several studies have shown that institutional factors, such as farmers' access to information and institutional credit, exert a considerable influence on the adoption of modern technologies, including crop varieties (Ali, 2012; Singh et al., 2015; Birthal et al., 2015; Paltasingh and Goyari, 2018). To observe this, we introduce dummies for farm households' access to information from formal as well as informal sources and access to institutional credit in our regressions (model 4). Both of these factors have a positive and significant effect on the adoption of modern varieties. Interestingly, formal sources of information have a larger and significant influence, as compared to informal sources. Birthal et al. (2015) have reported a larger impact of formal sources of information on farm income, which could be due to the greater role these sources play in influencing technology adoption. It may be noted that most of the other variables retain their sign and significance and also remain stable, as in model 3. These results suggest that with credit and information constraints relaxed the adoption of modern varieties is likely to occur faster, especially among smallholder farmers who face acute liquidity and information constraints.

Table 6.1: Fixed-effect estimates of multilevel regression model for adoption of new variety

	Model – 1		Model – 2		Model – 3		Model – 4	
Household characteristics								
Ln(Family size)			0.3029***	(0.0194)	0.0504**	(0.0168)	0.0498**	(0.0168)
Ln(Age of family head)			-0.0847*	(0.0402)	-0.1820***	(0.0342)	-0.1846***	(0.0342)
Ln experience			0.0615***	(0.0167)	0.0645***	(0.0141)	0.0624***	(0.0141)
Gender of the farmer			-0.0036	(0.0454)	-0.0078	(0.0394)	-0.011	(0.0394)
Education: up to primary (base category illiterate)			0.0510*	(0.0251)	-0.0243	(0.0213)	-0.0275	(0.0214)
Education: middle (base category illiterate)			0.0695**	(0.0268)	-0.0261	(0.0227)	-0.0294	(0.0228)
Education: secondary (base category illiterate)			0.1947***	(0.0249)	-0.0085	(0.0213)	-0.014	(0.0213)
Education: higher secondary & above (base category illiterate)			0.3426***	(0.0369)	-0.0059	(0.0315)	-0.0145	(0.0316)
Social group: scheduled castes (base category others castes)			0.1591***	(0.0458)	0.0242	(0.0384)	0.024	(0.0384)
Social group: scheduled tribes (base category other castes)			0.1625***	(0.0332)	-0.0019	(0.0282)	-0.0028	(0.0282)
Social group: other backward castes (base category other castes)			0.2671***	(0.0348)	0.0096	(0.0298)	0.0085	(0.0298)
Farm characteristics								
Ln (Operated area)					0.5997***	(0.0088)	0.5960***	(0.0088)
Soil types: sandy (base category clay soils)					0.0223	(0.0216)	0.0207	(0.0216)
Soil types: loam & sandy loam (base category clay soils)					0.0324	(0.0228)	0.0306	(0.0228)
Soil types: black soil (base category clay soils)					-0.1751***	(0.0332)	-0.1773***	(0.0331)
Soil types: red soil (base category clay soils)					-0.1858***	(0.0414)	-0.1885***	(0.0414)
Soil types: rocky soil (base category clay soils)					0.0432	(0.0791)	0.034	(0.0792)
Irrigation: tube-well & borewell (base category rainfed)					0.0403	(0.0275)	0.0429	(0.0276)
Irrigation: well, canal & pond (base category rainfed)					0.0339	(0.0300)	0.033	(0.0301)
Institutional characteristics								
Access to information – Formal							0.0468***	(0.0288)
Access to information – Informal							0.0075	(0.0284)
Loan availed							0.0605**	(0.0186)
Constant	-0.6351***	(0.1446)	-1.3017***	(0.2039)	-0.1905	(0.1597)	-0.1954	(0.1607)
AIC	26545.44		26087.27		21024.45		21015.53	
BIC	26589		26210.68		22204.74		21217.46	
Log-Likelihood	-13266.70		-13026.60		-10487.20		-10479.80	
Observations	10509		10501		10013		10013	

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively. Figures in parentheses are standard errors.

Table 6.2 presents the variance estimates and their decomposition at different geographical levels, i.e., household, village, block, district and state. The estimated variances at all geographical levels are smaller in the conditional model than in the unconditional model. Nonetheless, in both the cases, a larger proportion of the variation in adoption is explained by the household-level differences. For example, in the conditional model, between-household differences explain 56% of the total variation in area under modern varieties, as compared to 50% in the unconditional model. Nonetheless, this does not negate the presence of contextual effects of higher levels on the geographical pattern of diffusion of modern varieties. The contextual effects of states are larger; between-state differences explain 25-33% of the variation in area under modern crop varieties. The contextual effects of districts, blocks and villages are extremely small. The higher contextual effects of states indicate significant differences in agricultural development programs and policies across states.

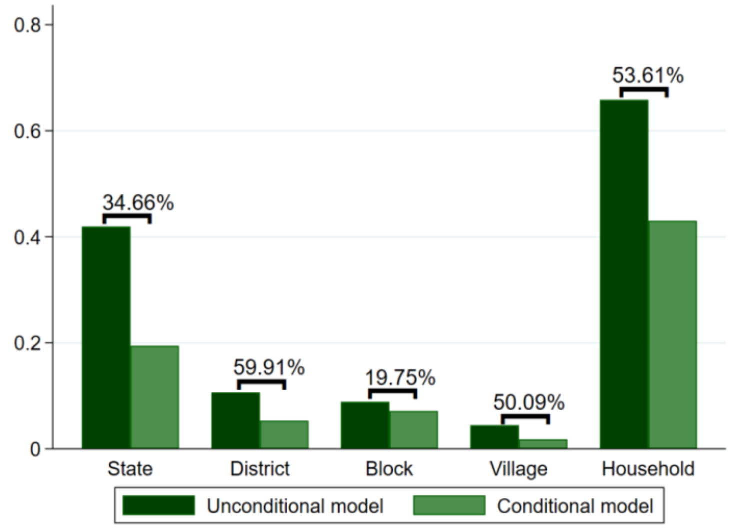
Table 6.2: Variance estimates & proportion of variation in new variety adoption attributable to different geographic levels

Level	Unconditional		Conditional	
	Variance	VPC (%)	Variance	VPC (%)
Household	0.6582 (0.0095)	49.99	0.4301 (0.0063)	56.12
Village	0.0444 (0.0073)	3.37	0.0178 (0.0038)	2.32
Block	0.0886 (0.0135)	6.73	0.0711 (0.0094)	9.28
District	0.1062 (0.0202)	8.06	0.0530 (0.0117)	6.92
State	0.4191 (0.1404)	31.84	0.1944 (0.0663)	25.37

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.
Notes: Figures in parentheses are standard errors; VPC = variance partitioning coefficient.

To know the extent of compositional effects on the adoption of modern varieties, we look at the difference between variance estimates of the conditional and unconditional models (Figure 6.1). The compositional effects are highest at the district level, followed by household, village, state and block levels.

Figure 6.1: Compositional effects at different geographical levels



Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Estimates for individual crops

Table 6.3 presents results of the unconditional and conditional models for the adoption of modern varieties separately for paddy, wheat and maize. Examining the results of the conditional models we find that most household-level fixed-effects covariates become statistically insignificant for all crops. However, the farm-level fixed-effects covariates remain significant. For all crops, the adoption of modern varieties is positively and significantly associated with landholding size. Irrigation, both from surface and groundwater, now turns out to be a statistically significant determinant of the adoption of modern varieties of wheat and paddy, though not of maize. Irrigation more strongly influences the adoption of wheat varieties, which is expected as the crop is grown in the winter season that receives just 15% of annual rainfall; and it is cultivated under irrigated conditions. On the other hand, paddy is a water-guzzling crop grown mainly in the rainy season, both under irrigated and rainfed conditions.

Farmers' access to institutional credit is statistically significant and positively associated with the adoption of modern varieties of wheat. Its influence on the adoption of modern varieties of paddy and maize is positive but not significant. Likewise, the coefficient of farm households' access to information, both from formal and informal sources, is positive, but only significant in the case of formal sources and maize.

Table 6.3: Multilevel regression model estimates for adoption of new variety by crop

	Paddy		Wheat		Maize	
	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Household characteristics						
Ln(Family size)		-0.01765 (0.0245)		0.05607* (0.0284)		-0.03454 (0.0346)
Ln(Age of family head)		0.003915 (0.0483)		-0.1191 (0.0629)		-0.04332 (0.0848)
Ln experience		0.01849 (0.0184)		0.04699 (0.0270)		0.02454 (0.0378)
Gender of the farmer		-0.01604 (0.0539)		0.06179 (0.0970)		-0.02245 (0.0613)
Education: up to primary (base category illiterate)		-0.03485 (0.0295)		-0.02447 (0.0406)		-0.00948 (0.0401)
Education: middle (base category illiterate)		-0.01486 (0.0318)		-0.0757 (0.0400)		-0.00605 (0.0483)
Education: secondary (base category illiterate)		0.001455 (0.0299)		-0.03782 (0.0379)		-0.08724* (0.0431)
Education: higher secondary & above (base category illiterate)		-0.09221 (0.0477)		0.002894 (0.0505)		-0.09289 (0.0659)
Social group: scheduled castes (base category others castes)		-0.01401 (0.0503)		0.08133 (0.1494)		0.02981 (0.0585)
Social group: scheduled tribes (base category other castes)		-0.05287 (0.0385)		0.05251 (0.0543)		0.005168 (0.0487)
Social group: other backward castes (base category other castes)		-0.004035 (0.0411)		0.05637 (0.0544)		-0.02686 (0.0543)
Farm characteristics						
Ln (Operated area)		0.5946*** (0.0120)		0.6003*** (0.0140)		0.6898*** (0.0243)
Soil types: sandy (base category clay soils)		-0.003355 (0.0316)		0.07320* (0.0345)		-0.3048*** (0.0494)
Soil types: loam & sandy loam (base category clay soils)		-0.0311 (0.0329)		-0.00241 (0.0336)		-0.1181 (0.0683)
Soil types: black soil (base category clay soils)		0.01604 (0.0391)				-0.1778 (0.1065)
Soil types: red soil (base category clay soils)		-0.04996 (0.0533)				-0.1839 (0.1053)
Soil types: rocky soil (base category clay soils)		0.5327* (0.2149)				-0.1734* (0.0840)
Irrigation: tube-well & borewell (base category rainfed)		0.07613* (0.0375)		0.4064*** (0.0795)		0.006676 (0.0446)
Irrigation: well, canal & pond (base category rainfed)		0.08589* (0.0399)		0.3375*** (0.0850)		-0.01372 (0.0503)
Institutional characteristics						
Access to information - Formal		0.03017 (0.0490)		0.004613 (0.0619)		0.1315*** (0.0395)
Access to information - Informal		0.01585 (0.0430)		-0.03249 (0.0619)		-0.00532 (0.0619)
Loan availed		0.02511 (0.0261)		0.1357*** (0.0302)		0.00715 (0.0433)
Constant	-0.7146** (0.1310)	-0.6706*** (0.1986)	0.0258 (0.2976)	-0.6882* (0.3216)	-1.0308*** (0.3248)	-0.5871 (0.3881)
AIC	14694.97	11421.60	7683.39	5910.429	3757.63	2988.46
BIC	14734.90	11605.76	7719.58	6060.96	3790.23	3140.07
Log-Likelihood	-7341.48	-5682.8	-3835.7	-2930.21	-1872.81	-1466.23
Observations	5743	5308	3075	3045	1691	1660

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively. Figures in parentheses are standard errors.

Table 6.4 presents the variance decomposition of area under modern varieties of each crop. As for the overall sample of crops, the conditional model has lower variances than the unconditional model at all geographical levels. In general, the variance estimates for all crops are larger at the household level, but amongst crops these are highest for paddy followed by wheat and maize. Accordingly, the household-level differences explain 69% of the variation in the area under modern varieties of paddy, 53% in the case of wheat and 37% in the case of maize.

Between-state differences comprise the next most important source of variation in the adoption of modern crop varieties. These explain 55% of the variation in area under modern varieties of maize, 38% in wheat and 16% in paddy, indicating that the contextual effects of states are stronger for maize than for wheat and paddy. Maize has emerged as a commercial crop in some parts of the country because of its increasing demand as a feed in a poultry industry that has become highly integrated over time. Until recently, India would import maize to be used for feed; but over time, because of a greater policy emphasis on domestic production through the diffusion of improved varieties, maize imports have become negligible. Note that hybrid maize is widely grown in some states in India. The relatively small contextual effects of other geographical levels, especially blocks and villages, are perhaps a result of greater homogeneity in agro-climatic conditions at these levels.

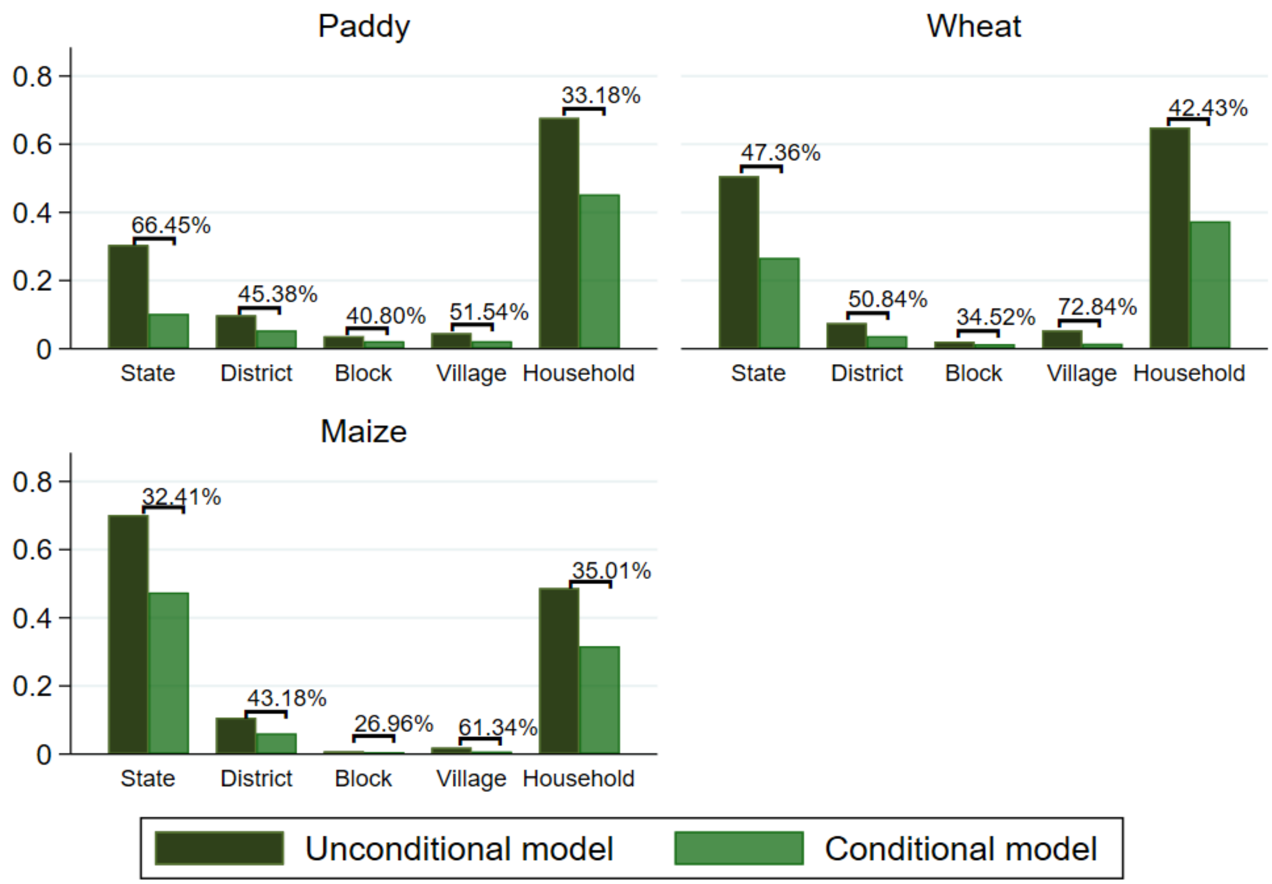
Table 6.4: Variance estimates & proportion of variation in new variety adoption attributable to different geographic levels by crop categories

Level	Paddy		Wheat		Maize	
	Variance	VPC (%)	Variance	VPC (%)	Variance	VPC (%)
Unconditional						
Household	**0.6773** (0.0134)	**58.26**	**0.6489** (0.0172)	**49.73**	**0.4870** (0.0176)	**36.81**
Village	0.0455 (0.0100)	3.91	0.0536 (0.0132)	4.11	0.0192 (0.0110)	1.45
Block	0.0368 (0.0131)	3.17	0.0208 (0.0159)	1.59	0.0082 (0.0108)	0.62
District	0.0982 (0.0199)	8.45	0.0752 (0.0261)	5.76	0.1069 (0.0329)	8.08
State	**0.3046** (0.1085)	**26.20**	**0.5063** (0.3064)	**38.80**	**0.7016** (0.3946)	**53.03**
Conditional						
Household	**0.4526** (0.0093)	**69.38**	**0.3736** (0.0099)	**52.98**	**0.3165** (0.0115)	**36.59**
Village	0.0221 (0.0065)	3.38	0.0145 (0.0053)	2.06	0.0074 (0.0049)	0.86
Block	0.0218 (0.0081)	3.34	0.0136 (0.0076)	1.93	0.00602 (0.0046)	0.70
District	0.0537 (0.0116)	8.23	0.0370 (0.0129)	5.24	0.0607 (0.0183)	7.02
State	**0.1022** (0.0390)	**15.67**	**0.2665** (0.1610)	**37.79**	**0.4742** (0.2645)	**54.83**

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.
Notes: Figures in parentheses are standard errors; VPC = variance partitioning coefficient.

The compositional effects at different geographical levels on the adoption of modern varieties differ widely across crops. For example, at the state level, these are highest for paddy, followed by wheat and maize (Figure 6.2). These findings suggest that household-level differences exert greater influence on the adoption of modern crop varieties, although the contextual effects of states are stronger for maize, the commercial crop, than for paddy the subsistence crop. The strong contextual effects of states on the adoption of modern varieties of maize are due to a greater policy emphasis on increasing maize production to support the growing poultry industry. On the other hand, the smaller contextual effects on the adoption of modern varieties of paddy can be explained by the crop's subsistence orientation – paddy is widely grown primarily to ensure household food security.

Figure 6.2: Compositional effects of new variety adoption at different geographical levels by crop category



Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

CONCLUSIONS

Using a multilevel modeling approach, this paper has demonstrated the relative importance of compositional and contextual effects of different geographical and administrative levels in the diffusion of modern varieties of cereal crops in India. Findings indicate that although household-level differences explain larger variation in the adoption of modern crop varieties, contextual effects also influence the diffusion process. The contextual effects are larger for maize, the commercial crop, than for paddy, the subsistence crop.

The purpose of this analysis was to identify the geographical or administrative level at which to implement programs and policies that would accelerate the speed of diffusion of modern crop varieties. Although level-specific recommendations are beyond the scope of this paper, our findings of strong contextual effects at the household and state levels imply a need for (a) greater investment in crop-breeding research and re-orientation of the research agenda consistent with the requirements of farmers and other stakeholders on the food value chain, (b) strengthening of the linkages between research and extension systems, and (c) coordination of programs and strategies across different geographical levels for better dissemination of modern technologies, including crop varieties.

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APPENDIX

Table A1. Number of observations

State	Maize	Paddy	Wheat	Total
Andhra Pradesh	96	528	-	624
Arunachal	-	437	-	437
Assam	-	2,677	-	2,677
Bihar	581	1,541	1,984	4,106
Chhattisgarh	354	1,552	-	1,906
Gujarat	-	558	557	1,115
Haryana	-	1,518	1,151	2,669
Jammu & Kashmir	-	824	-	824
Jharkhand	859	1,542	-	2,401
Karnataka	579	337	-	916
Kerala	-	260	-	260
Madhya Pradesh	-	-	1,982	1,982
Maharashtra	-	566	-	566
Manipur	-	426	-	426
Meghalaya	-	108	-	108
Mizoram	-	136	-	136
Nagaland	-	580	-	580
Odisha	-	1,541	-	1,541
Punjab	-	1,594	1,230	2,824
Rajasthan	-	-	720	720
Sikkim	-	89	-	89
Tamil Nadu	-	1,501	-	1,501
Telangana	110	580	-	690
Tripura	-	838	-	838
Uttar Pradesh	102	2,365	2,964	5,431
Uttarakhand	-	253	-	253
West Bengal	-	1,421	-	1,421
Total	2,681	23,772	10,588	37,041

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Table A2. Summary statistics

Variable	Paddy		Wheat		Maize		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Land size (hectares)	1.23	1.31	1.81	2.98	3.10	4.25	2.10	3.31
Household size (Nos.)	6.97	3.48	6.19	3.16	7.32	3.66	6.61	3.39
Age of family head (years)	48.51	12.28	49.60	12.43	46.58	12.80	48.60	12.58
Male household-head (Dummy)	0.93	0.25	0.94	0.24	0.98	0.13	0.95	0.22
Experience (Years)	24.51	11.48	24.07	12.23	24.12	12.78	24.14	12.29
Education level of the household-head (dummy variables)								
Not literate (=1 if yes, 0 otherwise)	0.37	0.48	0.23	0.42	0.17	0.38	0.23	0.42
Up to primary (=1 if yes, 0 otherwise)	0.21	0.40	0.24	0.43	0.16	0.37	0.22	0.41
Middle (=1 if yes, 0 otherwise)	0.13	0.34	0.18	0.39	0.19	0.39	0.18	0.38
Secondary (=1 if yes, 0 otherwise)	0.23	0.42	0.29	0.46	0.37	0.48	0.31	0.46
Higher secondary & above (=1 if yes, 0 otherwise)	0.06	0.24	0.05	0.22	0.11	0.31	0.07	0.25
Caste (dummy variables)								
Scheduled caste (SC) (=1 if yes, 0 otherwise)	0.14	0.35	0.09	0.29	0.07	0.25	0.09	0.29
Scheduled tribe (ST) (=1 if yes, 0 otherwise)	0.17	0.38	0.14	0.35	0.01	0.11	0.11	0.31
Other backward caste (OBC) (=1 if yes, 0 otherwise)	0.49	0.50	0.34	0.47	0.29	0.45	0.34	0.48
Others castes (=1 if yes, 0 otherwise)	0.20	0.40	0.42	0.49	0.63	0.48	0.45	0.50
Soil type (dummy variables)								
Clay (=1 if yes, 0 otherwise)	0.13	0.33	0.20	0.40	0.26	0.44	0.21	0.41
Sandy (=1 if yes, 0 otherwise)	0.39	0.49	0.37	0.48	0.42	0.49	0.39	0.49
Loam & sandy loam (=1 if yes, 0 otherwise)	0.09	0.29	0.20	0.40	0.33	0.47	0.22	0.41
Black soil (=1 if yes, 0 otherwise)	0.18	0.38	0.16	0.37			0.12	0.32
Red soil (=1 if yes, 0 otherwise)	0.17	0.38	0.06	0.23			0.05	0.23
Rocky soil (=1 if yes, 0 otherwise)	0.04	0.20	0.00	0.07			0.01	0.09
Irrigation source (dummy variables)								
Rainfed (=1 if yes, 0 otherwise)	0.37	0.48	0.26	0.44	0.01	0.10	0.20	0.40
Surface irrigation (=1 if yes, 0 otherwise)	0.46	0.50	0.48	0.50	0.82	0.39	0.57	0.49
Tube-well & bore-well (=1 if yes, 0 otherwise)	0.13	0.34	0.26	0.44	0.15	0.35	0.21	0.41
Access to institutional credit (=1 if yes, 0 otherwise)	0.51	0.50	0.28	0.45	0.28	0.45	0.31	0.46
Access to non-institutional credit (=1 if yes, 0 otherwise)	0.88	0.33	0.58	0.49	0.81	0.40	0.68	0.46
Loan availed (=1 if yes, 0 otherwise)	0.17	0.38	0.32	0.47	0.55	0.50	0.36	0.48

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Table A3. Variety-wise distribution of area and cultivators for paddy in India

Variety name	Year of release	Area (ha)	Percent farmers	Percent area
HKR 47	2005	426.30	0.18	0.92
ASD 16	1986	434.14	1.04	0.94
Ranjeet	1994	438.45	1.31	0.95
Sharbati	1900	475.47	1.75	1.03
Uma (MO 16)	2002	561.58	1.14	1.21
MTU 1001 (Vijetha)	1997	613.23	1.28	1.33
Local	1900	647.12	3.03	1.40
CSR 30	2001	691.05	0.71	1.49
Arize 6444	2015	798.04	2.64	1.73
Pusa Basmati 1509	2013	802.49	1.33	1.74
PR_121	2013	1021.00	0.76	2.21
Ranjeet	1994	1093.52	4.02	2.37
Masuri	1974	1190.45	4.39	2.57
MTU 1010	2000	1371.79	2.96	2.97
Pusa 1401	2008	1464.65	0.71	3.17
PR 114	2001	1905.60	1.33	4.12
BPT 5204	1989	2191.76	4.48	4.74
Swarna	1980	2531.23	8.54	5.48
Pusa_44	1994	4580.10	2.21	9.91
Pusa 1121	2005	5915.59	5.16	12.80
Others		17078.44	51.05	36.94

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Table A4. Variety-wise distribution of area and cultivators for wheat in India

Variety name	Year of release	Area (ha)	Percent farmers	Percent area
Raj-3077	1989	190.56	0.74	0.59
PBW-373	1997	237.65	1.95	0.74
DL-153-2	1985	244.41	1.90	0.76
HD-2733	2001	244.66	0.66	0.76
NL-297	1985	260.86	1.71	0.81
PBW-154	1988	266.12	2.78	0.82
Raj-4037	2003	309.19	1.42	0.96
HUW-234	1986	356.59	2.13	1.10
HD-2851	2005	455.72	0.58	1.41
Raj-1482	1983	474.05	2.07	1.47
GW-496	1996	553.40	4.19	1.71
WH-1105	2013	570.86	0.63	1.77
PBW-502	2004	620.96	4.62	1.92
UP-262	1978	642.72	6.37	1.99
HI-1544	2008	875.98	2.22	2.71
GW-322	2002	1416.64	3.61	4.39
PBW-343	1996	2305.37	16.21	7.14
HD-3086	2014	2431.41	2.99	7.53
Lok-1	1982	3228.22	14.17	10.00
HD-2967	2011	15079.92	23.09	46.73
Others		1506.05	5.93	4.67

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

Table A5. Variety-wise distribution of area and cultivators for maize in India

Variety name	Year of release	Area (ha)	Percent farmers	Percent area
Pioneer 1201	2013	31.01	0.54	1.07
30V92	2011	35.41	1.30	1.23
NMH-731	2015	42.02	0.63	1.45
KMH 3696	2012	49.76	1.09	1.72
Pioneer	2014	52.76	1.55	1.83
RMH 4620	2016	58.02	0.92	2.01
P3401	2010	59.03	1.05	2.04
900M Gold	2010	59.45	2.31	2.06
Kanchan	1986	79.91	7.50	2.77
Kaveri 2288 (Ekka)	2012	101.04	1.38	3.50
Kaveri 244	2013	107.05	1.68	3.70
GK 3150	2017	142.56	2.47	4.93
P3522	2014	152.06	5.41	5.26
DKC 9081	2011	154.23	4.23	5.34
Shankar	2013	178.12	21.21	6.16
NK 6240	2012	238.57	2.68	8.26
CP 818	2008	245.10	4.36	8.48
Local		269.71	19.20	9.33
Kaveri-50	2011	272.53	5.49	9.43
NK 30	2012	344.57	4.61	11.93
Others		216.48	10.39	7.49

Source: Authors' calculations using data from International Food Policy Research Institute - Indian Council of Agricultural Research national farm household survey, India, 2017/2018.

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