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Adoption and Outcomes of Hybrid Maize in the Marginal Areas of India

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Abstract

Smallholder maize cultivation is prevalent in the marginal areas of India, under diverse agro-climatic conditions. Abiotic stress tolerant maize cultivars are expected to be highly beneficial in reducing the production risks and enhancing farmer livelihoods, especially in the face of climate change. Nevertheless, the adoption and production risk implications of any of the crop varietal technologies in the marginal areas of India have not been widely examined. In this paper, we analyse the case of hybrid maize adoption, using data from a survey of 340 maize-growing households from three stress-prone regions in India. Hybrid maize adoption varies from 33% to 99% in these locations. A probit model is used to assess the factors determining adoption. The outcomes of hybrid maize adoption are examined in terms of yield and profitability, employing mean-variance analysis. We find a clear superiority of the hybrid technology with respect to yield enhancement, per-unit cost reduction and risk reduction only in one of the study locations. Our findings indicate significant economic potentials for developing abiotic stress tolerant maize cultivars for India's marginal environments.

Keywords: smallholder farming, Just-Pope model, risk management, technology adoption
JEL: O44, Q12, Q16

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1 Introduction

Abiotic stress tolerance has become one of the key crop attributes to enhance farm profitability and reduce livelihood vulnerability, in the face of increasingly erratic weather, irrigation water scarcity, and soil deterioration. At present, drought is one of the most important sources of yield loss in South Asia, reducing crop production annually on an average by 15-20% in rainfed regions (BERGVINSON, 2006). Severity of drought and other abiotic stresses is expected to rise further, and could critically affect the agricultural productivity on a global-scale (GORNALL et al., 2010). Due to climate change-induced heat and water stress, yields of staple crops in the region are predicted to decrease drastically – maize by 9-19%, wheat by 44-49%, and rice by 14% (NELSON et al., 2009). This would also undermine the capacity of rainfed agro-ecosystems across the sub-continent to regenerate, preventing farmers and farming communities from undertaking investments to ameliorate the situation (WANI et al., 2009), and would be highly detrimental to the poor and vulnerable smallholders associated with low-productivity rainfed systems. As a significant share of the South Asian population is currently vulnerable to hunger and under-nutrition, climate variability and change would exacerbate food insecurity in the sub-continent (WHEELER and VON BRAUN, 2013).

Different adaptation mechanisms to minimize farmer vulnerability to risk exist, including participation in insurance programmes, asset diversification and non-agricultural income diversification (DEMEKE and ZELLER, 2012). Although public sector crop insurance programmes are present in many South Asian countries (e.g., Weather-based Crop Insurance Programme of India) to minimize the impact of biotic and abiotic risks, farmer participation remains marginal due to a multitude of institutional constraints. In order to manage production risks and reduce livelihood vulnerability, farmers continue to rely largely on cultural practices, including crop diversification and varietal selection (MORDUCH, 1995). Farmer demand for on farm diversity could also restrain the pace of diffusion of new cultivated varieties (cultivars): when a new improved cultivar is introduced, farmers would adopt it only partially, especially in the absence of formal insurance markets (BAUMGÄRTNER and QUAAS, 2010). Further, the conventional wisdom suggests that modern varieties increase production risk and farmers who seek to avoid downside risk may choose to include lower-productive, but less-vulnerable traditional cultivars in their farm portfolio, even though full adoption of highly productive cultivars might be more profitable (KRISHNA et al., 2015; SMALE et al., 1994). Against this background, the present study examines maize varietal adoption and its implications in the face of abiotic stress in India. More specifically, the differences between hybrid maize adopters and non-adopters in three stress-prone districts of India with respect to yield and profitability are examined.

Various studies have modelled technology adoption in developing country agriculture (for example, KALIBA et al. (2000) and ISHAM (2002)), whereas SALASYA et al. (2007) and ALEXANDER and VAN MELLOR (2006) studied adoption behaviour of maize cultivars in particular. A number of adoption and impact studies of improved maize cultivars focus on Sub-Saharan African countries, where maize grains are used for human consumption. Recently, in Malawi, LUNDUKA et al. (2012) examined how specific attributes of maize varieties influence farmer's adoption decision, while GINE and YANG (2009) showed household wealth as the major factor affecting technology adoption. DE GROOTE et al. (2013) showed that there exists high demand for maize varieties with increased stover quantity and quality in Ethiopia and Tanzania – although this demand still seems limited in the case of India (ERENSTEIN et al., 2011). Since most of these studies are carried out in regions outside South Asia, common underlying factors and similarities are difficult to identify, and to the best of our knowledge, there are no such studies examining adoption of hybrid maize and its outcomes in India.

At present, maize is grown over a wide range of agro-climatic conditions in India, spanning from semi-arid to sub-humid zones (JOSHI et al., 2005). Much of the crop is grown in areas that are regarded as marginal, and are hence exposed to a number of physical constraints, viz., drought stress, low soil fertility, salinity, soil acidity, water logging, persistent weed problems, and steep slopes (HEISEY and EDMEADES, 1999). Such marginal production conditions, in the absence of locally adapted varietal technologies and cultural practices, not only contribute to lower crop yields but also increase the livelihood vulnerability. At the same time, abiotic stress tolerant, improved maize cultivars are still not widely available in both public and private sector technology development and dissemination programmes. Further, unlike in other developing regions, the agronomic and economic implications of adoption of available maize cultivars in South Asia are not widely examined so far, with only a few exceptions (e.g., RANSOM et al., 2003, which examined the adoption of improved maize cultivars in Nepal). A possible reason is that maize seed sector in the sub-continent is dominated by private sector cultivars, and attributes of proprietary cultivars are not easily available for empirical analysis. Maize hybrids and improved open pollinated varieties (OPVs) available from public sector research and development (R&D) in India are estimated at less than a quarter of the total seed marketed (KUMAR et al., 2012). Another reason could be that the produce of modern maize cultivars is not commonly used for household consumption in most parts of India, and hence the welfare impact may be only indirect – by increasing farm income and not by increasing subsistence consumption.

Despite the growing recognition of the potential of abiotic stress tolerance of maize cultivars, there is a relative under-investment to develop them in India, both by the public and private R&D sector. As indicated by VIRK et al. (2005), abiotic stress resistance is one of the key demands in the client-oriented plant breeding programmes. Information scarcity with respect to the inter-linkages between attributes of maize varieties released by the public and private sector R&D systems and farmer preferences for varietal attributes is also evident. How do popular maize cultivars perform under stress conditions in India? To answer this question, the present study takes the case of hybrid maize (vis-à-vis OPVs), and examines the yield and production risk changes associated with adoption.

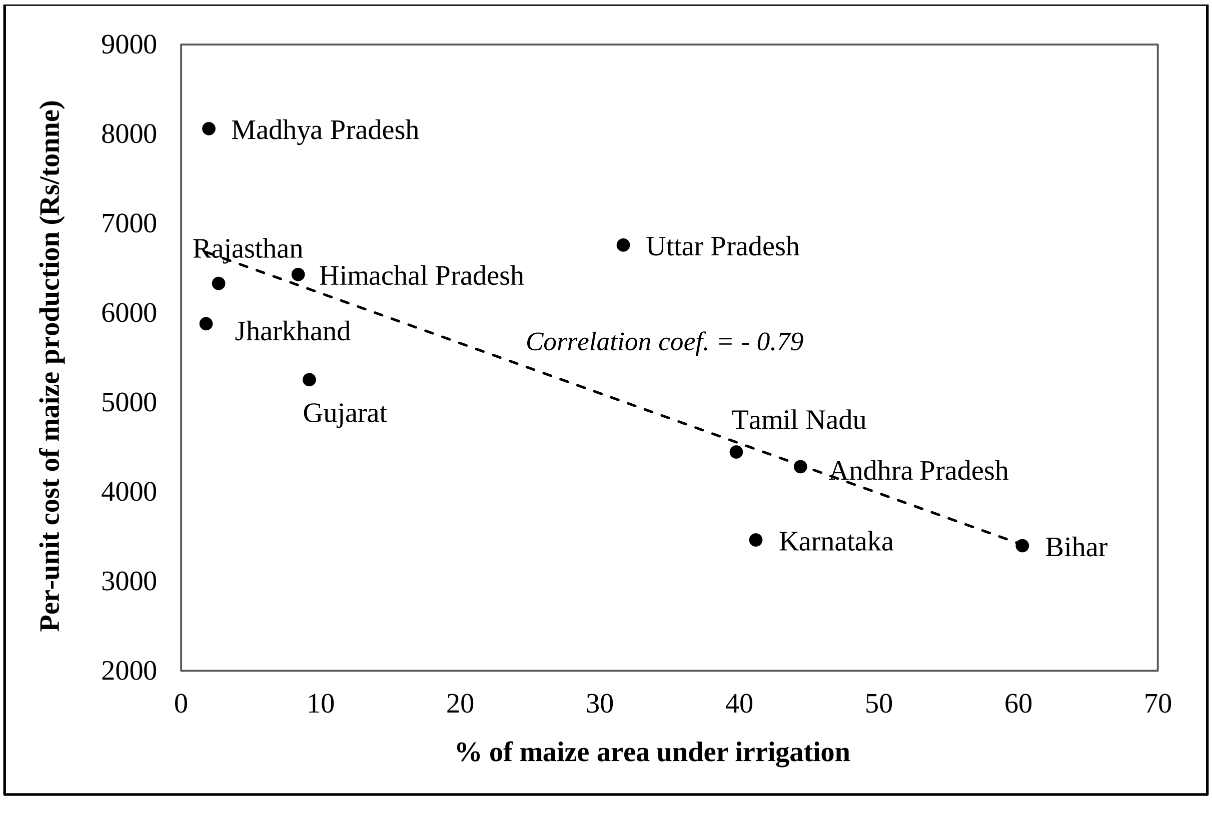
Although hybrids emerged as a key technological change in the developing country agriculture, its success on farm is criticized as being dependent on congenial production conditions and increased use of external inputs, like chemical fertilizers (SINGH and MORRIS, 1997; KUMAR, 1994). Some studies have questioned the ability of hybrids to withstand adverse production conditions in marginal lands and under abiotic stresses (CAVATASSI et al., 2011; BELLON, 2006). The prevailing perception is that local OPVs tend to be more resilient and better suited for abiotic stress conditions like drought. However, SMALE et al. (1998) and SMALE (1997) had shown that in the case of wheat, due to a complex interplay of factors, no causal relationship between modern varietal technology adoption and an increase in production risk could be empirically established. Attempts to link the products of modern plant breeding and biotechnology to farm production risk are seldom carried out, and there is not much evidence of hybrid maize technology altering the production risk in South Asian agriculture. Some studies have pointed out that Indian smallholders could successfully adopt hybrid seeds (MATUSCHKE et al., 2007), although their impact on production risk is not adequately examined. Capturing the agronomic and financial variability impacts of a given technology to smallholder farmers is critical to analyse the existing pitfalls of the associated R&D and seed distribution systems and to fully understand the diffusion process of improved cultivars and the implications.

The remaining part of the paper is organized as follows. In the next section, details on the study area and data sources are provided. The hypotheses and empirical methodology are presented in section 3. We present and discuss the estimation results, in two sub-sections: adoption of hybrid maize (in section 4.1) and the outcomes of adoption on mean-variance of yield and per-unit cost of maize production (in section 4.2). The final section concludes with some broader policy implications.

2 Study Area and Data

India is the sixth largest maize producer in the world (FAOSTAT, 2014), and maize is a crop of growing economic importance, largely due to the increasing feed demand from a rapidly expanding domestic poultry sector, which is itself driven by changing consumer habits, especially in the urban areas (KRISHNA et al., 2014; NARAYANAN et al., 2008). There has been a significant increase in the domestic maize production during the last decade, despite three-fourth of the crop area still being under rainfed conditions. During 2013-14, India produced around 24.2 million tonnes of maize grain from 9.3 million hectares with an average grain yield of 2.6 tonnes per hectare (MINISTRY OF FINANCE, 2014). Maize is traditionally cultivated in the *Kharif* (monsoon) season (78% of total maize acreage in India), although a rapid expansion of maize acreage is observed in *Rabi* (winter) season (WADDINGTON et al., 2012). However, water scarcity remains the major constraint, and drought, the major risk factor for maize production (JOSHI et al., 2005). An examination of secondary data indicates that the per-unit cost of maize production is the highest in rainfed maize producing belt, and is negatively correlated with the prevalence of irrigation (Figure 1).

Figure 1. Correlation between the prevalence of irrigation and cost of maize production



Notes: sample points represent the major maize producing states of India. Rs. stands for Indian Rupees (1 US$ = Rs. 46.46, average of 2010).

Source of data: Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Government of India (2010)

Two decades ago, the Indian Government liberalized seed production and marketing with the Industrial Licensing Policy of 1987, the New Policy on Seed Development of 1988, and the New Industrial Policy of 1991 (KOLADY et al., 2012). In India, hybrid maize seeds are now primarily produced and disseminated by the private sector. At present, there are 5 multinational and more than 400 domestic seed companies engaged in maize seed production.[1] Public R&D initially focused on developing composite OPVs, but has gradually shifted to developing hybrids (especially single-cross), suitable for different production environments.[2] Many of the proprietary maize hybrids marketed in India are not officially released and so the seed is sold to farmers as "Truthfully Labelled Seeds", normally subjected to rigorous quality control within the companies (WADDINGTON et al., 2012). The extensive dependence of farmers on private dealers for purchasing maize seed has been reported since the 1990s (SINGH and MORRIS, 1997), coinciding with the availability of maize hybrid seeds in the Indian seed market; OPVs once acquired are often recycled and used as farm-saved seeds. In our study areas, the seed supply system for hybrids is also dominated by the private dealers (Appendix 1, Table A1), although in Davanagere (Karnataka) the public seed distribution system through the government extension network is still prominent – but nonetheless advocates hybrids.

Maize in India is produced in two contrasting zones varying significantly with respect to the agro-ecological conditions (JOSHI et al., 2005). The traditional maize-growing states are located in a horizontal belt across northern and central India (Rajasthan, Madhya Pradesh, Uttar Pradesh and Bihar) and non-traditional maize-growing states are located in the South (mainly Andhra Pradesh and Karnataka). In the South, maize is a relatively recent addition to the cropping system, but these areas primarily contributed to the recent growth of domestic maize acreage and production. Here, maize is produced mostly for the feed market with widespread adoption of hybrids and use of external inputs.

The current research examines the hybrid seed adoption by farmers of three major maize producing districts of India, chosen purposively from these two regions: Davanagere district of Karnataka from the non-traditional belt of southern India and Udaipur district (Rajasthan state, western India) and Samastipur district (Bihar state,

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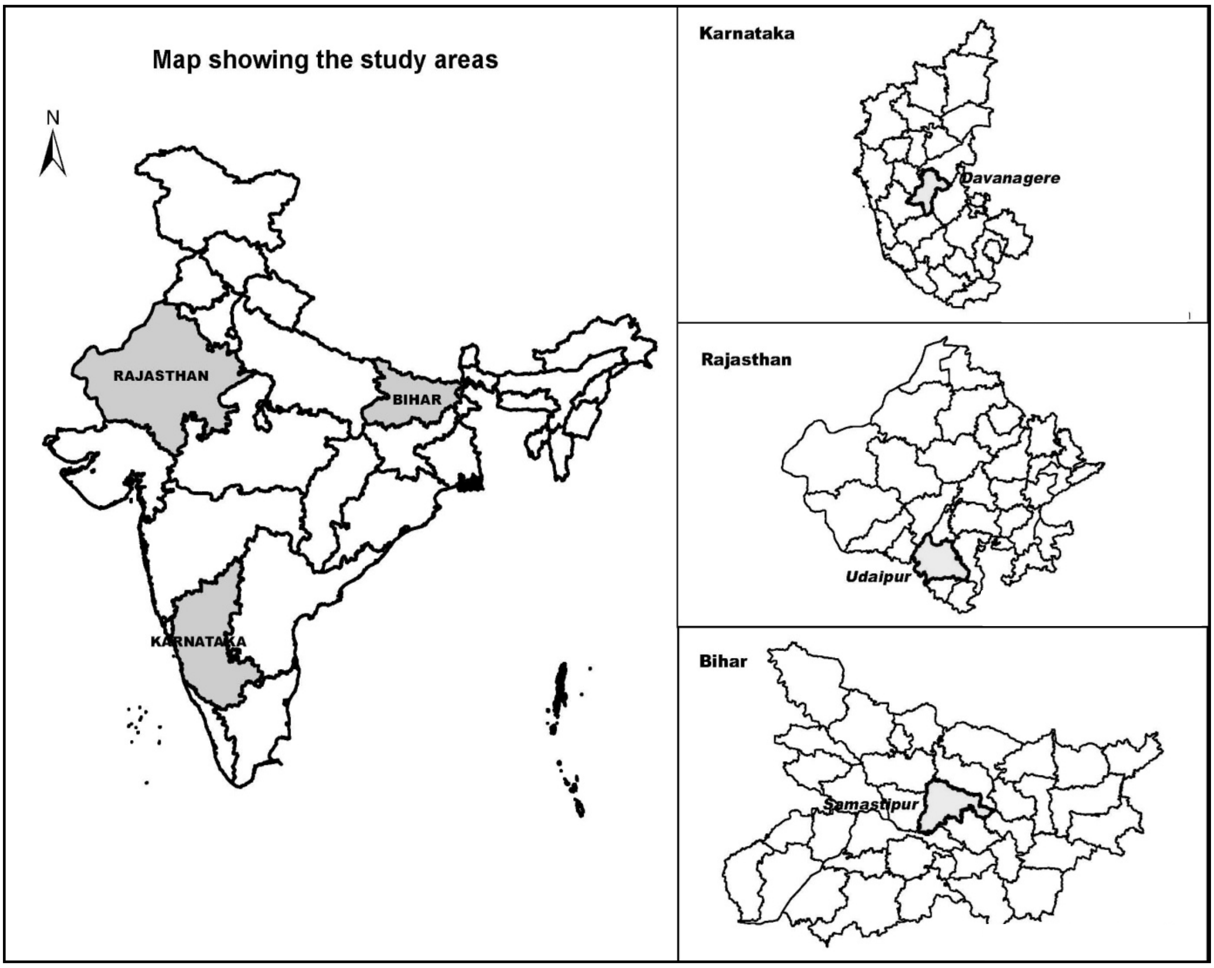
[1] Source: Seeds Division, Department of Agriculture and Cooperation, Government of India, New Delhi.

[2] The R&D in public maize breeding mainly focuses on location-specificity and resistance to biotic stresses. More than 90% of the public hybrids released during 1993-2011 were to impart resistance against different insect pests and diseases, 27% for enhanced nutrient levels, and 20% for lodging resistance (Source of data: Directorate of Maize Research, New Delhi). The corresponding figures are largely unavailable for the private seed sector, but the proprietary firms are also likely to focus only on mean yield increase and biotic stress tolerance.

eastern India) from the traditional belt (Figure 2). Selection of these districts was expected to reflect the diversity of agro-climatic situations in India's maize production including diverse adoption rates of hybrid seeds.

Figure 2. Location of the study areas



Source: P.T. Raghu, International Maize and Wheat Improvement Center (CIMMYT), New Delhi

Maize is produced in the *Kharif* (monsoon) season in Udaipur district under rainfed conditions. Non-hybrids are commonly cultivated and the output is mainly used for home consumption. Davanagere district receives relatively higher rainfall, but the rainfall and rainy days vary widely across years. Here maize, mostly hybrid, is cultivated in the *Kharif* season under rainfed conditions, and competes with sorghum, finger millet and cotton for acreage. Grains are produced for the feed market. In Samastipur, maize production takes place in two contrasting seasons – *Kharif* for food and *Rabi* for the feed grain market, with only a few exceptions. Hybrid seed adoption is low in the first season, but predominant in *Rabi*. This region belongs to the fertile

Indo-Gangetic Plains and maize gains more prominence in the eastern plains alongside rice and wheat. The *Kharif* maize receives high rainfall, but the *Rabi* season is rather dry. *Rabi* maize is grown mostly with groundwater irrigation and potato is the major competing crop. These contrasting production conditions provide an opportunity to study the risk impacts of modern varietal technologies across different levels of water stress.

The study employs a stratified random sampling approach. Two blocks (the administrative sub-districts in India), where maize was widely grown, were selected from each of the districts. Villages and households were selected randomly. Per block 3-5 villages, and per village 11-20 maize farmers were selected. A total sample containing 340 households was developed from 21 villages, and the input-output data were collected for the main maize plots, cultivated in different cropping seasons. The final dataset included about 422 plot-level observations (Table 1). The surveys were conducted during April-July 2010 in Udaipur and Samastipur, and early 2011 in Davanagere district, using a structured questionnaire and trained enumerators. Beside obtaining information on plot-level input-output data, the questionnaire also compiled household characteristics, cropping pattern, technology use, access to credit and information, and mechanisms for coping with abiotic stresses. The questionnaire is available online at **(**http://purl.umn.edu/204161**)**.

Table 1. Details of the study areas

Maize growing region	**Non-traditional**	**Traditional**	
State	Karnataka	Rajasthan	Bihar
District	Davanagere	Udaipur	Samastipur
No. of sample villages	9	6	6
No. of sample households	100	120	120
No. of plot-level observations	100	120	202 (*Kharif* 88; *Rabi* 114)

3 Empirical Framework

This paper examines the adoption pattern of hybrid maize and farm-level effects of the technology. Adoption of hybrid maize by farmers is determined by a comparison of the expected utility of adoption I_h^*, against the expected utility of using OPVs, I_o^*. While making this comparison, the farmers evaluate both the benefits and the cost of adoption. Farmers will adopt hybrid maize only if $I_h^* > I_o^*$, implying that the potential benefits outweigh the constraints. However, I_h^* and I_o^* are latent variables, and what is observed is actual adoption of hybrids, I, with $I = 1$ if $I_h^* > I_o^*$ and $I = 0$ if $I_h^* \leq I_o^*$. Adoption of hybrid maize can be modelled as follows:

$$I = \gamma Z + \nu \tag{1}$$

where Z is a set of socio-economic variables determining the utility of technology adoption, γ is the vector of parameters, and ν is an error term with zero mean and constant variance. Hybrid seed adoption is viewed as a binary choice decision problem faced by farm households and a probit model was employed to estimate the factors influencing adoption. Due to farm-household heterogeneity and diverse production conditions, not all of the farmers will adopt maize hybrids. For those who do so, adoption is expected to result in higher utility. We hypothesize that hybrid maize adoption has an important positive effect on yield and per-unit cost of maize production. We use the concept of per-unit cost (PUC) of production as the indicator of profitability of the crop, due to two major reasons.

1. The sample farmers are operating under significant abiotic stress, and many of their farms are established in the marginal, low-fertile areas. Rather than (or alongside) maximizing profit per unit of land, they try to limit the possibility of production or financial loss, and PUC minimization would be representing this goal clearly. In other words, maximisation of profit per land unit may be associated with higher variable cost, and incurring higher cost may not be a rational strategy when the production risk is high.
2. Estimation of per-hectare profitability depends critically on the market price of produce. The products from many plots are not marketed, especially for the OPVs, in many sample villages. Further, there exists significant price difference between hybrid and OPV products, making the calculation of shadow-prices a challenging task.

Production processes or technologies that result in PUC reduction are certainly economically advantageous for the farmer and hence the financial viability of the alternatives is clearly visible. Applying the concept of PUC is particularly useful to study technologies like hybrid maize where there could be significant changes in both cost of cultivation (through higher seed price, increased use of chemical fertilizers, and irrigation etc.) and land productivity. As the first step of mean-variance modelling, two quadratic functions were estimated to study the factors affecting the mean productivity and profitability:

$$Y_i = \alpha + \sum_j \beta_j X_{ij} + \sum_j \rho_j X_{ij}^2 + \delta H_k + \sum_k \theta_k R_i + \sum_l \varphi_k H_i R_i + \varepsilon_i \tag{2}$$

where, Y_i is maize grain productivity (tonnes per hectare) or per-unit paid-out cost of grain production (Rs. per tonne) and X_{ij} the quantity of j^{th} production inputs (fertilizers, irrigation, and weeding) in the i^{th} plot; H_i the hybrid adoption dummy variable and there are k region dummies; $\alpha, \rho, \beta, \delta, \theta$ and φ are the parameters to be estimated; and ε_i is the random error term with mean zero and variance σ^2.

Further, the production risk (variance) was modelled, following JUST and POPE (1979) and KOUNDOURI and NAUGES (2005), as a Generalized Cobb-Douglas form of explanatory variables. Similar models are used by CROST and SHANKER (2008) and KRISHNA et al. (2015) to study the production risk impacts of varietal technology in India.

$$E(\varepsilon_i^2) = \sigma^2 = f(X_i, H_i, R_i) \tag{3}$$

$$\ln(\sigma^2) = a + \sum_j b_j X_{ij} + \sum_j g_j X_{ij}^2 + dH_i + \sum_l p_l R_i + \sum_l q_l H_i R_i + e_i \tag{4}$$

where a, b, g, d, p and q are parameters to be estimated; e_i is the random error term. The Breusch-Pagan test for heteroskedasticity rejects the null hypothesis of constant variance of Ordinary Least Squares (OLS) estimates on mean yield/PUC, which was corrected following a Generalized Least Squares (GLS) estimation. Following TRAXLER et al. (1995), the exponentials of the predicted values from Equation (4) are used as analytical weights for generating GLS estimates. The objective of the econometric estimation is to test $(\delta + \varphi_l R_i) = 0$ in the mean functions, and $(d + q_l R_i) = 0$ in the variance function. Following HALVORSEN and PALMQUIST (1980), the percentage effects of dummy variables in the semi-logarithmic functions as mentioned above are estimated as $100 * (\exp(\delta + \varphi_l R_i) - 1)$. The similar method is followed to estimate variable elasticities from Eq. (4).

Although heteroskedasticity impacts were taken care in the estimation using GLS method, there could be a potential bias due to the endogenous nature of hybrid adoption in the outcome models. This would occur if hybrid maize adoption is correlated with unobserved factors (e.g., farmer motivation or skills) that also influence the outcome variable directly (DEATON, 2010; ANGRIST and PISCHKE, 2008). The common methods to address the bias are instrumental variable (IV) regression and endogenous switching regression (ASFAW et al., 2012). Due to the additional location-hybrid interaction terms, at least three instruments are required to make the model "just-identified" (ANGRIST and PISCHKE, 2008). After examining a number of potential candidates, none was found to be a valid instrument that would qualify considering the exclusion restriction. Given this, we use different proxy variables (e.g., access to different information sources, and primary occupation) that are likely to be correlated with unobserved variables that may influence technology adoption (KATHAGE et al., 2015) directly in the yield/PUC models. Although the method of using auxiliary regressors does not solve the endogeneity bias, they may help identify the presence and degree of bias associated with endogenous technology adoption by the smallholders. We run additional models with the auxiliary variables, as:

$$Y_i = \alpha + \sum_j \beta_j X_{ij} + \sum_j \rho_j X_{ij}^2 + \delta H_i + \sum_k \theta_k R_i + \sum_k \varphi_k H_i R_i + \sum_m \omega_m F_i + \varepsilon_i \qquad (5)$$

$$\ln(\sigma^2) = a + \sum_j b_j X_{ij} + \sum_j g_j X_{ij}^2 + dH_i + \sum_k p_l R_i + \sum_k q_l H_i R_i + \sum_m r_m F_i + e_i \qquad (6)$$

where F_i is the vector of farm-household variables, including age, and education of the household head, information access, etc., which are included also in the set Z (eq. 1), ω_m and r_m are the associated parameters to be estimated, where m denotes the farm-household. Since a single household could have more than one plot under maize, $i \geq m$. The yield/PUC elasticity of hybrid adoption is estimated and compared between Eq. (2) and (5) and between (4) and (6). Absence of a drastic change could be indicative of small endogeneity bias, although this method may not correct for the same. Further the seriousness of selection bias present in the latter models (5) and (6) depends on the percentage of correct predictions of adoption and non-adoption in the probit models by variable in set Z, which are also included in eq. (5) and (6).

4 Results and Discussions

4.1 Adoption of Hybrid Seeds

The three study areas show significant variation with respect to farm size, share of maize area, and adoption of irrigation and hybrid seeds (Table 2). The highest average cultivated area is found in Davanagere and the lowest in Samastipur district – albeit with widespread double-cropping (*Kharif* and *Rabi* seasons) in the latter. The share of maize area to total farm size also follows a similar pattern. Samastipur's *Rabi* season stands out with near universal use of both irrigation and hybrid maize. Adoption of these inputs is low in Udaipur – 33% for hybrid maize and 2% for irrigation. Hybrid adoption rate is lowest in *Kharif* maize of Samastipur (16%), although significant area is still under irrigation (78%). In Davanagere district, hybrid adoption is high (85%), but under rainfed conditions. The relative adoption figures across the three study states are comparable with that of SINGH and MORRIS (1997). Farmers in the study areas are well-aware of the hybrid maize technology and hence there would be limited non-exposure bias (SIMTOWE et al., 2011).

Adoption of hybrid maize in the study areas is determined by a number of factors, including household wealth, the end-use of maize grains, farmer perceptions on cultivar attributes and growing season conditions. Household wealth is the major factor affecting technology adoption – in line with other studies where hybrid use is correlated with wealth and other indicators of household socioeconomic status (e.g., GINE and YANG, 2009). The association between the rate of hybrid adoption and landholding size – a variable that proxies not only farmers' asset status but also their risk-bearing ability – is summarized in Table 3. The sample farmers are classified into categories viz. (i) full adopters cultivating only hybrid maize, (ii) partial adopters cultivating at least one plot each with hybrids and OPVs and (iii) non-adopters cultivating only OPV maize. As expected, there is an association between landholding size and hybrid adoption, but the relationship is not linear. Particularly in Davanagere and Udaipur, adoption is relatively low for those with the smallest farm sizes, but the larger farms are found to be partial adopters, rather than completely replacing OPVs with hybrids. This suggests it is primarily the intermediate smallholders that have both the incentives and possibility to intensify crop production by adopting high yielding technologies like hybrid maize.

Table 2. General characteristics of maize production systems

Season		***Kharif***			***Rabi***
District		**Davanagere**	**Udaipur**	**Samastipur**	**Samastipur**
Cultivated land per farm household (hectare)		2.71	1.66	1.11	1.06
Households cultivating maize (%)		100	100	73	95
Maize area share of total cultivated land (%)		77	50	25	38
Irrigated maize area share (%)		2	2	78	99
Maize hybrid use (% of maize farmers)		85	33	16	99
Maize grain marketed (%)	OPV	100	34	31	66
	Hybrid	99	94	51	65

Source: household survey (2010-2011)

Table 3. Maize hybrid adoption across landholding categories

Season	**Location**	**Hybrid adoption class (% of farmers)**			**Landholding (ha) per adoption class**			
		Full	Partial	None	Full	Partial	None	Sig.
Kharif	Davanagere	81	4	15	3.28 (3.27)	6.68 (1.50)	2.50 (1.98)	**
Kharif	Udaipur	22	11	67	1.94 (1.56)	2.54 (1.33)	1.40 (1.62)	***
Kharif	Samastipur	5	11	84	0.07 (0.05)	1.49 (1.60)	0.92 (1.42)	***
Rabi	Samastipur	88	11	1	0.99 (1.35)	1.14 (1.42)	0.02 (--)	

Notes: figures in parentheses show standard deviation of sample mean. ** and *** refer to statistical significance at 0.05 and 0.01 levels, respectively (in Kruskal-Wallis equality of populations rank test).

Source: household survey (2010-2011)

Across the study areas, most of the OPV production is used for home consumption, while grains of hybrid maize are marketed, as evident in both Udaipur and Samastipur (*Kharif* season). According to many farmers in these traditional maize growing areas, OPV maize grains are more palatable and hence a large share of maize production is used for subsistence consumption. In Davanagere, maize is not a traditional food crop and does not form part of the conventional everyday meal and the major share of grain output is marketed.

Farmer perceptions or expectations regarding hybrid and OPV maize are indeed important in determining the rate of adoption. Unsurprisingly, hybrid maize is adopted in order to maximize land productivity across the study locations (Table 4). On the other hand, OPVs are included in the varietal portfolio, partly because of their higher consumption utility and/or better adaptability to the location specific agro-ecological conditions. For example, in Udaipur, where maize is widely used for human consumption, about 72% of OPV farmers identify the local cultivars as having superior consumptive value, while both hybrids and OPVs are considered to have comparable location adaptability. In Davanagere, where maize is cultivated mainly as cash crop to feed the poultry industry, the role of the (human) consumptive value is naturally negligible – a few OPVs are popular only for their higher degree of adaptability to the rainfed conditions. Consumptive value of maize grains might be receiving only secondary importance in the national breeding programs in India, possibly because the per capita direct human consumption is low and declines over time (KEARNEY, 2010).

Table 4. Farmer perceptions on varietal attributes

Season	Location	Seed type	Most important reason for variety selection (% of farmers)			
			Mean yield	Adaptability	Consumption	Others
Kharif	Davanagere	Hybrid	81	5^{**}	0	14
		OPV	63	21	0	16
Kharif	Udaipur	Hybrid	80^{***}	7	2^{***}	11
		OPV	8	16	72	4
Kharif	Samastipur	Hybrid	50^{***}	7^{***}	7	35^{**}
		OPV	5	74	8	12
Rabi	Samastipur	Hybrid	88	10	0	2

Notes: ** and *** refer to statistical significance of difference from OPV category at 0.05 and 0.01 level of significance, respectively (Fisher's Exact Test).

Source: household survey (2010-2011)

Apart from the location and perception variables, a number of socio-economic factors potentially affect farmer's choice of cultivar type. To elicit the significance of these factors, a probit model was estimated and the results are provided in Table 5. Our data show that the location and season factors are of supreme importance in determining farmers' hybrid maize adoption. During *Kharif* season, the adoption is significantly higher in Davanagere in comparison to Samastipur, although the difference between Samastipur and Udaipur is negligible. There is a significant inter-seasonal difference. As observed also in Table 2, hybrid seeds are more prevalent during *Rabi* season compared to *Kharif* season in Samastipur. Large farmers and households with off-farm income opportunities are found adopting hybrid maize more frequently, possibly due to their higher risk-bearing ability. The households accessing information from either a public or a private source are found adopting hybrids at a lower rate, and those with access to information from both the sources are mostly adopters.

Table 5. Probit regression on factors affecting hybrid maize adoption

Variables	**Mean (Std. error)**	**Probit model coefficient (Std. error)**
Samastipur, *Rabi* (dummy)#	0.27	4.397 *** (0.487)
Udaipur (dummy) #	0.28	0.099 (0.814)
Davanagere (dummy) #	0.24	3.390 *** (0.583)
Land owned by the household (ha)	1.70 (0.11)	0.215 *** (0.084)
Square of land		-0.013 ** (0.006)
Education of the head of farm household (years)	6.02 (0.24)	-0.085 (0.062)
Square of education		0.008 (0.005)
Primary occupation of the head of household: non-farming (dummy)	0.10	0.563 * (0.297)
Access to government extension (scale)	1.93 (0.03)	-2.641 ** (1.249)
Access to private dealer information (scale)	1.45 (0.02)	-4.142 *** (1.329)
Interaction term: Access to public and private information		1.717 ** (0.756)
Intercept		4.166 * (2.278)
Log likelihood		-131.108
LR $\chi^2(11)$		314.24 ***
Percentage of		
(i) Correct prediction (adoption = 1)		88
(ii) Correct prediction (adoption = 0)		82

Notes: N = 340. Figures in parentheses are std. errors associated with the respective coefficients.
reference dummy: Samastipur, *Kharif* season
*, **, ***: statistically significant at 0.10, 0.05 and 0.01 levels, respectively.

Source: estimated from the household survey (2010-2011) data

Another important result from estimating the Probit model is that most of the variance in the adoption decision is captured by the observed variables. About 88% of the observed cases of adoption and 82% of the observed cases of non-adoption are correctly predicted by the variables included in this model. This means that, if we include these variables alongside hybrid seed adoption in the mean-variance impact regressions as explanatory variables, the degree of selection bias would be reduced significantly. This would be the next best procedure to address the bias, especially in the absence of an exogenous variable to instrument the hybrid adoption (KATHAGE et al., 2015).

4.2 Agronomic and Financial Effects of Hybrid Maize Adoption

According to descriptive statistics, Davanagere had the highest paid-out cultivation cost of maize, mainly due to higher chemical fertilizer application and lower involvement of family labour.[3] There also exist significant cost differences with respect to hybrid adoption, as it is associated with differing rates of application of material inputs (Table A2). In Udaipur, cost of hybrid maize cultivation is 68% higher than that of the OPVs, as the cost incurred to purchase seeds and the rate of application of chemical fertilizers are lower for the latter. The respective cost difference in Davanagere is about 12%, while the paid-out cost of OPV cultivation is on-par with that of hybrids in Samastipur. Unsurprisingly, grain yield of hybrids is higher than that of the OPVs, which results in a higher profitability per unit of cultivated land. Since, grains of OPV maize are largely used for home consumption, a market price is not observed in many cases, making conventional cost-benefit analysis less informative. Based on the per-unit cost of maize grain production, hybrids are found to be 7-47% cheaper than that of OPVs, owing largely to higher productivity of the former. However, the inter-location difference in relative advantage of hybrid adoption is noticeable, suggesting a stark difference in the location adaptability of commercialized maize hybrids. Unit cost of hybrid maize production is significantly higher in the rainfed tracts (Udaipur and Davanagere), compared to the irrigated farms of Samastipur in *Kharif* season. Amongst the sites assessed in this study, the most congenial location for maize production is the mostly irrigated, more fertile district, Samastipur. Here the per-unit cost of production of hybrids is less than one-fourth of the market price of maize grain.

Despite having strong evidence on superiority of hybrid maize in increasing mean yield, there are questions on the production risk impacts regarding the adoption of modern cultivars. Cross-sectional hybrid-OPV differences in yield and per-unit cost variability are provided in Appendix Table A3, in terms of coefficient of variation (CV) – the ratio of standard deviation to the sample mean. Lower CV values correspond to lower

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[3] The input-output relations are obtained from the main hybrid/OPV maize plot, and the cost of and returns from maize production are summarized in Appendix Table A2.

production risk. Across the study regions, maize cultivation is found to be highly risky in Udaipur district. However, hybrid seed adoption is associated with relatively lower production risk. The difference in CV of yield is not well-pronounced between hybrids and OPVs in other regions. Surprisingly, spatial variation in PUC of production is lower for maize hybrids than for OPVs. However, a number of factors may be contributing to yield and profit variability, including availability of irrigation and farmer characteristics. Hence, econometric estimations of maize productivity and profitability were carried out and the results are presented hereafter.

In order to completely capture the benefits associated with any farming technology to capital-constrained smallholder households, it is essential to analyse the technology impacts not only on the mean level of yield but also on the yield variability. In this paper, this is done by estimating the mean-variance functions on yield and PUC and the results are presented in Tables 6 and 7. Both these tables include models with a hybrid adoption dummy variable across study regions and basic production inputs, corresponding to Eq. (2) and (4). As a second step, an additional model including farm household attributes that may denote the nature and degree of selection bias associated with hybrid adoption is estimated, as shown in Eq. (5) and (6). The frequency of contact with public and private extension agents is expected to proxy the unobserved variables: farmer's skills and motivation.[4]

To examine the impact of hybrid adoption on mean-variance of yield and PUC, we have included hybrid-region interaction dummies. In comparison to OPVs, hybrids in Samastipur are found to be the most productive, followed by those in Udaipur and Davanagere (Model 1, Table 6). When other household variables are included, the magnitude of the effect changes and statistical significance is lost for the hybrid-Davanagere interaction (Model 2, Table 6). In the other two locations, hybrid seed adoption is certainly an important technology to augment maize yields by about 1.6 tonnes per hectare in Udaipur and 3.0 tonnes per hectare in Samastipur. However, hybrid adoption is found also to increase the yield risk in these locations (Models 3 & 4, Table 6). Further, irrigation is found to increase the mean yield and reduce risk.[5] Households accessing information from either a public or a private source are found to

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[4] It is shown that these information variables are strongly associated with the hybrid adoption decision. Nevertheless, the exclusion restriction, that the IVs are uncorrelated with other determinants of the dependent variable (ANGRIST and PISCHKE, 2008), is not fulfilled and hence these variables cannot be used as instruments. But these variables are directly included in the model estimation as explanatory variables that would proxy part of the heterogeneity.

[5] One should be careful while interpreting the coefficient of irrigation variable, as significant intra-regional/seasonal variation in irrigation use is observed only in Samastipur region during *Kharif* season (cf. Table 2). Hence, the coefficient could be more pertinent to that given case than the overall study area.

Table 6. Mean-variance functions on maize productivity (tonnes per hectare)

	Mean yield		Variance of yield	
	Model 1	**Model 2**	**Model 3**	**Model 4**
Davanagere (location dummy) $^{\#}$	1.482***	2.448***	0.693	0.810
	(0.285)	(0.465)	(0.585)	(0.899)
Hybrids in Davanagere (adoption dummy)	0.894***	0.568*	0.601	0.864
	(0.310)	(0.330)	(0.560)	(0.616)
Udaipur (location dummy) $^{\#}$	-0.887***	-1.752***	0.762**	1.957**
	(0.160)	(0.467)	(0.360)	(0.940)
Hybrids in Udaipur (adoption dummy)	1.524***	1.556***	0.683*	0.735*
	(0.279)	(0.290)	(0.405)	(0.445)
Hybrids in Samastipur (adoption dummy)	3.174***	3.041***	1.078***	1.563***
	(0.192)	(0.163)	(0.428)	(0.456)
Chemical fertilizers applied (kg/ha)	0.001	0.002**	5.E-04	-0.001
	(0.001)	(0.001)	(2.E-03)	(0.002)
Square of chemical fertilizers applied	-1.E-06	-2.E-06***	-1.E-06	-6.E-07
	(8.E-07)	(6.E-07)	(2.E-06)	(2.E-06)
Number of irrigation	0.190***	0.207***	-0.146	-0.200*
	(0.042)	(0.044)	(0.101)	(0.120)
Number of weeding operations	-0.190***	-0.205***	0.308**	0.090
	(0.069)	(0.069)	(0.140)	(0.170)
Land owned by the household (ha)		0.080		0.032
		(0.068)		(0.113)
Square of land		-0.006		0.006
		(0.007)		(0.009)
Education of the head of farm household (years)		0.010		0.227***
		(0.031)		(0.073)
Square of education		2.E-04		-0.019***
		(2.E-03)		(0.006)
Primary occupation of the head of household: non-farming (dummy)		-0.772***		0.045
		(0.162)		(0.371)
Access to government extension (scale)		-1.966**		-3.241*
		(0.926)		(1.882)
Access to private dealer information (scale)		-3.815***		-2.536
		(1.181)		(2.165)
Interaction term: Access to public and private information		1.554***		2.204*
		(0.596)		(1.171)
Model intercept	2.470***	7.179***	-2.498***	0.665
	(0.156)	(1.729)	(0.377)	(3.321)
Adj. R^2	0.744	0.792	0.048	0.096
Partial production/risk change with hybrid adoption (%) at				
(i) Davanagere	23***	15*	82	137
(ii) Udaipur	103***	105***	98*	108*
(iii) Samastipur	121***	116***	194***	377***

Notes: N = 422. Figures in parentheses are std. error associated with the coefficient. $^{\#}$ reference dummy: Samastipur. *, **, ***: statistically significant at 0.10, 0.05 and 0.01 levels, respectively. ^{a},^{b} : jointly significant at 0.10 and 0.05 levels, respectively.

Source: estimated from the household survey (2010-2011) data

Table 7. Mean-variance functions on per-unit cost (Rs per tonne) of maize production

	Mean PUC		Variance of PUC	
	Model 1	Model 2	Model 3	Model 4
Davanagere (location dummy) [#]	1584.052	-856.398	0.931	-0.237
	(985.000)	(1225.238)	0.621)	(0.901)
Hybrids in Davanagere (adoption dummy)	46.498	807.928	-0.150	0.594
	(1019.729)	(735.993)	(0.594)	(0.617)
Udaipur (location dummy) [#]	8790.273***	7999.794**	4.112***	2.954***
	(2101.089)	(2188.667)	(0.382)	(0.941)
Hybrids in Udaipur (adoption dummy)	-4800.704***	-4200.084***	-1.456***	-1.984***
	(2500.361)	(1941.369)	(0.430)	(0.446)
Hybrids in Samastipur (adoption dummy)	-228.634	12.167	-1.075**	0.308
	(357.262)	(468.311)	(0.454)	(0.457)
Chemical fertilizers applied (kg/ha)	-0.389	1.375	3.E-04	0.003
	(2.677)	(3.303)	(2.E-03)	(0.002)
Square of chemical fertilizers applied	0.004	0.004	2.E-06	-7.E-07
	(0.005)	(0.005)	(2.E-06)	(2.E-06)
Number of irrigation	-121.608	-210.421*	-0.031	-0.219*
	(75.048)	(128.892)	(0.108)	(0.120)
Number of weeding	15.790	78.536	-0.125	0.092
	(96.113)	(224.445)	(0.148)	(0.170)
Land owned by the household (ha)		-78.876		-0.155
		(205.453)		(0.113)
Square of land		40.064*		0.017*
		(21.711)		(0.009)
Education of the head of farm household (years)		200.601**		0.250***
		(96.400)		(0.073)
Square of education		-12.889*		-0.016***
		(7.394)		(0.006)
Primary occupation of the head of household: non-farming (dummy)		-34.820		0.137
		(521.002)		(0.371)
Household’s access to government extension (scale)		-802.416		1.052
		(4014.439)		(1.886)
Household’s access to private dealer information (scale)		1960.648		0.058
		(4769.630)		(2.170)
Interaction term: Access to public and private information		93.492		-0.502
		(2487.625)		(1.173)
Model intercept	3002.722***	674.288	13.663***	12.812***
	(381.934)	(7337.191)	(0.400)	(3.327)
Adj. R^2	0.134	0.151	0.423	0.292
Partial production/risk change with hybrid adoption (%) at				
(i) Davanagere	1	17	-14	81
(ii) Udaipur	-40***	-35***	-77***	-86***
(iii) Samastipur	-7	0	-66**	36

Notes: N = 422. Figures in parentheses are std. error associated with the coefficient.
[#] reference dummy: Samastipur, *Kharif* season. *, **, ***: statistically significant at 0.10, 0.05 and 0.01 levels, respectively. [a],[b] : jointly significant at 0.10 and 0.05 levels, respectively.

Source: estimated from the household survey (2010-2011) data attain lower yield but with more certainty. On the other hand, those accessing information from both the sources are attaining higher mean yield, but also increases the yield variability significantly. Farm size is found to have no role in increasing mean yield or yield variability, and there exists an inverse-U shape relation between formal schooling obtained by the household head and yield risk.

In a similar manner, the mean-variance impacts of hybrid maize on PUC were estimateed and the results are presented in Table 7. Farmers would favour conditions that lead to a reduction in the cost of maize production. We found that the impact of hybrid adoption on mean PUC is insignificant, compared to using OPVs, in both Davanagere and Samastipur (Model 2, Table 7). On the other hand, in Udaipur, the adoption of hybrids is associated with a significantly lower PUC. Since the mean yield is high and mean PUC is low, one may conclude that hybrid maize provides significant economic benefits to farmers of Udaipur. Further, in Udaipur, hybrids are associated with lower PUC variance, reducing the financial risk associated with maize cultivation (Model 4, Table 7). However, this impact is not pervasive. Hybrid adoption is found to have no impact on mean or variance of PUC in Davanagere and Samastipur.

Among other explanatory factors, irrigation is found to reduce the PUC of maize production, which supports the general pattern observed in Figure 1. However, ‘number of irrigation applications’ could be an endogenous variable, and hence the results should be interpreted keeping this potential issue in mind. Weeding, unlike in the yield functions, is found insignificant across the PUC models. Surprisingly, education of the household head is found to increase the mean PUC and also widen the yield variability – perhaps indicating that better educated farmers might over-use inputs. Among the medium and large farms, farm size increases the mean and variance of PUC of maize production. No significant relationship is observed with respect to information variables in the PUC models.

5 Summary and Conclusion

The study examines the adoption of hybrid maize and its agronomic and financial implications in India, where the crop is grown mostly under rainfed conditions, facing severe drought risk. We found heterogeneous outcomes with respect to hybrid seed adoption, contributed also by farmer heterogeneity and differing rate of application of material inputs. We employ a probit function to model the socio-economic determinants of hybrid adoption. The variables capturing information availability are particularly relevant. The model correctly predicts about 85% of adoption, indicating that the possible selection bias associated with the adoption variable would be negligible, if the socio-economic factors determining adoption are additionally included in the production function, alongside production inputs, as explanatory variables.

Across the study locations, adoption of hybrid maize is associated with yield increase, although the magnitude of increase varies widely. Nevertheless, it also tends to increase variance in yield, indicating that hybrid maize adoption tends to be riskier. Only in one of the three study locations (Udaipur), the hybrid maize adoption has clear superiority in financial terms – not only the per-unit cost of production is reduced drastically, the associated variability is also reduced. Hence, while the study cannot rule out the perception that hybrid seed adoption increases production risk, it points out the need to carry out such analysis case-by-case, as there exists significant heterogeneity in production impacts of the technology across locations and seasons. CROST and SHANKAR (2008) also have shown that the effect of varietal technologies is situation-dependent.

There are only a few abiotic stress tolerant maize hybrids currently available in India. Most of the sample farmers recognize composite and local varieties as more congenial for growing under abiotic stress conditions, compared to the available hybrids, while hybrids are selected mainly for attaining higher mean yields under favourable climatic conditions. Those differing preferences beyond an absolute yield increase have to be taken into account by maize breeders, and may make their products more likely to be adopted, especially in abiotic stress-prone regions. Irrigation clearly increases yield, reduces production cost and minimizes risks, and reiterates the potential of irrigation. However, irrigation also faces substantial access barriers – whereas seed is relatively divisible and faces less substantial access barriers. At the same time by reiterating the importance of water, it does suggest the scope for developing maize varieties that use scarce water more efficiently. In addition, such drought-tolerant cultivars can potentially lead to an increase in maize area, by extending the farming to marginal areas. Across the study locations, especially in the *Rabi* season, a large share of cultivable land is kept fallow due to inadequate irrigation facilities, which may potentially be used more economically by developing and disseminating drought-tolerant cultivars, and thereby increasing maize production in India.

There is a significant lack of public knowledge on maize varietal diffusion in South Asia, particularly in the face of a rapidly evolving seed production/marketing scenario in the region. Relatively little is known about which cultivars are grown in different locations and the corresponding farmers' preferences. The wide variation in both maize growing agro-climatic conditions and the end-use of maize output poses additional challenges for the national and state governments to plan for varietal development and diffusion in maize. Annual maize seed replacement rate is shown to be at least 60% in South Asia which is relatively high for a cereal crop (WADDINGTON et al., 2012). However, due to the increasing dominance of the trade-secretive private seed sector, little is known about the traits of their popular germplasm and their on-farm impacts. Although the public R&D sector releases many hybrids and composites every year in India, seeds of only a few are being produced commercially and even less are being widely adopted. From an egalitarian perspective, these public resources may be targeted to those environments and uses that are not being catered for by the private sector, especially for marginal and low potential environments where abiotic stresses are ubiquitous and severe. Also innovative models of public–private partnerships can be beneficial for the farming community at large. The relative advantage of the private sector in commercialization and marketing may be combined with the often longer R&D experience of the public sector in developing products for the marginal environments. However, more political will and financial support are needed to make such types of collaborative agreements successful on a larger scale and to spur even wider adoption of hybrid maize and enhance its impacts for marginal smallholders.

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Appendix

Table A1. Sources of maize seed in the study area

Season	Location	Seed type	% of farmers obtaining seeds from			
			Private dealer	Government	Farm-saved	Others (incl. other farmers)
Kharif	Davanagere	Hybrid	69	31	0	0
		OPV	53	47	0	0
Kharif	Udaipur	Hybrid	90	2	4$^{\#}$	4
		OPV	24	1	75	0
Kharif	Samastipur	Hybrid	93	0	0	7
		OPV	4	0	94	2
Rabi	Samastipur	Hybrid	95	0	2$^{\#}$	3
		OPV$^{\#\#}$	--	--	--	--

Notes: $^{\#}$ indicates use of F_2 seeds. $^{\#\#}$only one farmer cultivates OPV maize in his main plot during the *Rabi* season in Samastipur.

Source: household survey (2010-2011)

Table A2. Economics of maize production in study area

	Kharif						Rabi
	Davanagere		Udaipur		Samastipur		Samastipur
	Hybrid	OPV	Hybrid	OPV	Hybrid	OPV	Hybrid
Total paid-out variable cost (Rs/hectare)	22,326* (9,648)	20,338 (15,219)	13,608*** (6,094)	8,089 (5,101)	6,660 (1,311)	7,483 (4,694)	15,204 (4,438)
Yield (Tonnes/hectare)	4.77** (1.41)	3.81 (0.90)	3.08*** (1.53)	1.49 (1.29)	3.40 (1.07)	2.64 (0.65)	6.33 (1.14)
Grain price (Rs./tonne)	8,530 (942)	8,597 (274)	8,633* (1450)	8,417 (1017)	9,375** (946)	8,266 (667)	8,937 (854)
Gross revenue (Rs./hectare)	40,581** (12,888)	32,754 (7,920)	27,297*** (15,502)	12,683 (11,355)	32,048** (11,337)	21,815 (5,485)	56,216 (9,380)
Gross margin (Rs./hectare over paid out cost)	18,256 (14,906)	12,415 (13,654)	13,689*** (17,497)	4,650 (12,860)	25,387* (12,100)	14,332 (7,729)	41,012 (9,220)
Per-unit cost of production (Rs/tonne, on paid out cost)$^{\#}$	5,030	5,437	5,296	9,957	2,178	3,035	2,425

Notes: # per-unit cost of production (paid-out) is calculated by dividing paid cost (Rs) by yield (tonne). Rs stands for Indian Rupees (1 US$ = Rs. 46.46: average of 2010). *,** and *** refer to statistical significance of difference from OPV category at 0.10, 0.05 and 0.01 levels, respectively.

Source: household survey (2010-2011)

Table A3. Variability in maize yield and profitability with respect to hybrid seed adoption

Season	Location	Coefficient of variation (CV)			
		Maize yield		Per-unit cost (PUC) of production	
		Hybrids	OPVs	Hybrids	OPVs
Kharif	Davanagere	0.30	0.21	0.54	0.61
Kharif	Udaipur	0.50	0.86	0.80	1.11
Kharif	Samastipur	0.31	0.25	0.22	0.73
Rabi	Samastipur	0.18	na	0.31	na

Notes: CV is the ratio of standard deviation to sample mean, and hence devoid of unit of measurement. na stands for non-applicability of the measure as only one farmer cultivates OPV maize in his main plot during Rabi season in Samastipur.

Source: household survey (2010-2011)