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Farm households that adopt ICT change production decisions: evidence from India

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Abstract Farm households in India use information and communication technology (ICT) and ICT devices in making production related decisions. I explore the impact of ICT ownership and use on agricultural diversification and commercialization. Households that adopt ICT opt for higher commercialization, diversify towards high-value crops, invest in modern inputs, and hire more agricultural labour. Villages that adopted mobile technology early and households in those villages drove the impact of ICT adoption on farm diversification. The adoption of ICT leads to diversification by improving awareness and by facilitating access to the credit market, social interaction, and mass media.

Keywords ICT adoption, high value commodities, farm diversification, commercialization, market access

JEL codes Q12, Q19

Agriculture is the primary source of livelihood for over half the population of India, and over four-fifths of that population are small and marginal farmers. Farmers choose to produce fruits and vegetables if their landholding size and the urbanization-led demand is large enough and if they can access markets, roads, credit, irrigation, mass media, and the household size of labour endowments (Joshi et al. 2004; Birthal et al. 2013). Agriculture policy has always been biased towards cereals: since the green revolution, a focus on food security, and policies that ensured the procurement of rice and wheat at the minimum support price (MSP) at a few locations in the country, have ensured that cereals dominate (procurement of other crops, like pulses and oilseeds, started only recently). The cereal centred policy has led to the over extraction of groundwater, depletion of the water table, and reduction of soil fertility, however, and it has favoured large farmers in a few states. And a cereal centric diet low on minerals and vitamins causes malnutrition and poor health and it is a primary reason for India's ranking 94 on the Global Hunger Index out of 107 countries in 2020.

Policymakers and the government have been moving away from cereals and focusing on agricultural diversification because it can restrict the unsustainable use of soil and water resources; augment farm income, profitability, alleviate poverty, and food security; stabilize income across seasons; and promote exports (Ali and Abedullah 2002: Barghouti et al. 2004: Joshi et al. 2004: Weinberger and Lumpkin 2007: Birthal et al. 2013; Birthal et al. 2015a). And farm households have been adopting information and communication technology (ICT) in making production-related decisions and diversifying production towards high-value agricultural commodities. My definition of ICT is broad; it is a proxy for enhanced connectivity among households because of ICT devices; it is not restricted to agriculture-related interventions or extension services through SMS or email; and ICT adoption has two aspects: ownership and use. Diversification needs

infrastructure, like roads, and it requires farmers to adopt and use new technologies such as ICT, but information is a constraint, as in the adoption of hybrid seeds (Foster and Rosenzweig 2010). For farm production decisions, timely and correct information is critical; information requirements range from forecasts related to rainfall and other weather conditions, and the latest government welfare schemes and agricultural technologies and practices, to the availability and prices of agricultural inputs, the best prices for outputs, pest management, and markets (Aker 2011).

Mobile phone and internet connectivity has surged rapidly in the past two decades in low-income and developing countries, including in India. The gain in momentum can be judged from the high tele density in October 2020: 86.37% in urban areas, and 58.85% in rural India (BS, 2021),up from 92.18 million in 2014 to 302.35 million in 2020 (HBS, 2021). Connectivity may be seen as an input in the agricultural production process that reduces friction in information dissemination and transaction cost, especially in remote areas. Social learning helps to diffuse new technologies (Munshi 2004). The use of mobile phones and/or computers could connect households and make them communicate more, share information, become more aware of developments, and induce behavioural changes if government extension officers use ICT, mobile phones, and/or computers, effectively to disseminate this information to farmers timely, efficiently, and affordably and to make it cheaper and faster for them to hire labour, buy inputs, and sell their output.

Technology adoption is low in sub-Saharan Africa and in the eastern states of India because access to information is poor (De Janvry et al. 2016). In India, the net return per hectare is 12% more for farmers who use information than those who do not (Birthal et al. 2015b). Mobile-based price-related information reduced price dispersion in fisheries in Kerala; in Madhya Pradesh, it helped fishermen and soybean farmers realize higher prices (Jensen 2007; Goyal 2010). But providing SMS-based agricultural information to farmers in Maharashtra did not significantly affect cultivation practices or yields (Fafchamps and Minten 2012). Farmers in Gujarat had access to agricultural advice on the phone; the access impacted agricultural practices significantly but not yield (Cole and Fernando 2016). The adoption of high-yield variety (HYV) seeds and chemical fertilizers was higher in areas with mobile phone coverage; the uptake of agricultural credit was also higher in these areas (Gupta et al. 2019). The diffusion of ICT in India can ensure connectivity and the timely dissemination of information at a reasonable cost,[1] and its impact has been studied and found not to have been universal. All these studies focus on some specific type of ICT intervention, however, and most, except Gupta et al. (2019), have a small geographic focus.

This study explores whether the adoption of ICT impacts agricultural production decisions, the commercialization of farm output, and input use, and whether ICT adoption has led to an increase in the cultivation of high value crops in India. As in the literature, I define high value crops as comprising spices, oilseeds, fruits and vegetables, and others. I also explore the channels through which ICT adoption could possibly encourage the production of high value crops. To the best of my knowledge, this is the first study that uses a nationally representative dataset—the Indian Human Development Survey 1 (IHDS 1), conducted in 2004–05—and an instrumental variable estimation strategy to explore if ICT adoption drives decisions related to farm production, diversification towards high-value crops, input investments, and market participation.

Data

The IHDS 1 is a nationally representative survey conducted by the University of Maryland and the National Council of Applied Economic Research (NCAER) in 2004–05. The IHDS 2, conducted in 2011–12, and the Situation Assessment Survey, conducted by the National Sample Survey Office (NSSO) in 2013–14, are more recent, but the IHDS 2 has not made the data on crop production publicly available yet, and the Situation Assessment Survey does not provide details on the ownership, use, or expenditure on ICT devices (mobile phones or computers). Therefore, I use the IHDS. It covers all the states and (except for the union territories of Andaman and Nicobar Islands and for Lakshadweep)

[1]https://www.bbc.com/news/world-asia-india-47537201

all the union territories. The IHDS covers 41,554 households across 382 districts. My dataset comprises households that report agriculture as their primary source of income and provide information on crops cultivated by them in the 12 months preceding the survey.

For the analysis, I use information on the crops grown in each season (kharif, rabi, and summer) by plot, the area planted under a crop, total production, and its price. The other inputs are labour (person-days), farm equipment, water, seeds, fertilizers, manures, pesticides, and repayment of agricultural loans. Further, I use the data on the usage of these inputs in household level farm production in the previous 12 months for the entire agricultural year. From the total household expenditure, From the total household expenditure, I calcuate the expenditure on ICT over the 30-day period preceding the date of the interview.

Outcome variables

The main outcome variables relate to the production of high-value crops. I use two outcome variables. One is a dummy indicator variable, equal to 1 if the household had produced a high-value crop in the previous 12 months. The other is the share of the total area under high-value crops in both the seasons (Rabi and Kharif).

Channels

The adoption of ICT could be driving decisions on agricultural production by disseminating information through formal channels of mass media (television, radio, and newspapers) and through informal social networks; insuring households through other channels and therefore raising their risk appetite; improving access to credit markets.

Disseminating information through mass media

Farmers need correct information timely. Using ICT can efficiently disseminate correct and timely information. The coverage of relatively cheap internet and mobile connectivity is expanding. If farmers adopt ICT, their access to correct and timely information would improve, as information can be disseminated through formal mass media (television, radio, and newspapers) or informal social networks. Such access would drive diversification towards high-value crops and improve the commercialization of agricultural production.

Compared to farm households that do not use ICT, farm households that do are likelier to be part of a bigger social circle—such as their social peers and the influential people in their village and informal and formal groups in their village and neighbouring villages—and to access mass media and, therefore, be more aware of consumer demand, prices, new developments, best practices, and input and output markets (Table 1). Farm households that use ICT would be better informed of crops that could yield higher returns. Therefore, they are more likely to plant and sell those crops and make a higher income and profit.

Insuring households

The use of ICT can determine agricultural diversification by insuring households and therefore raising their risk appetite. Compared to households that do not adopt ICT, households that do are likelier to have ration and job cards and be aware of government welfare schemes and benefit from them. They are more likely to be aware of alternative income sources and to diversify their income sources (Table 1). High-value crops are considered to be riskier than cereals; and households that have diversified their sources of income and are relatively insured from production, health, and other risks could be more likely to diversify their production basket.

Adopting ICT improves access to credit markets

The use of ICT improves farm households' awareness of credit programmes, government agricultural loans, and interest subsidy announcements, and it could improve financial security which, in turn, could improve their risk appetite and ability to overcome financial constraints and enable them to cultivate high-value crops—more risky, and also more profitable. Compared to households that do not adopt ICT, households that do are likelier to access formal credit markets and take agriculture and business loans (Table 1).

Heading Outcome variables to explore the channels

This paper explores whether the adoption (use and ownership) of ICT drives these channels and, in turn,

Table 1 ICT adoption and broad pathways

	(1) Mean- No ICT use	(2) Mean- ICT use	(3) Difference	Mean-No ICT ownership	Mean- ICT ownership	Difference
			Formal information source			
Mass media access(1/0)	.329	.649	-.321***	.367	.81	-.443***
News(1/0)	.076	.244	-.169***	.095	.341	-.247***
			Informal source of information			
Membership(1/0)	.353	.461	-.107***	.372	.476	-.104***
Knowpeople(1/0)	.486	.735	-.248***	.526	.795	-.269***
			Diversified income source			
No of income source	2.047	2.034	.014	2.039	2.067	-.028
card (1/0)	.883	.933	-.051***	.888	.966	-.077***
			Access to credit			
loan (1/0)	.486	.541	-.055***	.208	.363	-.155***
Agri/business loan (1/0)	.228	.29	-.063***	.244	.263	-.018*
Formal source of loan(1/0)	.192	.313	-.121***	.208	.363	-.155***
No. of obs.	9927	4418				

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Source Author's calculations using data from IHDS1

the adoption of high-value crops, although I cannot rigorously identify causal pathways, and exogenous factors likely drive these pathways. I use several outcome variables to explore the three channels.

For the first channel, I use access to mass media (television, radio, or newspapers); whether the household members watch the news; and whether the household is a member of a social group and is acquainted with influential people in the village.

For the second channel, related to risk-taking ability, I use a household's income sources and whether a household has ration and job cards, Kisan Credit Card, and and Life Insurance policies

For the third channel, I use loans as the indicator variable (if the household took at least one loan in the preceding five years, the value of *loans* is 1; otherwise, it is 0). I consider whether the household took the largest loan for agricultural or other business. If the household took the largest loan from a formal source, the value of *formal loan* is 1; otherwise, it is zero. Finally, I consider the interest rate that the household paid for its largest loan in the preceding five years.

Other impacts of ICT

The other outcome variables I use to estimate the additional impacts of adopting ICT relate to input use and commercialization. The outcome variables related to input expenditure are the share of hired labour in total labour used for agricultural production by a household in the preceding 12 months, and the log of expenditure on seeds purchased from the market, pesticides, fertilizers, hired equipments, and the repayment of agricultural loans.

The outcome variables related to the commercialization of agriculture are sales, a dummy indicator variable equal to 1 if the household sells their produce and 0 if they do not; sales of high-value crops, a dummy indicator variable which is equal to 1 if a household sells high-value crops and 0 if they do not; and the impact of ICT adoption on income and profit from farm production.

I calculate the profit by deducting the total production expenditure from the total household farm income.

ICT-related variables

Our main variable of interest is the adoption of ICT,

measured using two variables: the use of ICT and the ownership of ICT. Both are binary variables with values equal to 0 or 1. The use of ICT takes the value of 1 if the members of the household either spends on telephone, cable, or internet, and zero if not. Ownership equals 1 if the household owns either mobile phones, telephones or computer and 0 if they do not.

Other controls

The household-specific characteristics included in the estimated models are household size, total land cultivated by the household, number of years of education completed by the head of the household, square of education, age of the head of the household, square of age, if household head is married, whether the household belongs to scheduled castes, scheduled tribe and other backward caste social categories and district fixed effects to control for unobservable district specific characteristics (Appendix Table A 1).

Given the heterogeneity among farm households in India, the impact of ICT adoption is unlikely to be the same across all households. It is plausible that farm diversification is dependent on infrastructure availability and therefore farm households residing in villages which are more connected, with well-developed infrastructural support would benefit from ICT use and ownership. However, if ICT impacts remotely located villages and small farmers, it can become a critical policy tool in making agricultural more profitable for farmers. Given that most farmers are small or marginal, and villages have poorly developed infrastructure support, it is interesting to explore heterogeneity in these aspects.

In this paper, I explore heterogeneity in impact because of all-weather or pucca roads and because of late/early adoption of mobile technology. Given that ICT is relatively new in India, especially among rural farming communities, some gestation period is likely required for ICT to work as an efficient tool of interaction and, hence, information dissemination.

Empirical strategy

I estimate the impact of ICT adoption on farm diversification as

$$Y_i = \beta_0 + \beta_1 ICT_i + \beta_2 X_i + \beta_3 d_i + \varepsilon_i \quad (1)$$

Our main outcome variables, to explain the extent of high-value crop cultivation, are a dummy indicator variable for high-value crops and the share of area under cultivation. The other outcome variables are related to input use and commercialization of agriculture.

X_i are other household specific factors which are likely to drive the outcome variables, d_i are district fixed effects and standard errors are clustered at the district level. Our goal is to estimate the impact of ICT adoption on our outcome variables, or β_1.

However, using ordinary least square (OLS) to estimate Equation 1 can be erroneous and coefficient-biased, since it is possible that $Corr(Outcome\ variable_i, \varepsilon_i) \neq 0$, because of unobserved household-specific characteristics—like ability, skill ,or motivation—that cannot be controlled for. To correct for that I use an instrumental variable strategy to estimate the impact among households of adopting ICT on the cultivation of high-value crops.

Choice of instrument

In specifying an instrumental variable I need an instrument that is correlated with the measure of a household's adoption of ICT and that does not directly affect our outcome variables. I appeal to the role of network and peer effects in the adoption of ICT (or any new technology, for that matter) and I use the adoption of ICT by a household's peer group, composed of households in geographic and social proximity, as our instrument. Given the Indian rural setting, I define a household's peer group as comprising households of the same social caste and religion and that reside in the same village. I calculate the share of households in a particular household's peer group who adopt ICT related devices. For each household, the instrument is derived after excluding that household's ICT adoption (Appendix Table A2). Other studies (Fontaine and Yamada 2011; Birthal et al. 2015a; Birthal et al. 2015b; Deng et al. 2019) use instruments based on peer group behaviour, and Songsermsawas et al. (2016) and Di Falco et al. (2020) use the average characteristics of friends of friends as an instrument for friends' characteristics.

Results

To indicate the extent of diversification, I use two measures of agricultural diversification: dummy

indicator variable of high-value crops and share of area under high value crops, and I find a statistically significant positive association between ICT adoption (use and ownership) and agricultural diversification (Table 2). The coefficients estimated are likely biased and misleading, however, and I estimate the instrumental variable and report the coefficients of interest (Table 3) and the impact of, respectively, ICT use and ownership on the likelihood of cultivating each crop group type (Table 4). I present the first stage regression estimates (Appendix Table 2) and the entire regression output with other controls (Appendix Table 3). I find that ICT use and ownership cause a statistically significant increase in the likelihood of cultivating high-value crops and in the area under cultivation. The use of ICT increases the probability of cultivation by 12.8%[2] and ownership by 7.9%. That use impacts agricultural diversification more than ownership is expected as it is obvious that mere ownership of devices would not have the same impact as actual use of ICT.

The impact of ICT adoption on the production of spices and other high-value crops is positive and statistically significant; it is statistically and significantly negative on the production of pulses and not statistically significant on the production of cereals. Our result is

Table 2 OLS regressions

	(1) HVC	(2) HVC	(3) HVCshare	(4) HVCshare
ICT use	0.0373***		0.0183**	
	(0.0122)		(0.00736)	
ICT own		0.0483***		0.0365***
		(0.0150)		(0.0108)
Other controls	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
_cons	0.0983**	0.0965**	0.0926***	0.0953***
	(0.0465)	(0.0470)	(0.0271)	(0.0274)
N	14275	14275	14275	14275

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 and 2 are dummy indicator variable which equals 1 if household cultivates HVC and 0 if not. Outcome variable for column 3 and 4 are share of total land under HVC cultivation.

Table 3 Instrumental variable regression

	(1) HVC	(2) HVC	(3) HVCshare	(4) HVCshare
ICTuse	0.121*		0.0875**	
	(0.0662)		(0.0408)	
ICTown		0.0757*		0.0546**
		(0.0406)		(0.0252)
_cons	0.133**	0.105**	0.122***	0.101***
	(0.0528)	(0.0471)	(0.0307)	(0.0273)
N	14272	14272	14272	14272

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 and 2 are dummy indicator variable which equals 1 if household cultivates HVC and 0 if not. Outcome variable for column 3 and 4 are share of total land under HVC cultivation.

[2]The treatment effect in the percentage terms is calculated as: $(e^{\hat{\delta}}-1)*100)$, where $\hat{\delta}$ is the estimated coefficient.

Table 4 Instrumental variable regression- food group dummy indicator outcome variable

	(1) cereals	(2) pulses	(3) spices	(4) oilseeds	(5) vegfruits	(6) others
			ICT use			
ICT use	0.00587	-0.103**	0.0897***	0.0546	0.0591	0.0618*
	(0.0392)	(0.0402)	(0.0285)	(0.0465)	(0.0570)	(0.0345)
_cons	0.873***	0.0505	-0.0372	0.0284	0.213***	-0.100***
	(0.0290)	(0.0386)	(0.0234)	(0.0441)	(0.0357)	(0.0288)
N	14272	14272	14272	14272	14272	14272
			ICT ownership			
ICT own	0.00367	-0.0644**	0.0560***	0.0341	0.0369	0.0386*
	(0.0244)	(0.0252)	(0.0176)	(0.0288)	(0.0352)	(0.0212)
_cons	0.872***	0.0747**	-0.0582***	0.0155	0.200***	-0.115***
	(0.0270)	(0.0367)	(0.0222)	(0.0406)	(0.0286)	(0.0256)
N	14272	14272	14272	14272	14272	14272

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 to 6 are respectively dummy indicator variables for each of the crop groups which equal 1 if household cultivates the same and 0 otherwise.

in line with Birthal et al. (2015a), which finds that households produce both cereals and high-value crops; they rarely switch completely from cereals to high-value crops. The impact of ICT use is greater than that of ownership.

Heterogeneity

The late or early adoption of mobile phones, and the remoteness of a village (pucca road or all-weather), determines the impact of adopting ICT. I define "early adopters of mobile technology" as villages that had mobile telephone services earlier than the median number of years when villages had first mobile telephone service. The IHDS 1 provides data on the number of years that households in a village had mobile telephone services. Early adopters drive the likelihood and extent of cultivating high-value crops; however, ICT related devices start impacting farm households only after a gestation period (Table 5- Panel A).

Heterogeneity based on early and late adopting villages and presence or absence of pucca (all-weather road)

Households in villages that do not have pucca roads (Table 5, Panel B, Columns 1, 2, 5 and 6) are likelier to adopt ICT than households in villages with pucca roads (Table 5, Panel B, Columns 3, 4, 7 and 8) The impact of ICT adoption is positive and statistically significant for villages with no pucca road; the impact for villages with pucca roads is not statistically significant. The result suggests that households that adopt ICT overcome the bottleneck of poor connectivity. The impact of ICT adoption was driven by early adopters of ICT that had no pucca roads.

The Pradhan Mantri Gram Sadak Yojana (PMGSY) aimed to build by 2003 pucca roads for all villages with a population of at least 1000 and by 2007[3] for all villages with a population of at least 500. Investments started in 2000. Higher populated villages were prioritized first. The data used for this analysis was collected in 2004–05, and only a few villages would have been covered by then, but late adopters were fewer in villages with pucca roads (1,149) than without (5,685). Interventions supporting investment in ICT adoption clearly did not correlate with investments to connect villages with pucca roads and the rate of ICT diffusion was much higher than of road connectivity. Policy must be formulated, and implemented, to improve the penetration of ICT in remote, poorly connected villages.

[3]https://web.archive.org/web/20121221150318/https://pmgsy.nic.in/pmg31.asp#2

Table 5 Heterogeneity based on early and late adopting villages and presence or absence of pucca (all-weather road)

	Panel A-Early and late adopting villages							
	(1) HVC early	(2) HVC late	(3) HVC early	(4) HVC late	(5) HVC share early	(6) HVC share late	(7) HVC share early	(8) HVC share late
ictexp	0.126*	-0.0286			0.120**	-0.104		
	(0.0694)	(0.371)			(0.0475)	(0.192)		
ictown			0.0821*	-0.0131			0.0784**	-0.0474
			(0.044)	(0.168)			(0.031)	(0.081)
_cons	0.0570	0.772***	0.0255	0.776***	0.101***	0.914***	0.0714**	0.929***
	(0.065)	(0.107)	(0.059)	(0.090)	(0.039)	(0.055)	(0.035)	(0.053)
N	9209	1149	9209	1149	9209	1149	9209	1149
	Panel B-Heterogeneity on the basis of presence or absence of Pucca (all-weather) roads							
	(1) HVC No Pucca road	(2) HVC Pucca road	(3) HVC No Pucca road	(4) HVC Pucca road	(5) share No Pucca road	(6) share Pucca road	(7) share No Pucca road	(8) share Pucca road
ICTuse	0.262**		0.0464		0.119*		0.0510	
	(0.105)		(0.0732)		(0.0654)		(0.0473)	
ICTown		0.193***		0.0267		0.0874*		0.0293
		(0.0749)		(0.0421)		(0.0468)		(0.0273)
_cons	0.161**	0.134**	0.169**	0.155**	0.0869***	0.0749**	0.171***	0.156***
	(0.0703)	(0.0680)	(0.0688)	(0.0608)	(0.0308)	(0.0293)	(0.0445)	(0.0401)
N	5685	5685	8587	8587	5685	5685	8587	8587

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1,2,3 and 4 are dummy indicator variable which equals 1 if household cultivates HVC and 0 if not. Outcome variable for column 5 ,6, 7 and 8 are share of total land under HVC cultivation. In Panel A, Columns 1, 3, 5 and 7 pertain to early adopters subsample while 2, 4, 6 and 8 pertain to late adopters subsample. In Panel B, Columns 1, 3, 5 and 7 pertain to no-pucca roads subsample while 2, 4, 6 and 8 pertain to villages with pucca roads subsample.

Channels

The adoption of ICT impacts farm production and the diversification towards high-value crops by improving farmers' access to credit markets, formal sources of information (Table 6- Panel A) and informal social networks (Table 6- Panel B), and enabling them to diversify their sources of income—although I am not able to identify causal pathways, and these channels could be driven by other, exogenous factors. Mass media makes it easier for government and policymakers to reach farm households. and mass media can raise their awareness of daily market prices, the availability and prices of inputs, and farmer support initiatives taken by the government.

The adoption and use of ICT connects farmers to each other. To capture the impact of ICT adoption on social informal networks, I use two measures: membership in social groups and acquaintance with influential people. The indicator for membership in social groups equals 1 if any household member is a member of a trade union, caste association, or a women's, self-help, or religious group. People may be influential in society owing to their role as medical professionals, schoolteachers, or as employee of the central

Table 6 Channels- education, mass media and news

	Panel A: education, mass media and news			
	(1)	(2)	(3)	(4)
	Mass-media	Mass-media	News	News
ICTuse	0.431***		0.323***	
	(0.0478)		(0.0469)	
ICTown		0.269***		0.202***
		(0.0294)		(0.0278)
_cons	0.318***	0.217***	-0.0384	-0.114***
	(0.0534)	(0.0495)	(0.0330)	(0.0311)
N	14272	14272	14272	14272
	Panel B: Membership and information			
	membership	membership	knowpeople	knowpeople
ICTuse	0.0496		0.273***	
	(0.0610)		(0.0537)	
ICTown		0.0310		0.170***
		(0.0381)		(0.0323)
_cons	-0.171***	-0.183***	0.546***	0.482***
	(0.0489)	(0.0443)	(0.0483)	(0.0433)
N	14272	14272	14272	14272

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ In Panel A, Outcome variable in column 1 and 2 are dummy indicator variable which equals 1 if household has access to mass media and 0 if not and Outcome variable for column 3 and 4 are dummy indicator variable which equals 1 if household watches news and 0 if not. In Panel B, outcome variable in column 1 and 2 are dummy indicator variable which equals 1 if household is a member of some social group and 0 if not and outcome variable for column 3 and 4 are dummy indicator variable which equals 1 if household has acquaintance with some influential person.

government or state governments. I find that ICT adoption does not have a statistically significant impact on membership of any group but it does have a positive, statistically significant impact on acquaintance with influential people. Households that adopt ICT are possibly more informed than those that do not because they are more connected with others and more aware of new agricultural developments, good practices, input and output markets, and therefore more likely to commercialize and diversify production.

Farm households diversify into cultivating high-value crops that are riskier if they have access to credit markets that lets them hedge risk (Table 7). And they can take new initiatives and adopt new technology if they have food and financial security through insurance, several sources of income, a ration card, and a Kisan Credit Card. The adoption of ICT might help farmers access the benefits of government social welfare schemes and diversify their portfolio by working in more than occupation. I find that ICT adoption has a positive and significant impact on the number of income sources of farm households but I do not find any statistically significant impact of benefits from social welfare schemes or a Kisan Credit Card.

Next, I explore whether farm households that adopt ICT enjoy differential access to credit markets than households that do not. I consider the likelihood of taking a loan in the previous five years, purpose of the largest loan, source of the largest loan, and the monthly interest rate on the largest loan.[4] I use indicator variables

[4]Survey provides detail only on the largest loan taken by the household and therefore I explore impact of ICT on the largest loan

Table 7 Channels-more sources of income

	(1) sumdivincsource	(2) sumdivincsource	(3) card	(4) card	(5) kcc	(6) kcc
ICTuse	0.213***		0.0146		0.0405	
	(0.0815)		(0.0217)		(0.0423)	
ICTown		0.133**		0.00913		0.0253
		(0.0517)		(0.0135)		(0.0258)
_cons	1.868***	1.818***	0.501***	0.497***	-0.161***	-0.171***
	(0.0775)	(0.0740)	(0.0417)	(0.0410)	(0.0329)	(0.0289)
N	14272	14272	14272	14272	14272	14272

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 and 2 are sum to total income sources for households. Outcome variable for column 3 and 4 are dummy indicator variable which equals 1 if household some card and 0 if not. Outcome variable for columns 5 and 6 are dummy indicator variable which equals 1 if household has kcc card and zero otherwise.

Table 8 Channels- credit market access

	(1) loan	(2) loan	(3) agriloan	(4) agriloan	(5) formalloan	(6) formalloan	(7) loginterest	(8) loginterest
ictexp	0.00918		0.0642		0.202***		-0.152**	
	(0.0541)		(0.0405)		(0.0446)		(0.0671)	
ictown		0.00573		0.0401		0.126***		-0.0910**
		(0.0338)		(0.0250)		(0.0270)		(0.0396)
_cons	-0.150***	-0.152***	-0.0845*	-0.0996**	-0.163***	-0.210***	0.845***	0.861***
	(0.0494)	(0.0466)	(0.0486)	(0.0463)	(0.0488)	(0.0452)	(0.0644)	(0.0642)
N	14272	14272	14272	14272	14272	14272	7191	7191

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 and 2 are dummy indicator variable which equals 1 if household has taken atleast one loan in the last five years and 0 if not. Outcome variable for column 3 and 4 are dummy indicator variable which equals 1 if household's largest loan was an agri or business loan, columns 5 and 6 are dummy indicator variables which equals 1 if household's largest loan in the last five years was from a formal source and columns 7 and 8 are log of interest rate at which the household took the largest loan in the last five years.

for loan, agri/business loan, formal loan and use log of monthly interest rate as the final outcome variable. I find that ICT adoption has no statistically significant impact on the probability of taking a loan in the previous five years or on the purpose of the largest loan, but it increases the likelihood of borrowing from a formal source (Column 5 and 6), and those who adopted ICT pay statistically and significantly lower interest rates for the largest loan they took in the previous five years (Table 10). Households that use ICT have better awareness then those who do not, and it is plausible that this awareness led to cheaper loans from formal sources.

Other impacts of ICT adoption

I explore the impact of ICT adoption on two aspects of agricultural production: farm commercialization and investment in inputs. I measure market activity using four indicators: the log of income profit from agricultural production; the log of profit from agricultural production; an indicator variable, market sale (mktsale), which equals 1 if the household sells any of its agricultural output; and another indicator variable, HVC market sale (HVCmktsale), which equals 1 if a household sells high-value crops.[5] I find no statistically significant impact of ICT on overall

[5]I also explored impact of ICT adoption on prices received by farm households on sale of their produce. I do not find any statistically significant impact of ICT adoption on prices.

Table 9 Instrumental variable regressions- farm commercialization

	(1) mktsale	(2) mktsale	(3) HVCmktsale	(4) HVCmktsale	(5) loginc	(6) loginc	(7) logprofit	(8) logprofit
ICTuse	0.0487		0.146**		0.627***		0.543**	
	(0.0570)		(0.0652)		(0.203)		(0.272)	
ICTown		0.0304		0.0913**		0.400***		0.345**
		(0.0353)		(0.0394)		(0.124)		(0.165)
_cons	0.0963*	0.0848*	0.0561	0.0217	7.011***	6.860***	6.811***	6.706***
	(0.0497)	(0.0459)	(0.0506)	(0.0467)	(0.164)	(0.149)	(0.214)	(0.202)
N	14272	14272	14272	14272	12852	12852	9450	9450

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 and 2 are dummy indicator variable which equals 1 if household has sells his production in the market and 0 if not. Outcome variable for column 3 and 4 are dummy indicator variable which equals 1 if household sells HVCs it cultivates in the market, columns 5 and 6 are log of income earned from farm production, and columns 7 and 8 are log of profit gained from farm cultivation.

Table 10 Instrumental variable regression- input expenditure

	(1) hiredlabratio	(2) logseedsmkt	(3) logfertilizer	(4) logpesticide	(5) loghiredequip	(6) logagriloanrepayment
ICTuse	0.144***	0.427**	0.876***	1.283***	0.377	0.954***
	(0.0285)	(0.188)	(0.290)	(0.437)	(0.409)	(0.360)
_cons	0.0935***	4.522***	5.145***	3.192***	6.224***	-0.919***
	(0.0265)	(0.144)	(0.213)	(0.299)	(0.361)	(0.296)
N	10892	14146	13950	13253	13557	12494
ICT own	0.0934***	0.266**	0.544***	0.794***	0.233	0.590***
	(0.0164)	(0.114)	(0.170)	(0.256)	(0.255)	(0.214)
_cons	0.0618**	4.422***	4.941***	2.908***	6.134***	-1.134***
	(0.0250)	(0.134)	(0.190)	(0.267)	(0.338)	(0.272)
N	10892	14146	13950	13253	13557	12494

Source authors' computation using IHDS-1 data. Robust Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Outcome variable in column 1 is ratio of hired labour to total labour employed by the household in cultivation, column 2 is log of expenditure on seeds from the market, column 3 is log of expenditure on pesticide, column 4 is log of expenditure on pesticide, column 6 is log of expenditure on hired equipments and column 7 is log of expenditure on repayment of loan taken for purpose of investing on agriculture.

market sale. However, ICT adoption has a positive and statistically significant impact on likelihood of HVC market sale, and households that use or own ICT earned statistically significant and higher agricultural incomes and profit (Table 9). As with all other results, impact of ICT use is higher than ICT ownership. These results point towards overall commercialization of agriculture for households which have adopted ICT.

Agricultural inputs are measured using the ratio of hired labour to total farm labour, log of total expenditure on purchased seeds from the market, log of fertilizer expenditure, log of total pesticide expenditure, log of expenditure on irrigation, hired equipments and log of expenditure incurred on agricultural loan repayment. I find that ICT adoption has a statistically significant and positive impact on ratio of hired labour, seeds purchased, fertilizer and pesticide purchased from the market and expenditure incurred on repayment of agricultural loans (Table 10). Given that inputs, specifically productivity enhancing technologies, complement each another (Foster and Rosenzweig, 2010; Suri, 2011), these findings on an increase in expenditure for these inputs are not surprising.

Conclusions

Agriculture is the main source of livelihood for more than 50% of the population. And the increasing penetration of cheap mobile phones and internet connectivity over the past two decades makes India an interesting case study for estimating the impact of ICT as a means of effective communication on farm decisions. This study uses the IHDS-1 dataset and an instrumental variable strategy to explore the impact of ICT ownership and use on agricultural diversification, farm commercialization, and investment in new technology; it does not evaluate ICT related interventions (like agri-extension through SMS/internet or weather or any other information dissemination through SMS/internet).

Villages that adopted mobile technology early reaped the benefits of ICT best. The adoption of ICT facilitates farm diversification but the benefits depend on whether a village was early or late to adopt it, implying that ICT adoption and use has a gestation period before it can serve as an efficient means of communication among farmers.

The benefits of ICT adoption are driven by villages that do not have an all-weather (pucca) road, suggesting that ICT can reach the remotest villages.

We hypothesized that the adoption of ICT drives farm diversification through awareness, information (formal and informal sources), risk bearing capacity, and access to credit markets. Our findings confirm the hypothesis.

Households that adopt ICT are likelier to spend on agricultural inputs and technologies, hire labour for farm work, sell their output in the market, earn higher income and profits, and commercialize farms. The adoption of ICT has a positive and significant impact on agricultural diversification towards high-value commodities. In India most farmers are small or marginal and villages poorly connected, and ICT holds promise and potential in promoting diversification and commercialization.

References

Aker, J. C. 2011. Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agricultural economics*, *42* (6), 631-647.

Ali, M and D Abedullah. 2002. Nutritional and economic benefits of enhanced vegetable production and consumption. *Journal of crop production*, *6*(1-2), 145-176.

Barghouti, S, S Kane, K Sorby and M Ali. 2004. Agricultural Diversification for the Poor Guidelines for Practitioners.

Birthal, P S, P K Joshi, D Roy, and A Thorat. 2013. Diversification of Indian agriculture toward high-value crops: The role of smallholders. Canadian Journal of Agricultural Economics, 61, 61–91.

Birthal, P S, Roy, D., & Negi, D. S. 2015a. Assessing the impact of crop diversification on farm poverty in India. *World Development*, *72*, 70-92.

Birthal, P. S., Kumar, S., Negi, D. S., & Roy, D. 2015b). The impacts of information on returns from farming: Evidence from a nationally representative farm survey in India. *Agricultural Economics*, *46*(4), 549-561.

Camacho, A., & Conover, E. 2010). The impact of receiving price and climate information in the agricultural sector. *Documento CEDE*, 2010-40).

Cole, S. A. and A. Fernando 2016). Mobile-izing agricultural advice: Technology adoption, diffusion and sustainability.

De Janvry, A., E. Sadoulet, D. Manzoor, and E. Kyle 2016). The agricultural technology adoption puzzle: What can we learn from field experiments? Technical report.

Deng, X., Xu, D., Zeng, M., & Qi, Y. 2019). Does Internet use help reduce rural cropland abandonment? Evidence from China. *Land use policy*, *89*, 104243.

Desai, S., Vanneman, R., and National Council of Applied Economic Research, New Delhi. India Human Development Survey (IHDS), 2005. Inter-university Consortium for Political and Social Research [distributor], 2018-08-08. https://doi.org/10.3886/ICPSR22626.v12

Di Falco, S., Doku, A., & Mahajan, A. 2020). Peer effects and the choice of adaptation strategies. *Agricultural Economics*, *51*(1), 17-30.

Fafchamps, M. and B. Minten 2012). Impact of sms-based agricultural information on Indian farmers. The World Bank Economic Review 26 (3), 383{414.

Fontaine, X., Yamada, K. 2011). Envy and hope: Relevant others' consumption and subjective well-being in urban India. GCOE Discussion Paper 212, Osaka University.

Foster, A. D. and Rosenzweig, M. R. 2010). Microeconomics of Technology Adoption. Annual Review of Economics, 2: 395-424.

Index, G. H. (2020). 2020-G LOBAL HUNGER INDEX-ONE DECADE TO ZERO HUNGER.

Goyal, A. 2010). Information, direct access to farmers, and rural market performance in central India. *American Economic Journal: Applied Economics*, *2*(3), 22-45.

Gupta, A.; Ponticelli, J.; Tesei, A. 2019) : Technology adoption and access to credit via mobile phones, Working Paper, No. 892, Queen Mary University of London, School of Economics and Finance, London

HinduBusiness Line, 2021 (HBS), India's wireless teledensity, Internet subscribers grow manifold in last 6 years: TRAI, https://www.thehindubusinessline.com/info-tech/indias-wireless-teledensity-internet-subscribers-grow-manifold-in-last-6-years-trai/article34700143.ece

Business Standard, 2021 (BS), India's Tele-density Surges Above 86%, https://www.business-standard.com/article/news-cm/india-s-tele-density-surges-above-86-121011100690_1.html#:~:text=The%20tele%2Ddensity%20has%20reached,726.32%20million%20in%20September%202020.

Jensen, R. 2007). The digital provide: Information (technology), market performance, and welfare in the south Indian Fisheries sector. The Quarterly Journal of Economics 122 (3), 879{924.

Joshi, P. K., Gulati, A., Birthal, P. S., & Tewari, L. 2004). Agricultural diversification in South Asia: Patterns, determinants and policy implications. Economic and Political Weekly, 39(24), 2457–2468.

Munshi, K. 2004). Social learning in a heterogeneous population: technology diffusion in the Indian green revolution. Journal of development Economics 73 (1), 185-213.

Rao P., P. S. Birthal and P. K. Joshi. 2006. Diversification towards high-value agriculture: Role of urbanization and infrastructure. *Economic and Political Weekly* 41 (26): 2747–53.

Songsermsawas, T., Baylis, K., Chhatre, A., & Michelson, H. 2016). Can peers improve agricultural revenue? *World Development*, *83*, 163-178.

Suri, T. 2011). Selection and Comparative Advantage in Technology Adoption. Econometrica, 79(1):159-209.

Weinberger, K., & Lumpkin, T. A. 2007). Diversification into horticulture and poverty reduction: A research agenda. World Development, 35(8), 1464–1480.

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Annexure

Table A1 Descriptive statistics- outcome variables and controls in the regression

Variable	Obs	Mean	Std. Dev.
High Value Commodities related			
High Value Commodities (1/0)	14345	.403	.491
High Value Commodities (share area)	14345	.193	.305
ICT related			
ICT use (1/0)	14345	.308	.462
ICT own (1/0)	14345	.135	.342
Inputs in cultivation			
Hired labour ratio	10938	.161	.203
Seed expenditure (Rs)	14217	1824.626	4113.153
Fertilizer and manure expenditure (Rs)	14018	2571.936	8103.267
Pesticides and herbicides expenditure (Rs)	13306	1051.552	4538.92
Irrigation expenditure (Rs)	13060	517.964	1871.472
Tractor and equipment expenditure (Rs)	13614	1388.369	3024.445
Agriculture loan repayment expenditure (Rs)	12545	1297.519	9180.913
Income & profit from production			
Income for farm (Rs)	14345	22594.414	77758.795
Profit from farm (Rs)	14205	10715.275	72036.444
Household characteristics			
Head age (in years)	14345	49.026	13.438
Head edu (in years)	14275	4.477	4.437
Head married (1/0)	14345	.885	.319
Caste SC(1/0)	14345	.158	.364
Caste ST (1/0)	14345	.118	.323
Caste OBC (1/0)	14345	.416	.493
Household size (no)	14345	5.89	2.84
Total land (acre)	14320	4.51	8.035

Source Author's calculations using data from IHDS1

Table A2 Instrumental variable regression- first stage

	(1) ictexp	(2) ictown	(3) ictexp	(4) ictown
instictown	0.495***	0.792***	0.495***	0.792***
	(0.0272)	(0.0108)	(0.0272)	(0.0108)
headage	0.00584***	0.00231**	0.00584***	0.00231**
	(0.00148)	(0.000916)	(0.00148)	(0.000916)
agesq	-0.0000320**	-0.00000215	-0.0000320**	-0.00000215
	(0.0000141)	(0.00000893)	(0.0000141)	(0.00000893)
headedu	0.00789***	-0.00227	0.00789***	-0.00227
	(0.00241)	(0.00167)	(0.00241)	(0.00167)
edusq	0.000831***	0.00124***	0.000831***	0.00124***
	(0.000210)	(0.000159)	(0.000210)	(0.000159)
headmarried	-0.0324***	-0.0147*	-0.0324***	-0.0147*
	(0.0120)	(0.00830)	(0.0120)	(0.00830)
castesc	-0.0343***	0.00593	-0.0343***	0.00593
	(0.0132)	(0.00375)	(0.0132)	(0.00375)
castest	-0.0603***	0.00937**	-0.0603***	0.00937**
	(0.0175)	(0.00401)	(0.0175)	(0.00401)
casteobc	-0.0249**	0.00104	-0.0249**	0.00104
	(0.0111)	(0.00361)	(0.0111)	(0.00361)
loghhsize	0.0771***	0.0457***	0.0771***	0.0457***
	(0.00864)	(0.00630)	(0.00864)	(0.00630)
totalland	-0.0000116***	-0.00000629*	-0.0000116***	-0.00000629*
	(0.00000316)	(0.00000350)	(0.00000316)	(0.00000350)
District FE	Yes	Yes	Yes	Yes
_cons	-0.385***	-0.240***	-0.385***	-0.240***
	(0.0415)	(0.0291)	(0.0415)	(0.0291)
F test of excluded instruments:				
Sanderson-Windmeijer test	330.01***	5403.90***	330.01***	5403.90***
Under identification test				
Kleibergen-Paap rk LM statistic	72.64***	112.06***	72.64***	112.06***
Weak identification test				
Cragg-Donald Wald F statistic	758.56	4412.05	758.56	4412.05
10% maximum IV value	16.38	16.38	16.38	16.38
N	14272	14272	14272	14272

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3 Instrumental variable regression- main results- all controls

	(1) hyv	(2) hyv	(3) hyvshare	(4) hyvshare
ictexp	0.121*		0.0875**	
	(0.0662)		(0.0408)	
ictown		0.0757*		0.0546**
		(0.0406)		(0.0252)
headage	0.00258	0.00311*	0.00114	0.00152
	(0.00173)	(0.00170)	(0.00107)	(0.00104)
agesq	-0.00000319	-0.00000691	-0.00000683	-0.00000951
	(0.0000164)	(0.0000164)	(0.0000102)	(0.0000101)
headedu	0.00795***	0.00908***	0.00239	0.00321**
	(0.00262)	(0.00258)	(0.00164)	(0.00159)
edusq	0.0000315	0.0000385	0.0000599	0.0000650
	(0.000224)	(0.000222)	(0.000135)	(0.000133)
headmarried	0.0227**	0.0199*	0.0105	0.00845
	(0.0113)	(0.0110)	(0.00695)	(0.00670)
castesc	-0.0947***	-0.0993***	-0.0188*	-0.0221**
	(0.0198)	(0.0191)	(0.0105)	(0.0103)
castest	-0.0708**	-0.0788***	-0.0403**	-0.0461***
	(0.0302)	(0.0291)	(0.0160)	(0.0152)
casteobc	-0.00498	-0.00808	-0.00233	-0.00457
	(0.0160)	(0.0156)	(0.0108)	(0.0104)
loghhsize	0.0495***	0.0554***	-0.00354	0.000702
	(0.0114)	(0.00968)	(0.00701)	(0.00595)
totalland	0.00000113	0.000000199	-0.00000889**	-0.00000956**
	(0.00000707)	(0.00000717)	(0.00000446)	(0.00000444)
District FE	Yes	Yes	Yes	Yes
_cons	0.133**	0.105**	0.122***	0.101***
	(0.0528)	(0.0471)	(0.0307)	(0.0273)
N	14272	14272	14272	14272

Standard errors in parentheses* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$