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## Article

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## GENERAL & APPLIED ECONOMICS | RESEARCH ARTICLE

# Production technology adoption and electronic market participation intensity of chilli (dry) farmers in India: Application of triple-hurdle model

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### ABOUT THE AUTHORS

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### PUBLIC INTEREST STATEMENT

In this paper, we integrate farmers' adoption decision of a new variety of chilli crop ('Teja') along with their electronic market participation decision and e-market participation intensity, based on data from the chilli farming sector in India, where agricultural markets have been modernized through digitization (Kalgudi e-Market). We employed Triple-Hurdle Model (THM) to integrate adoption decision of 'Teja' variety of chilli, e-Market Participation Decision and e-market participation intensity thereby, allowing us to make inferences relating to chilli farmers in Andhra Pradesh, India. Our results, showed that the drivers of 'Teja' variety adoption, e-market participation, and e-participation intensity include education, reliable extension services, access to seeds of high yielding varieties, market information, and membership in farmer-producer organizations. Added to these, personnel training visits, prompt deliveries of inputs, and prompt payment of sales proceeds are also important in influencing participation and intensities. Also our results showed that the three stochastic decisions of THM are strongly correlated implying that the adoption decision of 'Teja' variety of chilli by the farmers influences the e-market participation decision and consequently, e-market participation intensity and these three decisions are sequential. On the basis of the result we recommended for future farm policy and agricultural-research and innovations must recognize the potential that the digital marketing systems have to offer. Such considerations coupled with the provision of market infrastructure including assaying, grading, storage, and market information will promote digital transformation in agricultural value chains in developing countries like India.

**Abstract:** Agricultural and food system transformation helps increase farm productivity and encourages farmers to participate in updated value chains, adopt newer technologies, thereby helping farmers transform their livelihoods in a sustainable manner. Relatedly, value chain innovations depend on multiple decisions farmers make at various stages of the value chain, adequate participation being a primary factor. In this paper, we integrate farmers' adoption decision of a new variety of chilli crop ("Teja") along with their electronic market participation decision and e-market participation intensity, based on data from the chilli farming sector in India, where agricultural markets have been modernized through digitization (Kalgudi e-Market). Thus, the employed Triple-Hurdle Model (THM) integrates adoption decision of "Teja" variety of chilli, e-Market Participation Decision and e-market participation intensity thereby, allowing us to make inferences relating to chilli farmers in Andhra Pradesh, India. Our results, showed that the drivers of "Teja" variety adoption, e-market participation, and e-participation intensity include education, reliable extension services, access to seeds of high yielding varieties, market information, and membership in farmer-producer organizations. Added to these, personnel training visits, prompt deliveries of inputs, and prompt payment of sales proceeds are also important in influencing participation and intensities. Results show that the three stochastic decisions of THM are strongly correlated implying that the adoption decision of "Teja" variety of chilli by the farmers influences the e-market participation decision and consequently, e-market participation intensity and these three decisions are sequential. On the contrary, the decisions viz., e-market participation decision and e-market participation intensity as input buyers and consequent adoption of "Teja" variety of chilli are simultaneous. So, the policy measures that promote production technology interventions (say, "Teja" variety of chilli) will definitely enhance better e-market access of chilli farmers. Accordingly, the breeding programs of the agricultural research stations should enhance the uptake of improved varieties in tune with modern marketing (e-market) technologies. Future farm policy and agricultural-research and innovations must recognize the potential that the digital marketing systems have to offer. Such considerations coupled with the provision of market infrastructure including assaying, grading, storage, and market information will promote digital transformation in agricultural value chains in developing countries like India.

**Subjects:** Agricultural Economics; Statistics for Business, Finance & Economics

**Keywords:** Adoption; production technology; e-market participation decision; market participation intensity; chilli; triple-hurdle mode

**JEL Classification:** C51; C81; M31; Q13; Q18

## 1. Introduction

Agricultural and food system transformation requires the development of efficient and effective value chains where farmers are well integrated into markets with a high level of productivity and the markets serve the consumers effectively by reducing transaction costs for both farmers and the consumers. Indeed, as Singbo et al. (2021), Poole (2017), Abu et al. (2016) and Barrett (2008) demonstrate, farmers' market participation generates positive economic outcomes, by incentivizing the adoption of improved technology and crop varieties. Existing literature also supports the

premise that the adoption of improved crop varieties leads to higher incomes through output marketing in modernized market outlets (Ochieng et al., 2019; Ogutu & Qaim, 2019). In turn, improved access to marketing opportunities and transition towards modern market outlets also intensify the adoption of crop production technologies. Thus, to enhance market-orientation of farmers, it is essential to have effective linkages between farmers and consumers in the food value chains. So, modern outlook of farmers both in terms of adoption of production technologies and modern market outlets participation certainly contribute towards agricultural productivity and profitability.

Likewise, recent studies from Africa such as Ebenezer et al. (2019), Gebremedhin et al. (2017), Okoye et al. (2016) and Akrong (2020) note the positive relations between access to technology and greater market participation in the farming sector. Further, the successful transformation of traditional market systems into modern supply chains, such as digitalization, is possible only if the prevalent farming community exhibits sufficient enthusiasm and readiness to adapt to such innovations.

The extant research cited above indicates that the relation between farmers' market participation and their adoption of new technologies is complex. For example, farmers who adopt high-yielding varieties of seeds, may still not realize the full benefits from such adoptions, if they fail to participate in modern market systems. Similarly, farmers who are quick in adopting modern marketing systems may not sufficiently realize the maximum gains from such participation, if farm productivity and marketed surpluses are low.

Studies from the farm sectors in India (Annemie & Christopher, 2013) and Madagascar (Moser and Barrett, 2006) voice the important concern that, while technology increases farm productivity and economic outcomes, its adoption among all potential users in the population is not guaranteed, because technology diffusion depends upon the pre-existing dynamics and behavioural patterns of the adopters. As Barrett et al. (2012) point out, that while market modernization assists farmers' economic status, it is important to consider the impact of economic development on generating the needed market innovations. Consequently, economic policies must find the right balance between targeted subsidies and effective extension services.

Relatedly, Barrett et al. (2012) also note that agricultural markets have undergone rapid transformations with fast-food chains, supermarkets, and related developments. During the same time, however, small farmer participation in modern value chains has remained low. Further, Barrett et al. (2012) conducted a meta-narrative analysis from five countries to indicate the comparative advantages of farmers who participate in modern value chains, and also the barriers that impede such participation, which mainly arise due to small farmers' lack of access to farmer groups, supply chains, and cooperatives.

Indeed, Barrett (2008) finds compelling evidence from the African farming sector to demonstrate that in almost all instances, macroeconomic and trade-policy tools are least effective in incentivizing market participation among small farmers. However, noticeable gains in farmers' market participation are generated with targeted interventions, such as those that are specifically directed to farmer organizations, which reduce transaction costs, and improve access to productive assets.

Consequently, policies that aim to transform agricultural practices must consider not just farmers' awareness of modern technologies and crop varieties, but also their capacity to engage in modern transactions within the enhanced supply chain links. Policy proposals that focus solely on encouraging farmers towards new adoption techniques may not necessarily produce their full impact if farmers do not have the necessary complementary support systems in place. Access to and participation in modern market systems are key factors that motivate farmers to adopt newer production methods and crop varieties. However, access to modern supply chains is often inhibited

by high transaction costs, such as distance to markets, middlemen fees, market misinformation, lack of knowledge about newer methods of production, pre-existing and often exploitative local network, and institutional links.

The economic problem can be posed succinctly by asking the following counterfactual question: how many of the currently non-producing farmers are likely to become *potential* producers if they could have easier access to modern markets? The answer to this counterfactual question becomes important, from a policy perspective. That is, the potential economic impact of an income-enhancing farm policy may be overstated if the policy fails to discount the non-participation effects of the non-actors within the population.

To adequately model the production-participation decisions, and address the counterfactual question posed above, Burke et al. (2015) and others have developed methods that incorporate sequential decision-making, taking endogeneity and self-selection into account. Specifically, Burke et al. (2015) envisage the household's economic problem and outcome in different stages, wherein, in the first stage, the economic agent decides to be a producer or a non-producer. In the second stage, the agent decides on whether to participate in the market, say as a seller or a buyer or as both types, given the decision in the first stage. The third stage examines the outcomes in terms of net-gains realized, based on the decisions taken in the first two stages. The three-stage process by Burke et al. (2015), or the Triple-Hurdle Model (THM) extends the Double-Hurdle Model (DHM) framework (Musara et al., 2018), by treating the decision to be producers in the first stage endogenously.

From a policy perspective, the THM methodology can shed light on the factors that inhibit production and technology adoption, and simultaneously help explain insufficient participation and the low participation intensity commonly observed in agricultural markets. Our paper employs the THM methodology to examine the adoption-participation outcomes within the chilli farming sector in South India. The main contribution of our paper is two-fold. Firstly, our paper integrates adoption, participation, and intensity decisions and outcomes in updated market supply chains transformed through digital technologies, which have not been considered in previous studies. Secondly, our study is the first to characterize the institutional linkages and performance within updated value chains established in the Indian economy. Indian agricultural sector provides an excellent case study to examine the counterfactual question posed by Burke et al. (2015) since a major portion of the population engages in rural agricultural and allied activities. Moreover, India has also experienced rapid modernization and digitization of its supply chain, thanks to the enhancement of global expo-markets through liberalization.

The rest of the paper is organized into five sections. In section two, we describe the institutional background, covering the chilli sector from South India, and the recent digital innovations in farming markets. In section three, we present the THM econometric framework and the estimation strategy. Section four presents the data and discusses the results of the estimation. Section five provides a brief summary and policy conclusions.

## 2. Problem statement

Lack of fair marketing mechanism is one of the major limitations for transacting chillies in Guntur district and also identified as the major constraints to increase production by the farmers (Shaker et al., 2019). According to Financial Express Bureau (2019), chilli farmers in Andhra Pradesh have limited access to e-markets and this prevent them from purchasing quality inputs and hence, in producing both quantity and quality output. This raised the questions of why chilli farmers were not participating in e-markets despite increasing importance for chilli production in Andhra Pradesh and what other factors constrain chilli farmers to participate in the e-market? Though a number of studies have been conducted on determinants and extent e-market participation, they may not be conclusive and apply to the chilli farmers of Andhra Pradesh due the heterogeneity in infrastructure, transaction costs, institutional arrangements and among farmers.



Further, no studies correlating the Adoption Decision (AD) of chillies production technology, e-Market Participation Decision (e-MPD) and e-Market Participation Intensity (e-MPI) have been conducted so far in the chilli sector of Andhra Pradesh despite farmers having challenges in accessing the e-market. On the other side, the pace of growth of Kalgudi e-market in terms of number of commodities dealt with; linkages with farmers, traders, processors; digitization of transactions for both inputs and output, etc., in the recent period is really encouraging and this led to analyze the causal relation between production technology adoption ("Teja" variety of chilli) and e-MPI of chilli farmers. So, the current paper exploits the e-transactions in Kalgudi e-market, which was established in the year 2020, in the Guntur district of Andhra Pradesh, South India. This e-market can be considered as a novel innovation that takes the advantages of Information Technology (IT) to grassroots.

Within the Kalgudi e-market, the iAgriMarC is the agricultural produce marketing platform, which automates the operations of APMCs. Incidentally, iAgriMarC has been designed and operationalized in multiple States in India, to facilitate business interactions between farmers, traders, and processing firms. The iAgriMarC platform restricts malpractices, increases the effectiveness of marketing administration, and handles produce trade across India with minimum customizations. Up to this point, iAgriMarC has overseen, approximately 40B US transactions among 50,000 traders, and over a million farmers have directly or indirectly benefitted through this innovative platform.

Further, the iAgriMarC digital supply chain enables farmers and micro-entrepreneurs to purchase requisite inputs and transact their produce directly to consumers. Farmers have also largely benefited with price discovery, Minimum Support Prices (MSP) enforcement, optimal pricing through e-auctions, transparent purchases and maintenance of farmers' databases to aid future service delivery. Similarly, traders are also benefitted through online services, payments, connections, price discovery, and increased business hours and business areas.

### 3. Institution background

With the advent of digital agriculture solutions such as access to the internet and the popularization of e-commerce services, electronic markets are gradually gaining popularity in India. e-markets and internet platforms can assist in smooth information transmission. One of the goals towards their establishment is to ensure an adequate supply of desired quality inputs at affordable prices, aggregation of outputs from farmers, and digitization of marketing operations and services, to ensure traceability and realization of remunerative prices for the produce transacted.

By and large, e-markets help establish transparency and in removal of trade barriers across geographical boundaries. Indeed, e-market operations correct for information asymmetry within the e-marketing process, by strengthening both backward and forward linkages within the supply chain (Aggarwal et al., 2017; Reindl et al., 2019). e-markets also effectively address major marketing challenges faced by farmers, such as multiple levies (or mandi fees), multiple licenses for trading in Agricultural Produce Market Committees (APMCs), inadequate infrastructure in APMCs, absence of a price discovery mechanism, higher market charges from intermediaries and movement controls. Consequently, e-markets provide an environment, where farmers can freely conduct their transactions and establish greater control over the trade. Their establishment further leads to decongestion of APMC mandies and make the supply chain agile for agricultural commodities.

To sum up, e-services help in creating transparency in sale transactions, price discovery, enhancing traceability, provision for quality testing, and reducing overall business risks. e-markets also successfully shield farmers against unethical marketing practices and simultaneously create more flexible marketing processes (Amarender et al., 2019; Reddy, 2016).

Consequently, the Kalgudi e-market system can be considered as a network interaction platform that actively engages all stakeholders of agriculture and allied sectors. For example, the e-market

platform connects farmers, traders, input dealers, logistics, academia, market facilities, institutional buyers, Farmer-Producer Organizations (FPOs), Non-Government Organizations (NGOs), Government departments, and consumers across the spectrum and generates system-wide positive externalities. The e-platform system thus establishes convergence of all economic agents within an innovative network, with adequate potential to generate value for the entire ecosystem and facilitate further online purchases and sales of requisite inputs and produce.

Our paper examines whether the innovative e-market platform performs to its fullest potential. We uncover this issue by examining the participation rates and intensities of farmers in the chilli-producing sector in South India. Chilli is one of the major crops in India, and is currently cultivated in roughly 0.70 million hectares (Agricultural Statistics at a Glance, 2019). Our study area is located in the State of Andhra Pradesh, which leads the nation in the production of dry chillies, with an annual output of roughly 0.8 million tons. Our primary data is from a district in Andhra Pradesh, called Guntur, which itself constitutes about 50.32% of the total area under chilli in the state, and is considered the Asia's largest chilli market.<sup>1</sup>

The Kalgudi e-market, mentioned earlier, has also established links with the FPOs in major districts of Andhra Pradesh, our study area. Most of the farmer-members of the e-system cultivate and transact "Teja" variety of chilli through the online platform. Further, the e-market works together with related agricultural extension initiatives in place, such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Centre for Good Governance (CGG).

The factors mentioned above, namely the district's amount of chilli cultivation, its national reputation in the chilli market, and the participation rate of its farmers in the e-system, motivate us to select Guntur district for our study area. Guntur district is a natural setting to examine the relationship between technology adoption and e-Market Participation Intensity (e-MPI), given the extensive links between farmer-members and the Kalgudi e-market transactions platform in this region.

Given the sizeable positive externalities from e-services, and a dominant chilli production sector, one would expect an active e-participation within the chilli production units and the related supply chain. On the contrary, paradoxically, there is insufficient take-up of the Kalgudi e-services platform within the different chilli farming units.

The lack of e-participation is particularly noteworthy, given that the traditional market for transactions is often viewed as working unfairly and has been identified as inhibiting production and expansion (Shaker et al., 2019). Lack of access to e-markets is cited as a reason for non-participation, and hence, indirectly affects farmers' adoption and production decisions.

The purpose of this paper is to identify a set of factors that link decisions surrounding production and e-participation. To the best of our knowledge, this is the first study of its kind from India that links production technology ("Teja" variety of chilli) and AD to e-MPD and e-MPI. Our study area provides a natural setting to examine the adoption-participation relationships, given the heterogeneity among farmers with respect to infrastructure facilities, transaction costs, and institutional arrangements within the supply chain.

Our study sheds light on effective policy proposals that can encourage e-market participation, establish better buyer-seller interactions, promote profitable production adoption decisions, and provide pragmatic promotional awareness campaigns to increase the role of digital value chains in developing and emerging economies.

#### 4. Conceptual framework

It is known that enhancing crop productivity through the adoption of improved production technologies presents a credible pathway to economic development of farmers especially through



increased participation in modern market outlets (Paul et al., 2022). This led to the use of a Triple-Hurdle Model to integrate AD of “Teja” variety of chilli, Kalgudi e-MPD and e-MPI. The estimation strategy is from the recent lines of empirical research pioneered by Burke et al. (2015). As Burke et al. (2015) note, for popular and high-value crops like chilli, the initial production decision regarding the adoption of varietal technology is an important additional consideration that can distinguish factors that could induce formerly non-producing farmers to become producing farmers. The proposed framework using a triple-hurdle model (THM) incorporates households’ choice mechanisms in a sequential decision-making framework. THM models are currently adopted in agricultural economics, as in Paul et al. (2022) for Ethiopia, Singbo et al. (2021) for Mali, Ebenezer et al. (2019) and Akrong (2020) for Ghana, Gebremedhin et al. (2017) for Ethiopia, Okoye et al. (2016) for Madagascar and Kondo et al., 2019 for Ghana.

Estimation through the THM procedure is based on incorporating the production decision or AD along with e-MPD and e-MPI decisions sequentially, and the underlying methodology is represented in Figure 1. Following, Burke et al. (2015) THM indicates agents’ choices in three stages, where the adoption decision (AD) of the crop is determined in the first stage. In the second stage, the agents decide on market participation (MPD) either as net buyers or net sellers or autarkic and in the third stage, the intensity of e-market participation (MPI) for net buyers and net sellers is determined. Formal expressions that capture the three stages in the THM setup are as follows:

$$\text{Stage 1: } y_1 = y_1(x_1, \omega)$$

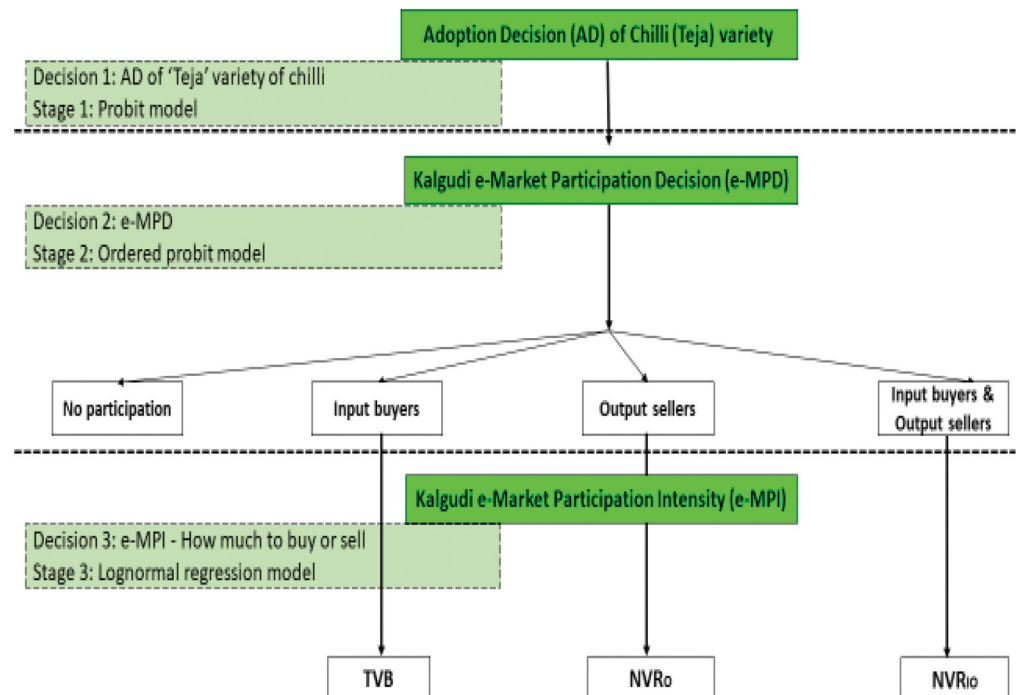
$$\text{Stage 2: } y_2 = y_2(X_i, \delta)$$

$$\text{Stage 3: } I_1 = I_1(X_a, \gamma_1)$$

$$N_1 = N_1(X_b, \gamma_2)$$

$$N_2 = N_2(X_c, \gamma_3)$$

**Figure 1. Illustration of THM.**



where  $y_1$  is a binary indicator that indicates, whether a farmer produces the Teja variety of chilli,  $y_2$ , is an indicator that takes one of four values depending upon whether the farmer is a nonparticipant ( $y_2 = 0$ ), (is an input buyer ( $y_2 = 1$ ), an output seller ( $y_2 = 2$ ) or both seller and buyer from the e-market ( $y_2 = 3$ ),  $x_1$  and  $X_i$  representing the exogenous variables, with parameters  $\omega$  and  $\delta$ . Net values realized if the agent is an input buyer ( $I_1$ ), a net seller ( $N_1$ ), both seller and buyer ( $N_2$ ), are expressed as functions of exogenous variables  $X_a$ ,  $X_b$ , and  $X_c$  with the associated vector of parameters,  $(\gamma_1, \gamma_2, \gamma_3)$ .

*Econometric estimation.* The three stages that encapsulate the THM modeling framework are operationalized using a likelihood function that combines a probit, an ordered-probit, and three lognormal models. Note that in stage 1, the production decision is binary and hence, a probit model is employed towards adoption decision (AD) for the cultivation of “Teja” variety of chillies by the sample farmers.

In stage 2, second, an ordered-probit model is employed to analyse the factors that influence e-MPD (no participation, purchase of inputs only, sale of output only and both purchase of inputs and sale of output).

Finally, in stage 3, three lognormal models are used to analyze the net returns for each agent type. Net returns in the e-market setup are Total Value Bought ( $TVB = I_1$ ) for input buyers, Net Value Realized for sellers, from selling output ( $NVR_O = N_1$ ) and Net Value Realized from both purchasing inputs and selling output ( $NVR_{IO} = N_2$ ). Estimation of the three stages proceeds sequentially.

**Decision-Hurdle 1:** The AD of “Teja” variety of chilli has indeed increased e-MPD in view of fetching higher prices for the farmers in e-market (Verkaart et al., 2019). That is, the AD of farmers has been driven by significantly higher returns to this variety, which made them attractive and helped their widespread adoption (Michler et al., 2019). So, the AD of farmers has been largely supported by available e-market access in the study area (Verkaart et al., 2019). So, the farmer’s decision to produce “Teja” variety of chilli is measured as a dichotomous variable that assumes a value of “1”, if the farmer decides to produce “Teja” variety and “0” otherwise. Let,  $q_1$  represent the level of “Teja” variety of chilli production. Then,

$$y_1 = \begin{cases} 1 & \text{if } q_1 > 0 \\ 0 & \text{if } q_1 = 0 \end{cases}$$

Consequently, a standard probit representation enables stage 1 estimation:

$$\Pr(y_1 = 1 | x_1, \omega) = \Phi(x_1 \omega)$$

$$\Pr(y_1 = 0 | x_1, \omega) = 1 - \Phi(x_1 \omega)$$

where “ $\Phi$ ” is the standard normal cumulative distribution function, The full distribution of  $y_1$  is:

$$f(y_1 | x_1) = [1 - \Phi(x_1 \omega)]^{y_1=0} [\Phi(x_1 \omega)]^{y_1=1}$$

**Decision-Hurdle 2:** It is known that successful e-MPD allows farmers to sell surplus production for income generation, growth and improved livelihoods (Siziba et al., 2011; Ochieng et al., 2019; Ogutu and Qaim, 2019). So, the considerations of e-MPD by the farmers is setup using an ordered-probit model, where the indicator function  $y_2$  is defined as follows:

$$y_2 = 0 \text{ (for non-participants in e-market)}$$

$y_2 = 1$  (for farmers purchasing only inputs from e-market,  $X_i > 0$ )

$y_2 = 2$  (for farmers selling output in e-market, or  $q_1 - q_2 > 0$ )

$y_2 = 3$  (for farmers purchasing input and selling output in e-market, or  $q_1 - X_i - q_2 > 0$ )

where  $X_i$  refers to the amount of inputs purchased, and  $q_2$  is the amount of produce held for household consumption. The ordered-probit model defines the latent variable,  $y_2^*$ :

$$y_2^* = x_2 \delta + \mu_i$$

where the random error term,  $\mu_i$  is assumed normal (Greene, 2003) and  $x_2$  is a vector of explanatory variables explaining e-MPD.

For a  $j^{\text{th}}$  farmer, where normalization is considered, the regressors  $x_2$  do not include an intercept, such that

$$\Pr(\text{Outcome}_j = i) = \Pr(k_{i-1} < x_2 \delta + \mu_i \leq \alpha_i)$$

The coefficients,  $\delta_1, \dots, \delta_k$  are jointly estimated with the cut-points  $\alpha_1, \alpha_2, \dots, \alpha_{k-1}$ ; where “ $k$ ” is the number of possible outcomes estimated and  $\mu_i$  is the error term.

**Decision -Hurdle 3:** For stage 3, for each farmer-type, three log-normal models are employed. Let  $X_i$  represent the quantity of inputs purchased and  $P_i$  the price of inputs paid, by the farmers who only buy input in e-market. Then, the Total Value Bought ( $TVB = I_1$ ) is:

$$TVB = I_1 = \sum_i P_i X_i$$

The Net Value Realized for sellers, from selling output ( $NVR_o = N_1$ ) can be defined as:

$$NVR_o = N_1 = P_y q_1 - P_y q_2 = P_y q_3$$

where  $q_1$  and  $q_2$  represent total quantity of Teja chilli produced and retained for household consumption ( $q_3 = q_1 - q_2$ ) and  $P_y$  is the price of output. Similarly, the Net Value Realized for farmers who buy inputs and sell output ( $NVR_{IO} = N_2$ ) is expressed as:

$$NVR_{IO} = N_2 = P_y (q_1 - q_2) - \sum_j P_j X_j$$

where  $P_j$  and  $X_j$  represent the prices and quantities of inputs respectively purchased by this group of farmers.

Let  $X_a$ ,  $X_b$  and  $X_c$  be the explanatory variables for  $TVB$  ( $I_1$ ),  $NVR_o$  ( $N_1$ ) and  $NVR_{IO}$  ( $N_2$ ). The individual distribution of e-MPI for the different categories of farmers is represented as:

$$TVB : f(I_1 | X_a, \gamma_1) = \varphi[\{\log(I_1) - X_a \gamma_1\} / \sigma_1] / I_1 \sigma_1$$

$$NVR_o : f(N_1 | X_b, \gamma_2) = \varphi[\{\log(N_1) - X_b \gamma_2\} / \sigma_2] / N_1 \sigma_2$$

$$NVR_{IO} : f(N_2 | X_c, \gamma_3) = \varphi[\{\log(N_2) - X_c \gamma_3\} / \sigma_3] / N_2 \sigma_3$$

where,  $\sigma_i$  is the standard deviation of  $I_1$ ,  $N_1$  and  $N_2$  and  $\varphi$  is the standard normal probability density function

Estimation of the THM follows a three-step process, aligned with the three-stage decision process outlined above. In the first stage, a probit model that characterizes the probability of being a Teja-variety producer is estimated. The estimation procedure following MLE, yields  $\lambda_i$ , the value of Inverse Mills Ratio, written as IMRp, which is ratio of the ordinate of a standard normal distribution to the tail area of the distribution (Greene, 2003):

$$\lambda_i = \varphi(p + \alpha X_i) / \Phi(p + \alpha X_i)$$

where  $\phi$  = standard normal density function,  $\Phi$  = standard normal distribution function.

The second-stage estimation follows an ordered-probit framework, which includes IMRp from the first-stage as an independent variable. The results from the ordered-probit model are used to predict the IMR the probability of being a net-buyer ( $IMR_B$ ), a net-seller ( $IMR_S$ ) and both a buyer and a seller ( $IMR_{BS}$ ). The third-stage estimation is achieved by regressing the log of net returns for each farmer-type on a set of exogenous variables, along with the corresponding IMR values.

THM will employ Inverse-Mill Ratios (IMRs) at successive stages to test the hypotheses whether the successive stages of e-market participation by the farmers are correlated or not? If the coefficient of IMRp from the first-stage probit estimates is significant in the ordered-probit regression in Stage 2, it implies that the adoption decisions in Stage 1 and the e-market participation decision in Stage 2 are correlated or *vice versa*. Similarly, if the coefficients of  $IMR_B$ ,  $IMR_S$ , and  $IMR_{BS}$  for TRB,  $NVR_{IO}$  and  $NVR_{IO}$  of the decisions in Stage 3 are found significant, then the formulated hypotheses of not having sequential correlation among the three hurdles or decisions viz., AD, MPD and MPI with reference to TVB,  $NVR_O$  and  $NVR_{IO}$  are rejected. Further, following Y N (2018) and W J (2019), selection between the one-step, the double hurdle and the triple-hurdle models can be tested by the likelihood ratio test statistic (LR), which is based on the principle of maximum likelihood estimation.

The above estimation procedure assumes uncorrelated errors and meets exclusion restrictions, such that not all equations include the same set of explanatory variables. Anderson (2007), Bushway et al. (2007) and Sartori (2003) note that including justifiable exclusion restricts helps alleviate the issue multicollinearity that usually arise, with the incorporation of IMR in the second and third stages.

Further, Greene (2003) notes that inclusion of IMR corrects for the problem of selection bias in the model. The statistical significance of  $\lambda_i$  implies, that there is a significant difference between the farmers, who participated in the e-market and those that did not. The computation of above disparity i.e.,  $\lambda_i$  must be considered when estimating the three e-MPI equations. On the contrary, if the IMR is not statistically significant, it gives the evidence that the null hypothesis should not be rejected i.e., the evidence suggests there is no selection bias. If IMR is statistically insignificant, then it should be omitted from final analysis, and the model can be re-estimated (Leung and Yu, 1996; De Luca & Perotti, 2011).

The use of THM enables the researchers to explore the integration of production technology adoption, e-market activities and participation, effective market linkages between FPOs and e-market and buyer-seller interactions (through converging all possible stakeholders on a common platform) towards sustaining the farmers in chilli cultivation. It further explores the adoption of modern chilli variety do support a market-oriented development pathway and in turn, also highlight the positive impact of commercialization on the adoption of modern production technology. This will certainly ensure successful commercialization of the chilli sub-sector in the future that anchors more of public-private partnerships.

Table 1. Description of the variables in the empirical models

Decisions/ Hurdles		Variable	Variable name	Variable type	Variable measurement
Dependent Variables					
1. Adoption	AD		AD of 'Teja' variety of chilli	Binary	1 if farmer adopts 'Teja' variety of chilli, 0 otherwise
2. Market Participation Decision	MPD		e-MPD by chilli farmer	Binary	0: No participation in the e-market 1: Farmer only purchases inputs only from the e-market 2: Farmer only sells output in the e-market 3: Both purchase of inputs and sale of output in the e-market
3. Market Participation Intensity	MPI		e-MPI by chilli farmers	Continuous	• TVB of inputs from e-market • NVR <sub>0</sub> from the sale of output only from e-market • NVR <sub>10</sub> from the purchase of inputs and sale of output from e-market
Exogenous Variables					
AGE			Age of the farmer	Continuous	Age in years
EDU			Education of the sample farmer	Continuous	Number of years of education
FEXP			Farming Experience	Continuous	Number of years engaged in crop production
LHS			Size of land holding	Continuous	Acres of land under chilli cultivation
PS			Price of chilli seed in e-market	Continuous	Rupees per kg
TV			Training Visits by e-market personnel	Continuous	Number of training visits to farmer's field
EXTN			Access to extension network	Binary	1 if farmer has access, 0 otherwise
ATHYV			Access to high yielding varieties in e-market	Binary	1 if farmer has access, 0 otherwise
FPO <sub>M</sub>			Membership in FPO	Binary	1 if farmer has FPO membership, 0 otherwise
ATMI			Access to market information from e-market	Binary	1 if farmer has access, 0 otherwise
PDI			Prompt disposal of inputs from e-market	Binary	1 if farmer receives inputs promptly, 0 otherwise
PPSP			Prompt payment of sales proceeds to farmer from e-market	Binary	1 if farmer receives prompt payment from e-market transactions, 0 otherwise

**Table 2. Descriptive statistics of sample farmers according to market participation status**

Variables	No e-market participation (a)	e-market participation				Pooled	Test of difference		
		Input buyers only (b)	Sale of output only (c)	Both purchase of inputs and sale of output (d)	(b-a)		(c-a)	(d-a)	
AGE	50.23	47.28	53.61	49.77	48.51	1.61	1.17	1.69	
EDU	5.61	10.23	8.17	9.29	7.06	0.73**	0.78**	0.89**	
FEXP	20.27	18.26	22.16	20.61	22.37	0.91	0.62	0.57	
LHS	1.21	4.96	3.19	3.86	2.11	3.81**	2.06*	2.73**	
PS	69.18	75.63	71.28	77.49	72.18	0.19	0.23	0.14	
TV	4.07	12.33	15.19	14.67	10.13	0.56**	0.71**	0.62**	
EXTN	0.29	0.77	0.71	0.62	0.64	0.69**	0.82**	0.74**	
ATHYV	0.41	0.84	0.71	0.74	0.61	0.96**	0.64**	0.79**	
FPO <sub>M</sub>	0.21	0.79	0.88	0.81	0.70	0.82**	0.86**	0.84**	
ATMI	0.34	0.69	0.82	0.78	0.72	0.82**	1.91**	0.79**	
PDI	-	0.79	-	0.84	0.82	-	-	-	
PPSP	-	-	0.92	0.83	0.88	-	-	-	
Outcome variables from e-market									
TVB (Rs)	-	10311.59	-	-	-	-	-	-	
NVR <sub>O</sub> (Rs)	-	-	162376.61	-	-	-	-	-	
NVR <sub>IO</sub> (Rs)	-	-	-	171956.34	-	-	-	-	
	73	103	231	93	-	-	-	-	

Note: \*\* & \* - Significant at 1 and 5 per cent levels, respectively.



## 5. Data sources and variables description

The data is from four FPOs from two different districts within the state of Andhra Pradesh. The first two FPOs are from Guntur district, while the second two FPOs are from Krishna District.<sup>2</sup> The districts have been selected based on the frequency of the linkages between farmers and the Kalgudi e-market. The data has been collected both from farmer-members of selected four FPOs and non-members cultivating chilli ( $n = 500$ ) selected randomly from the Krishna zone of Andhra Pradesh. A survey has also been conducted in 2021, using a pre-tested schedule about farmers' socio-economic characteristics, chilli improved varieties' AD, e-MPD and e-MPI (Table 1).

### 5.1. Results and discussion

Table 2 presents the mean values of the variables by farmer types: non-participants, input buyers, output sellers, and those who buy inputs and sell output. Table 3 indicates that farmers who participate in e-market differ considerably from the farmers not participating in e-market in terms of all the variables, except AGE, FEXP and PS, based on tests of difference between paired sets.

Input buyers, output sellers and both input buyers and output sellers represent 20.6 per cent, 46.2 per cent and 18.6 per cent respectively of total sample selected for the study. Around 86 per cent of sample farmers cultivate the "Teja" variety of chilli. The selected respondents are on an average are 49 years old with relatively low education levels (7 years).

From the perspective of our study, it is important to note that a majority of farmers in the study area enjoy FPO<sub>M</sub> (70%) and consequently, have good contacts with EXTN services (64%), ATHYV (74%), ATMI (72%) and receive sufficient training (10/year) on the modern production and marketing techniques of chillies and they opined PDI (82%) and PPSP (88%) from e-market. However, the per capita land holding of the sample farmer is only 2.11 hectares.

Table 3 presents the results of THM estimation. The first-stage decision regarding the adoption of the Teja variety is estimated using a probit model, and the estimates along with the standard errors are in the first two columns of Table 3.

The second-stage estimation examines e-market participation (e-MPD), and the resultant-ordered probit estimates are presented under the corresponding column. Note that the Inverse-Mills Ratio (IMRp) from the first stage probit regression is included in the second-stage analysis.

In the third stage, three lognormal models for e-market participation intensity (e-MPI) are estimated, for the three farmer-types, with respect to TVB, NVR<sub>O</sub>, and NVR<sub>IO</sub>, after controlling for endogeneity (Angrist, 2001) and self-selection through the inclusion of the corresponding Inverse-Mills Ratios (IMR<sub>B</sub>, IMR<sub>S</sub>, IMR<sub>BS</sub>).

THM estimation also satisfies the exclusion restrictions by allowing Years of Farming Experience (FEXP) and Land Holding Size (LHS) to influence adoption decision (AD) in the first stage, as these variables are most likely to influence AD surrounding the production of the Teja variety, and results show that both FEXP and LHS are statistically significant and are directly related to the likelihood of adoption of the advanced Teja variety. Further, the two variables are insignificant in the Stage 2 regression and are excluded in the second stage.<sup>3</sup> Likewise, AGE and AGE<sup>2</sup> are included in the ordered-probit model in Stage 2, but excluded from Stage 3 estimation. Both AGE and AGE<sup>2</sup> are statistically significant and positively influence e-market participation, but are not significant in the log-normal regressions.

PS has exerted negative and significant influence on all the three decisions. That is, an increase in PS in the e-market will reduce the probability of adoption of "Teja" variety among chilli farmers and consequently, their e-MPD will get affected due to low-scale production. For the farmers, who participate in e-market with regard to purchase of inputs, an increase in PS will reduce the TVB accordingly and farmers also realize lower NVR<sub>O</sub> (due to low-scale production). Consequently, the

**Table 3. THM estimates for e-MPI (bivariate lognormal)**

Variables	Decision 1			Decision 2			Decision 3 (e-MPI)					
	AD			e-MPD			logTVB			logNVR <sub>o</sub>		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
AGE	0.0077	0.0116		0.0392*	0.0189		-	-		-	-	
AGE <sup>2</sup>	0.0004	0.0003		0.0156**	0.0051		-	-		-	-	
EDU	0.0066	0.0136		0.2309**	0.0770		0.3052*	0.1502		0.3716**	0.1192	
FEEXP	0.0475**	0.0139		-	-		-	-		-	-	
LHS	0.0297*	0.0148		-	-		-	-		-	-	
EXTN	0.4004**	0.1407		3.4447**	1.3437		3.3407*	1.5946		0.5514*	0.2546	
ATHW	0.3486**	0.1172		1.9901**	0.3933		1.7766*	0.8145		3.1267**	0.9258	
PS	-0.0215*	0.0104		-0.2033**	0.0599		-0.0293**	0.0097		-	-	
ATMI	0.5240*	0.2507		0.6406**	0.2466		0.4216*	0.1918		0.4010**	0.1462	
FPO <sub>m</sub>	0.6554**	0.2491		0.9930**	0.3212		1.4597**	0.4216		0.5032*	0.2474	
TV	-	-		0.4308**	0.1206		0.2422**	0.0548		0.0619**	0.0100	
PDI	-	-		-	-		0.3520**	0.1070		-	-	
PPSP	-	-		-	-		-	-		0.0137**	0.0025	
IMR <sub>p</sub>	-	-		-4.6146**	1.2143		-7.6857**	2.4938		-7.2346*	3.2979	
IMR <sub>b</sub>	-	-		-	-		-1.6136**	0.2480		-	-	
IMR <sub>s</sub>	-	-		-	-		-	-		-1.0834**	0.2965	
IMR <sub>85</sub>	-	-		-	-		-	-		-	-	
CONS	0.4920	0.0754		-	-		15.2487	6.3862		13.3857	5.9838	
LR ( $\chi^2$ )	LR $\chi^2$ (10) = 21.62**			LR $\chi^2$ (13) = 28.15**			-			-		
R <sup>2</sup>	0.21			0.33			0.81**			0.89**		
n	500			427			103			231		

**Note:** \*\* & \* - Significant at 1 and 5 percent levels, respectively.

farmers realize lower  $NVR_{IO}$ , on account of narrowed price differences between purchase of seed and sale of output in e-market and due to low-scale production.

The coefficient of IMRp from the first-stage probit estimates is significant in the ordered-probit regression in Stage 2. This implies that the adoption decisions in Stage 1 and the e-market participation decision in Stage 2 are correlated. Further, this result implies that that decisions surrounding adoption of “Teja” variety precedes decisions surrounding e-market participation. Hence, the AD of “Teja” variety influences farmers’ e-MPD and realize remunerative prices. This result is further reinforced by noting that the coefficient of IMRp from the first stage probit is significant in all the three log-normal regressions in Stage 3, representing buyers, sellers and both buyers and sellers. Hence, once the decision to participate in the e-market is made, the adoption of Teja variety influences the net remuneration for all farmer types. This result is also in contrast with those found by Singbo et al. (2021) and Burke et al. (2015), as we considered three categories of farmers in Stage 3 (i.e., input buyers (TVB), output sellers ( $NVR_O$ ) and both input buyers and output sellers ( $NVR_{IO}$ )). Our results for the Indian chilli sector, is therefore important, and lend insight to strategies that policymakers can establish, to improve supply chain management.

Similarly, the coefficients of  $IMR_B$ ,  $IMR_S$ , and  $IMR_{BS}$  for TRB,  $NVR_O$  and  $NVR_{IO}$  of the decisions in Stage 3 are also significant indicating that the three decisions viz., AD, MPD and MPI with reference to TVB,  $NVR_O$  and  $NVR_{IO}$  are strongly correlated. Hence, the decision to adopt “Teja” variety by the farmers influences their e-MPD and consequently, e-MPI with respect to TVB,  $NVR_O$  and  $NVR_{IO}$ . Thus, these three decisions viz., AD, e-MPD and e-MPI for  $NVR_O$  and  $NVR_{IO}$  are sequential.

The THM estimation process allows for cross interpretation of factors surrounding the three decisions in the chilli farming sector, AD, e-MPD and e-MPI. For instance, the coefficient of EDU is positive and significant in e-MPD and also across the three log-normal equations. This implies that the likelihood of e-market participation increases with farmers’ education level (EDU). Higher EDU levels are also associated with higher e-participation intensities across buyers and sellers. This finding is consistent with Enete and Igbokwe (2009), who note that higher education enables farmers to understand prevailing market dynamics and the advantages of adopting modern techniques and producing higher yield varieties.

Results from Table 3 indicate that complementary services and support systems within the chilli farming sector are important drivers of all decisions surrounding adoption, e-participation and intensity. Farmer-extension services measured via Access to Extension Network (EXTN), Access to High-Yielding Varieties in the e-market (ATHYV), membership in FPO ( $FPO_M$ ), and access to information in the e-market (ATMI) are all positive and significant across all equations pertaining to the three stages. Previous studies by Alene et al. (2008); Key et al. (2000) had similar insights.

The importance of robust extension services and support systems in improving farmers’ economic returns, market participation and production is in keeping with the findings in Barrett (2008), Okoye et al. (2010), Bardhana et al. (2012), Bezu et al. (2014), Shiferaw et al. (2014), Bezabih et al. (2015), Benfica et al. (2017), Tarekegn et al. (2017), Nyein Kyaw et al. (2018), Cornel and Zhang (2021) and Akter et al. (2021). The presence of robust extension services and the resultant positive feedback on adoption is evidenced in the chilli market, with increased likelihood of farmers’ adoption of the “Teja” variety, within the Kalgudi e-platforms. Bardhana et al. (2012) notes similar results for milk producers, with access to milk co-operatives and marketing societies in the Uttarakhand District in Northern India.

Likewise, access to improved chilli variety (ATHYV) increases the probability of both e-MPD and e-MPI of farmers in transacting the produce through e-market. The coefficient of ATHYV across all equations are positive and significant. The likelihood of selling “Teja” variety of chilli through e-market (e-MPD) increases by 1.99 percentage points, on an average, if the access to this variety is improves by one percentage point. Further, the importance of the “Teja” variety as the main

source of farmers' income is also area as evidenced by increases in  $NVR_o$  by 3.13 per cent and  $NVR_{IO}$  by 4.89 per cent from e-market. This result highlights the causal relation between improved varietal technology adoption and e-MPI.

The findings from THM support Barrett's (2008) theoretical proposition that the promotion of advanced agricultural technology can act as a catalyst for the market participation of smallholder farmers. Further, from a policy perspective, these findings are highly promising as they suggest that e-services and internet platforms enhance farmers' market access and generate positive spillover effects for realizing quality agriculture (Akter et al., 2021). Our results are consistent with Bezu et al. (2014) for Malawi, Shiferaw et al. (2014) for Ethiopia and Benfica et al. (2017) all of which indicate that increased productivity of crops is positively associated with market participation.<sup>4</sup>,

Similarly, our results also indicate that access to information from the e-market (ATMI) is an important driver of farmers' production and adoption of new practices in marketing of chillies. In other words, similar to Bezabih et al. (2015), e-market facilitates adoption of modern agricultural inputs, and enables the farmers to select those markets which offer the best returns.

Farmer's membership in FPO also ensure profitable prices for their produce because of improved bargaining power and strengthened backward and forward linkages, and this result is also reinforced by the positive and significant influence of Training Visits of e-personnel (TV) across e-MPD and the log-normal equations. Taken together, these results indicate that the Kalgudi e-market establishes linkages and networks with the local FPOs (see Appendix 1) in the Krishna zone, which facilitates farmers through skill-oriented training programs, exposure visits to e-market, and technical assistance through field visits. The awareness through the e-process creates a trust in the e-market operations while making both production and marketing decisions.

Consequently, the strong linkage between e-market and FPOs strongly influences AD, e-MPD, and e-MPI of chilli farmers. These findings further highlight that interventions that facilitate e-MPI and e-MPD would enhance improved chilli (Teja) variety AD. Prompt delivery of inputs and a seamless supply chain also help those farmers who are buyers, given the positive and significant influence of PDI on the log TVB and log  $NVR_{IO}$  equations in Table 4. Likewise, Prompt Payment to the farmer from the e-markets (PPSP) drives sellers to enhance their participation intensities, given the positive and significant influence of PPSP in the log  $NVR_o$  equation.

In summary, the THM results yield important insights into farmers' production and e-market participation decisions in chilli farming, which is an important sector in Indian agriculture. THM estimation processes distinguish factors determining the production from factors affecting e-participation decisions, and identifies those determinants that influence both decisions.

## 5.2. Robustness testing

Finally, we check if the THM estimation employed for our data is robust, by comparing the results to a Double-Hurdle Model (DHM). First, a single-step simultaneous seemingly unrelated regression (SUR) is performed for the variables in the third-stage decision, to test if the three decisions are undertaken simultaneously, without any influence of participation or production strategies, following Bellemare and Barrett (2006) and Burke et al. (2015).

The three log-normal SUR equation estimates are in Table 4. Table 5 incorporates the DHM estimation procedure, wherein the first stage presents the results of an ordered probit model to obtain the determinants of e-MPD. The three log-normal equations for TVB,  $NVR_o$  and  $NVR_{IO}$  are estimated in the second-stage after incorporating IMRp to control for self-selection and endogeneity. The log-likelihood value is significant, implying that the SUR system is biased and cannot sufficiently explain e-MPI, and that intensity of e-market transactions must take participation decisions into account, which is consistent with the results obtained by Barrett (2008) and

Y N (2018). Finally, results from Table 3 corresponding to decisions in stages 1 and 2 indicate the significance of LR values, implying that THM is a preferred estimation procedure for our data to understand production and e-participation outcomes from the chilli farming sector in South India.

## 6. Summary and conclusions

Chilli (dry) being a promising commercial crop to achieve the transition of farmers towards modern market orientation and profitability, this study analyzed the AD of farmers with respect to “Teja” variety, participation decisions in e-market and consequent higher returns, which in turn made them attractive and widespread adoption of this variety in the study area (Michler et al., 2019; Verkaart et al., 2019). Several conclusions could be drawn from the above analysis. By integrating decisions surround adoption of high yielding variety of variety of chilli, e-market participation, and e-intensity of participation, this paper makes inferences about the study population, where some parts of the population are non-producers of selected chilli variety.

The findings show that farmer extension services and a reliable supply chain and payment systems are major influential factors that contribute for causal relation between AD (“Teja” variety) and e-MPI. The model estimates further indicate that for the farmers involved in e-market either as buyers of inputs or sellers of produce, respond positively to adoption, given adequate incentives to e-market participation and support systems in the form of FPOs.

The above findings that indicate that relate AD and e-MPI have important policy implications concerning actions that promote extension efforts and e-market access to chilli farmers. Accordingly, emphasis should be in strengthening FPO membership, and in promoting effective implementation of the Farmer Field Schools programme to assist farmers produce more market-able surplus, and encourage the take-up of the market innovations by the non-producers.

**Table 4. One-step method estimates for e-MPI (bivariate lognormal) by the farmers cultivating “Teja” variety of chilli**

Variables	logTVB		logNVR <sub>o</sub>		logNVR <sub>io</sub>	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
AGE	−0.0022	0.0025	−0.0014	0.0024	−0.0007	0.0030
EDU	0.0029	0.0027	0.0233	0.0125	0.0106**	0.0042
EDU <sup>2</sup>	0.0003	0.0001	0.0005	0.0004	0.0030	0.0016
FEXP	−0.0002	0.0030	0.0008	0.0027	0.0028	0.0037
LHS	0.0220**	0.0031	0.0201**	0.0028	0.2039**	0.0147
EXTN	0.0140	0.0433	0.2221**	0.0499	0.2181**	0.0667
ATHYV	0.0457**	0.0165	0.1217**	0.0439	0.2324**	0.0784
PS	−0.0052*	0.0024	−0.0167	0.0114	−0.0011	0.0034
ATMI	0.0115**	0.0051	0.1623**	0.0588	0.1246*	0.0611
FPO <sub>M</sub>	0.0294	0.0494	0.3209**	0.0510	0.3791**	0.0632
TV	0.0213**	0.0075	0.3045**	0.0175	0.2196**	0.0520
PDI	0.2248**	0.0480	–	–	0.2328**	0.0705
PPSP	–	–	0.3072**	0.0540	0.2077**	0.0691
CONS	3.7259	0.2236	4.8897	0.2180	4.6110	0.4041
Goodness of fit						
R <sup>2</sup>	0.61		0.72		0.66	
n	103		231		93	

Note: \*\* & \* - Significant at 1 and 5 per cent levels, respectively.

**Table 5. DHM estimates for e-MPI (bivariate lognormal)**

Variables	Decision 1		Decision 2 (MPI)					
	MPD		logTVB		logNVR <sub>0</sub>		logNVR <sub>10</sub>	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
AGE	0.0043	0.0100	−0.0020	0.0023	−0.0019	0.0025	−0.0007	0.0030
EDU	0.0460**	0.0114	−0.0031	0.0027	0.0040	0.0026	0.1102	0.3143
EDU <sup>2</sup>	0.0053**	0.0017	0.0001	0.0012	0.0000	0.0000	0.0000	0.0000
FEXP	0.0166	0.0119	–	–	–	–	–	–
LHS	0.0104	0.0126	–	–	–	–	–	–
EXTN	0.4156*	0.2071	0.1492*	0.0682	−0.0108	0.0645	0.0076	0.0870
ATHYV	0.4491*	0.2203	0.1569*	0.0753	–	–	0.0493	0.1181
PS	−0.0319**	0.0089	−0.0072**	0.0022	–	–	−0.0007	0.0040
ATMI	0.5893	0.4190	0.1334**	0.0511	0.2291**	0.0646	0.1351*	0.0639
FPO <sub>M</sub>	0.6395**	0.2205	−0.1411	0.0807	0.3126**	0.0683	0.1860**	0.0737
TV	–	–	0.0311*	0.0150	0.1076**	0.0132	0.0163	0.0209
PDI	–	–	0.0236	0.0523	–	–	−0.0273	0.0775
PPSP	–	–	–	–	0.2287**	0.0589	0.2215**	0.0775
IMR <sub>1</sub>	–	–	−0.3622**	0.1316	−0.4274**	0.1533	−0.5470	0.3210
CONS	–	–	3.7520	0.4078	4.7554	0.4408	4.7104	0.6565
Goodness of fit								
LR ( $\chi^2$ )	−41.22**		–		–		–	
Pseudo R <sup>2</sup> / R <sup>2</sup>	0.13		0.63		0.69		0.71	
n	427		103		231		93	

Note: \*\* & \* - Significant at 1 and 5 per cent levels, respectively.

In this study, we hypothesised that commercialisation of chilli (dry) farmers depends not only on production technology (“Teja” variety), but also on the availability of improved marketing technology often designed to increase profitability and productivity. In this context, THM is employed and as a robustness check, we tested the standard DHM against the THM and show that the TH model is preferred. Even our findings further revealed that looking beyond a two-staged MP decision of households add relevant insights into the farmers’ adoption of production technology and e-market decision-making process.

This study also emphasizes about adoption of modern variety of chilli (dry) do support a market-oriented development pathway. In line with earlier studies (Michler et al., 2019; Verkaart et al., 2019), this study highlighted that easy access to modern markets will further scale the improved varieties adopted by large number of farmers. As the AD and e-MPI decisions of farmers are sequential, both local research institutes and policy-makers should formulate a comprehensive design to produce and promote sustainable access to improved varieties of chillies, strengthen farmers’ integration with the e-market and agricultural value chain.

Until recently, the focus of most agricultural intervention programs in India has traditionally been on the development and release of improved crop varieties without emphasis on market access. Our results argue that access to the e-market technology and robust linkages as primary and crucial qualifications, which enable farmers to choose quality output production and distribution and allow them to sell surplus produce. Relatedly, similar sentiments have been shared by participants in an informal survey conducted with a sample group of e-participants, who are members in chilli FPOs, and have received TVs from the personnel of Kalgudi e-market.



It is clear that even though investment in the provision of public goods is essential, it may not be sufficient to enable all chilli farmers to ensure e-market linkages. Consequently, one option is to mobilize existing services such as, the Agriculture Infrastructure Fund facility from the Government of India to effectively invest in viable projects relating to post-harvest management infrastructure and community farming (FPOs) assets to promote quality production, improve e-market access and to increase value realization for the farmers. The first-best solution in this context is through improving physical infrastructure to support e-market connectivity. Further, the sequential causal relation between AD and e-MPI of chilli farmers established from this study serves as a sustainable pathway towards poverty alleviation in the long run.

The findings from this study highlight important implications for future research. Though the analysis may be location-specific, the applied investigation mechanism can be further explored to assess the impact of a good number of modern agricultural (production and marketing) technologies. This study highlighted that poor commercialization of farmers is not only from lack of market access, but may also from production-technology constraints. Further, unless the farmers are well connected to modern markets, the theorised improvements in welfare outcomes based on the adoption of improved production technologies may not hold good.

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#### Notes

1. Recently, other states such as Madhya Pradesh have also become an important supply centres of chillies to Guntur, and Lakshmi (2014) examines the influence of

production trends in Madhya Pradesh on Guntur chilli market.

2. The first two FPOs from Guntur district are Agriculture Related Producers Mutually Aided Cooperative Federation Ltd (from Macherla) and Vyavasaya Mariyu Anubanda Raitu Utpatti Darula Sangam (from Pedanandipadu). The second two FPOs from Krishna district are Utpathidala Paraspura Sahayaka Sangam (from Chandralapadu) and Vetsavai FPO (from Vetsavai). See Appendix 1 for an exhaustive list of FPOs in the Kalgudi e-market.
3. Since all farmers in collected sample data do not adopt "Teja" chilli variety, a probit model is preferred over a tobit model. It is standard to impose at least one justifiable exclusion restriction when estimating the second stage (JM, 2020).
4. Bezu et al. (2014) show that a one percentage point increase in the area planted under modern varieties increases farmers' income by 0.48 percentage points. For Shiferaw et al. (2014) a one percentage point increase in area under improved wheat variety in Ethiopia leads to a marketed surplus of 4.5 kg of wheat.

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### Appendix 1: FPOs-Kalgudi: e-market linkages in Krishna zone of Andhra Pradesh

Mandal	District	Name of FPO	Number of Farmers
Macherla	Guntur	Agriculture Related Producers Mutually Aided Cooperative Federation Ltd	3143
Durgi	Guntur	Vyavasaya Mariyu Anubanda Raitu Utpatti Darula Sangam	2453
Pedanandipadu	Guntur	Vyavasaya Mariyu Anubanda Raitu Utpatti Darula Sangam	2031
Veldurthy	Guntur	Agri Related Ppsss Ltd	2002
Bollapalli	Guntur	Vyavasaya Mariyu Anubanda Raitu Utpatti Darula Sangam	1975
Amaravathi	Guntur	Agri & Allied Producers Cooperative Society	1885
Chandarlapadu	Krishna	Utpathidala Paraspasa Sahayaka Sangam	2650
Vetsavai	Krishna	Vetsavai Mandal FPO	1832
Dornala	Prakasam	Vyavasaya Mariyu Anubanda Utpatti Darula Sangam	2245
Peddakadabur	Kurnool	Agri And Allied Producers Macs Ltd.	1807

Source: Officials from Kalgudi e-market.