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Increasing smallholder farmers' market participation through technology adoption in rural Timor-Leste

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Abstract

This study examines the role of high-yielding maize varieties as one of the key drivers of smallholder farmers' market participation in a highly subsistence rural economy. The analysis is based on the End-of-Program Survey data collected by the Seeds of Life program in 2016 covering 700 households in rural Timor-Leste. The results reveal significant positive impacts of technology adoption on farmers' market participation. Households where women are relatively more active in agriculture than men are more likely to engage in agricultural commerce. The results also show a positive impact of technology adoption on maize productivity. These findings present the first empirical evidence of the causal link between technology adoption and market participation choices.

KEYWORDS

high-yielding varieties, instrumental variable, market participation, Seeds of Life, Timor-Leste

1 | INTRODUCTION

The development and dissemination of high-yielding crop varieties are at the centre of national and international efforts to reduce poverty and hunger in developing countries. The overarching objective of these efforts is to improve food and nutritional security and the economic well-being of smallholder farmers by enhancing their farm productivity. Market participation plays a vital role in this dynamic (Barrett, 2008; Koppmair et al., 2017). Productivity gains achieved from the adoption of high-yielding varieties (HYVs) not only increase household food supply but also lead to surplus that can be traded to generate cash income. Cash income generated through market participation increases farmers' access to diverse and nutritious food (Barrett, 2008; Sibhatu & Qaim, 2018), and improves access to non-food commodities such as education and health (Mmbando et al., 2015).

While the impact of agricultural technology adoption on household economic well-being and food security is thoroughly evaluated (see, for example, Bezu et al., 2014; Kassie et al., 2011, 2014; Shiferaw et al., 2014), the impacts of HYV adoption on smallholder farmers' market participation are poorly understood. Previous research in Africa has shown that market participation improves smallholder farmers' economic welfare and food security (Koppmair et al., 2017; Mmbando et al., 2015; Montalbano et al., 2018). However, these studies do not explore the role of technology adoption as a driver of market participation.

Household production technology choices are inextricably linked to their market participation choices (Barrett, 2008). This is because households that use highly productive modern technologies are more likely to produce marketable surplus than those who use traditional production technologies (Barrett, 2008). Promotion of advanced agricultural technology, therefore, has the potential to act as a catalyst for broader-based market participation (Barrett, 2008).

In this study, we test these theories by examining the causal effect of maize HYV adoption on smallholder farmers' market participation in rural[1] Timor-Leste. Our study offers three contributions to the literature. First, to the best of our knowledge, this is the first study that investigates a causal link between HYV adoption and smallholder farmers' market participation in the context of a nationwide agricultural intervention program. Second, we examine the causal mechanisms through which adoption of HYVs translate into higher market participation for the adopters—that is, through higher crop productivity. Our final contribution is the geographical scope of our study. Most impact assessment studies pertaining to agricultural interventions were conducted in Africa. Moreover, Timor-Leste is a new country where the agricultural extension system, knowledge and skills, and infrastructure are at an infant stage. The effectiveness of a large-scale agricultural intervention program in a poor country which is in the early stages of development is of considerable interest and relevance globally.

Our analysis shows that the adoption of maize HYVs increases farmers' market participation across a number of market participation outcomes. Further, we observe a significant positive impact of technology adoption on maize productivity supporting the hypotheses that farmers who produce more maize per hectare are more likely to participate in the market than those who produce relatively less maize per hectare.

[1]Urban households mostly engage in small-scale agriculture. The 2015 census found that the HYV uptake in Dili—where 88% of the district's population lives in urban areas—was very small at 4% (General Directorate of Statistics, 2018).

The next section presents a brief background of the case study and policy context followed by a description of the survey and the key variables in Section 3. Section 4 presents descriptive statistics. Section 5 presents the empirical strategy followed by the results in Section 6. Section 7 discusses the results and presents concluding remarks.

2 | BACKGROUND

2.1 | Agriculture and food security in Timor-Leste

Timor-Leste is one of the poorest and most food insecure countries in the world. In the 2020 Global Hunger Index, Timor-Leste scores 37.6, making it the second lowest ranked country globally, and one of five countries where more than 45% of children under the age of five suffer from stunting (von Grebmer et al., 2020). Approximately 80% of its labour force relies exclusively on non-mechanised, low input/output subsistence farming (Nesbitt et al., 2016). Farming systems are household-centric with each fit adult household member playing a role in farm operations (Akter et al., 2016). The most commonly grown staples are maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* (L.) Lamb.), and rice (*Oryza sativa* L.). Maize is the most widely grown staple crop cultivated by 96% of the rural households (General Directorate of Statistics, 2018). The high cost of production, low soil fertility, low use of fertiliser, high input price, lack of mechanisation, labour shortage and lack of access to extension services are some of the leading causes of low productivity and insufficient food supply in Timor-Leste (Akter et al., 2020; Nesbitt et al., 2016). For example, maize had an average yield of 1.4 tonnes per hectare in Timor-Leste compared to the overall mean of 4.1 tonnes per hectare for Southeast Asia in 2013.[2]

Farmers' market participation in Timor-Leste is very low primarily due to low production (Inder et al., 2014). Most farmers do not produce sufficient food to support household consumption for the whole year (Market Development Facility [MDF], 2013). Additionally, rural agricultural markets are poorly developed. Timor-Leste is characterised by underdeveloped road infrastructure, lack of transportation and absence of commodity price information (Lundahl & Sjöholm, 2013). The major obstacles to connecting smallholder farmers to the broader market supply chain are high procurement costs due to bad roads and infrastructure, high transaction costs due to small-scale production, and poor quality produce (MDF, 2013).

2.2 | Seeds of Life program

The government of Timor-Leste has intensified investment to increase farmers' access to HYVs. A key agricultural intervention undertaken to achieve this objective was the Seeds of Life (SoL) program, the third phase of which ran from 2001 to 2016.[3] The program aimed to increase the productivity of the major food crops in Timor-Leste by selecting and distributing HYVs. The Ministry of Agriculture and Fisheries (MAF) of Timor-Leste, under the SoL program, released

[2] Food and Agriculture Organization at http://www.fao.org/faostat/en/. For a more in-depth discussion on agriculture in Timor-Leste, see Lundahl and Sjöholm (2019, pp. 199–263). For a discussion on food security in Timor-Leste, see World Food Programme (2019).

[3] Seeds of Life was a program within the Timor-Leste Ministry of Agriculture and Fisheries and was funded jointly by the Governments of Timor-Leste and Australia.

14 HYVs of maize, rice, peanut, sweet potato and cassava. Of all the HYVs released, maize varieties were the most widely distributed and the most highly adopted (Seeds of Life, 2016). The two maize HYVs with the highest uptake were: *Sele* (a yellow maize variety sourced from CIMMYT in India), with yield advantages over local varieties of 50% at research stations and 41% in on-farm demonstration trials; and *Noi Mutin* (a white maize variety sourced from Central Mindanao University in the Philippines), with a yield advantage of 43% over local varieties in on-farm demonstration trials (Seeds of Life, 2014).

The program was implemented in three phases. Phase 1 (SoL1: 2001–2004) focused on the introduction and testing of new varieties on research stations. Phase 2 (SoL2: 2005–2011) built on this with a focus on the identification of HYVs with farmers through small-scale, participatory on-farm testing. Phase 3 (SoL3: 2011–2016) expanded the scope by establishing a national seed system across the country using a community-centric seed multiplication and dissemination model to ensure wide availability and diffusion of the high-yielding planting materials.

The focus of our study is SoL3 (February 2011 to June 2016) during which certified and foundation seed was made available to community seed groups. The seed groups received training from MAF extensionists (Community Seed Production Officers) on seed production and storage. Two types of seed groups were formed by the MAF extensionists under SoL3: (1) community seed producer groups; and (2) commercial seed producer groups. All seed groups started off as community seed groups with no commercial objectives. The community seed groups produced seed for themselves and distributed seed to relatives, friends and neighbours. When some of the community seed groups performed well in terms of growing good quality community seed, they were upgraded to commercial seed producer groups.

The community seed production in SoL3 was implemented in four phases (Appendix S1). The first phase (2011–2012) covered ten villages from the seven municipalities (districts) where SoL2 had operated. The following year (2012–2013), five additional villages from each of the seven municipalities were brought under coverage along with 30 villages from four adjacent municipalities. In 2013–2014, 185 of the 442 villages from all municipalities were brought under SoL3 coverage, followed by another 44 villages in 2014–2015. The remaining villages were not covered because they were either categorised as ‘urban’ or they had no assigned MAF extensionist. The number of seed groups (community and commercial) established in each village varied considerably. The preferences and attitude of the extensionists responsible for the expansion in each village was a key determinant of the variation. Some of these officers opted to establish fewer groups, so that they could give more attention to help them to become successful; other officers preferred to establish many groups, perhaps with the belief that success in seed production was difficult to predict, and more groups could give a better overall result. Additionally, duration of program exposure was an important determinant of the variation in seed group numbers. The longer a village was exposed to the program, the higher the likelihood of the formation of a community seed group.

3 | DATA COLLECTION AND VARIABLE DESCRIPTION

3.1 | Data collection

We use the End-of-Program Survey (EoPS) data collected by the SoL project team during February and March 2016 (Seeds of Life, 2016). A sample of 700 households was interviewed across 60 villages (locally called *sucos*) selected randomly from the 13 municipalities of the

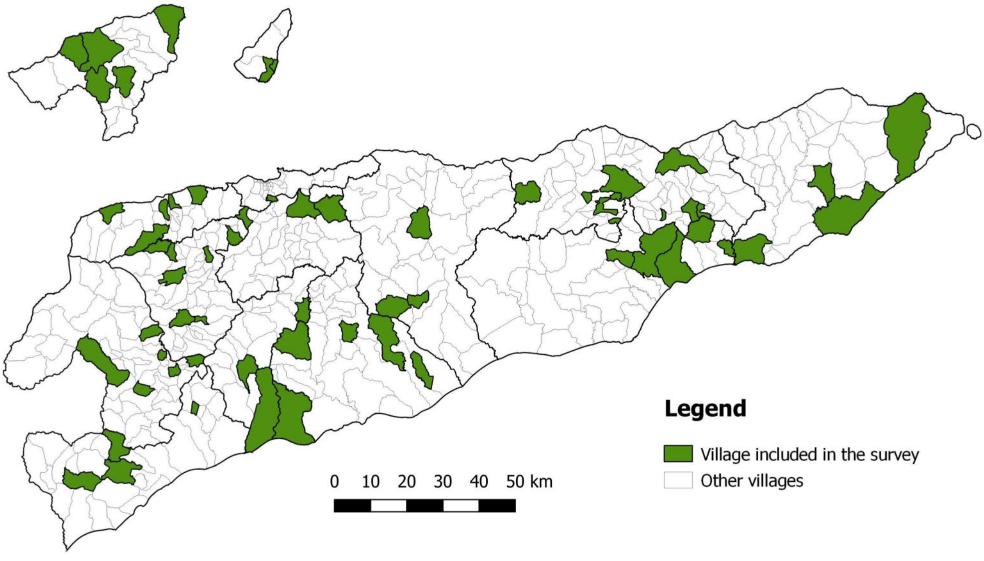

FIGURE 1 Sample villages in the End-of-Program Survey, 2016. Inset: Municipality of Oecusse

country (Figure 1). The sample size was determined based on data from the 2015 Population Census (152,429 rural households). Data were collected by a team of 13 local enumerators using tablet computers. They were recruited on a short-term contract to conduct the interviews, and were dispatched into different teams, each headed by a team supervisor. Team supervisors were responsible for contacting local leaders, making the random selection of households for interview, providing logistical support during interviews and data checking before submission.

The questionnaire covered a rich set of variables including demographic and socio-economic characteristics of the farm household, the number and size of plots, types of crop and varieties grown, food security and participation in agricultural and non-agricultural groups. The time period covered by the data referred to the 12 months prior to the survey which corresponded to the period from February 2015 to January 2016. The main respondent was the head of the household in 57% of cases. In the remaining cases, interviews were conducted with the wife or with one of the eldest sons/daughters of the household head. Over half (55%) of the respondents were men.

3.2 | Treatment variables

Since maize is the most widely grown crop in Timor-Leste, the scope of the analysis is limited to maize. Most of the previous impact assessment studies on HYV adoption define adoption as a binary variable, which takes a value of 1 if farmers cultivate the improved variety and zero otherwise. Recent literature on high-yielding maize germplasm elsewhere suggests that such a dichotomy is rare as farmers generally grow multiple varieties of crops to spread production risks (Becerril & Abdulai, 2010; Mottaleb et al., 2015). We, therefore, use two indicators of adoption. The first indicator is a dummy variable which assigns a value of 1 to all farmers who cultivated maize HYVs during 2014–2016 and zero otherwise. The second indicator measures adoption intensity in terms of the proportion of crop area of a household under maize HYV cultivation during the 2015–2016 cropping year.

3.3 | Outcome variables

We use three indicators of market participation. The first is the natural logarithm of the total quantity of maize sold. Second, we use an indicator that equals 1 if the farmer only sells maize and does not buy maize from the market. This outcome isolates farmers who fulfil their own consumption requirement and produce marketable surplus. The first outcome, the quantity of maize sold, may include farmers who simply exchange one variety of maize for their preferred variety. The latter outcome overcomes issues related to missing and potentially erroneous observations.[4] Finally, we use a dummy variable that equals 1 if a household indicates selling maize in the market is the main source of household income and zero otherwise.[5]

3.4 | Mechanism

The literature suggests that the effect of agricultural technology adoption on market participation manifests through higher productivity (Barrett, 2008). Simply put, higher maize productivity would meet households' own consumption requirement and generate a marketable surplus. To verify whether increased productivity underlies our market participation outcomes, we estimate the causal effect of technology adoption on maize productivity.

3.5 | Control variables

Market participation is not only influenced by HYV adoption but also by a large number of other factors such as socio-economic (e.g., household head's age, gender and education) and farm characteristics (e.g., land and non-land asset, farmer's risk preference, experience of shock and remoteness) as well as village characteristics (e.g., level of commercialisation, size of the village and availability of agricultural services). Some of these factors may potentially be correlated with HYV adoption. Hence, controlling for such variables is essential to avoid confounding effects. We control for household characteristics including age of the household head and its quadratic form, gender and education of the household head, household size, number of household members engaged in agriculture and distance from the households' location to the municipal capital (an indicator of remoteness). Additionally, we control for farm characteristics including land ownership, agricultural asset index,[6] crop diversity index[7] (an indicator of risk

[4]Since farmers do not maintain any record of their market activities, market transaction data are associated with missing and inaccurate observations.

[5]Collection of maize revenue data was not possible as there were no records maintained by farmers.

[6]The sum of the number of all agricultural machinery and equipment—that is, hoe, axe, shovel, water can, wheelbarrow, oxcart, thresher, sprayer, drum, silo, hand tractor and big tractor. This index does not include agricultural land. Note that we have tested the robustness of all the findings using Principle Component Analysis (PCA) to generate the asset index. The key findings remain unchanged.

[7]The sum of the number of total crops grown by the households. The crops included are maize, rice, other cereals, peanut, cassava, sweet pea, roots, beans, vegetables, fruits, coffee, coco and other crops. We assume that a farm household will grow multiple crops, instead of relying on only one crop, if they want to avoid being too badly affected by a crop failure. The nature of the crop portfolio will depend on the growing conditions and land type. Note that most crops are grown in only one season, with only about a fifth of the farmers growing a second crop of the same variety. A multiple cropping season is highly region-specific and we, therefore, believe that this variation is captured by region fixed effects.

aversion), and the number of farm animals that died in the previous 12 months (an indicator for shock). The village level controls include the number of commercial maize seed groups (an indicator of commercialisation), irrigated land in the village as a percentage of total cropped land (an indicator of service availability) and area of the village in square kilometres. Finally, we control for region fixed effects representing the three regions—east, west and centre—that control for any region-specific unobserved factors such as geography, climate and culture.

4 | TECHNOLOGY ADOPTION AND MARKET PARTICIPATION AMONG THE SAMPLED FARMERS

Table 1 presents the summary statistics of the variables that are included in the regression model.

TABLE 1 Summary statistics

Variables	N	Mean	SD	Min	Max
Panel A: Household characteristics					
Age of household head	700	48.237	13.243	19	84
Gender of household head					
Male	700	0.936	0.245	0	1
Female	700	0.064	0.245	0	1
Education of household head					
No schooling or Primary 1	700	0.461	0.499	0	1
Primary 2 to 5	700	0.211	0.409	0	1
Primary 6 to Secondary 2	700	0.15	0.357	0	1
Secondary 3 or more	700	0.177	0.382	0	1
Household size	699	6.333	2.633	1	20
Number of household members engaged in agriculture	699	2.831	1.252	0	8
Women's share of total agricultural labour (%)	698	48.817	18.902	0	100
Panel B: Farm characteristics					
Household cultivates own land	700	0.917	0.276	0	1
Total farm area under food crops (hectare)	700	0.721	0.725	0.005	4.4
Crop diversity index	700	6.634	2.14	1	11
Number of farm animals died	700	1.906	3.865	0	35
Agricultural asset index	700	5.159	4.044	0	45
Distance to municipal capital (km)	700	30.832	18.204	2	79.2

TABLE 1 (Continued)

Variables	N	Mean	SD	Min	Max
Panel C: Village characteristics					
Number of commercial maize seed groups	700	0.097	0.296	0	1
Irrigated land as a % of total farm land	700	7.177	12.577	0	60.75
Area (square km)	700	33.076	27.286	2.984	133.272
Panel D: Regions					
West	700	0.463	0.499	0	1
Centre	700	0.206	0.405	0	1
East	700	0.331	0.471	0	1
Panel E: Outcome and mechanism variables					
Total sale of maize (kg)	625	28.381	115.430	0	1485
Selling crop is the main source of income (Yes = 1, No = 0)	700	0.466	0.499	0	1
Household only sells (and does not purchase) maize	690	0.206	0.405	0	1
Total maize production (kg)	654	219.519	310.686	0	2475
Maize productivity (kg/hectare)					
Panel F: Endogenous treatment variables					
Maize HYV adopter	700	0.434	0.496	0	1
Proportion of cropland under maize HYV (%)	698	32.816	43.519	0	100
Panel G: Instrumental variable					
Number of seed groups	700	2.057	1.553	0	6
Historical annual average rainfall (mm)	700	1758	383.3	873	2481

Respondents in our sample are from smallholder farm households with an average land area under food crops of 0.721 hectares. Of the sampled farmers, 90% grew maize, and 43% of the sampled farmers grew maize HYVs. On average, one-third (33%) of the total cropland was used to grow maize HYVs in the 2015–2016 cropping season. On average, the adopters planted maize HYVs in around three-quarters (76%) of their cropland. Of the three maize HYVs introduced by the SoL program, *Sele* was the most popular variety grown by nearly 29% of the farmers in the sample. The second most popular variety was *Noi Mutin* grown by 22% of the sampled farmers. *Sele* was released in 2007, and *Noi Mutin* was introduced five years later in 2012. A majority (43%) of the adopters were growing the maize HYVs for the first time, while approximately a third of them (33%) were growing them for the second consecutive year.

Almost two-thirds (62%) of the sampled maize growers did not buy or sell maize between February 2015 and January 2016. Close to 15% (14.6%) of the sampled maize growers only purchased maize from the market, while 20.5% of the maize farmers only sold maize. A small percentage of the maize growers (2.8%) both bought and sold maize. Collection of accurate market transaction data was a challenge given that farmers do not maintain any records of their market engagement. With about 10% missing data on buying and selling, 20% of the sampled maize growers were identified as net maize sellers. On average, the maize sellers sold 28 kg of maize in the market.

The number of seed groups per village varied from 0 to 6 with an average of 2 seed groups per village. Only 11 of the 60 sampled villages (18.3%) had four or more seed groups. The 30-year annual rainfall varies across Timor-Leste with an average of 1,757 mm received in the sampled villages. The central region receives the highest rainfall in the country.

The size of land under food crop cultivation is not significantly correlated with the indicators of maize HYV adoption (Table 2). Household wealth is also not significantly correlated with maize HYV adoption. The age of the head of the adopting household[8] is slightly higher (approximately two years) than the non-adopting households ($p < 0.10$). Land ownership is significantly ($p < 0.10$) negatively correlated and the head of the households' education is significantly ($p < 0.10$) positively correlated with the proportion of land cultivated under maize HYV. The two factors that are highly significantly correlated ($p < 0.01$) with the indicators of maize HYV adoption are the number of household members employed in agriculture and agricultural asset index. This implies that the households that were more invested in agriculture in terms of human and financial capital were significantly more likely to adopt maize HYVs. Additionally, a larger percentage of women's involvement in agriculture is significantly ($p < 0.05$) positively correlated with the proportion of land cultivated under maize HYV.

TABLE 2 Correlation coefficients between maize HYV adoption and farm households' socio-economic characteristics

Household characteristics	Maize HYV adopter Difference (adopter–non-adopter)	% of cropland under maize HYV Correlation coefficient
Age of household head	1.803*	0.031
Education of household head[a]	0.075	0.066*
Number of household members engaged in agriculture	0.205**	0.066*
Women's share of total agricultural labour (%)	1.242	0.078**
Household wealth (productive and non-productive assets)	6.598	0.052
Agricultural asset index	1.100***	0.104***
Total farm area under food crops (hectare)	0.062	0.002
Household cultivates own land	0.917	0.067*

Abbreviation: HYV, high-yielding variety.

[a]Not schooled or grade 1 = 1; grade 2 to 5 = 2; grade 6 to 9 = 3; grade 10 and over = 4.

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

[8]Due to a small number of female headed households in the sample, HYV adoption is not compared across household head's gender.

5 | EMPIRICAL STRATEGY

The empirical challenge in establishing a causal relationship between adoption and market participation is endogeneity. Farmers may decide to adopt or not adopt HYVs based on unobserved factors such as progressiveness, motivation, individual risk preferences, and external risks such as market failures. To address this issue, we utilise the instrumental variable (IV) approach. This involves identifying an instrument that is highly correlated with technology adoption, is uncorrelated with the error term and does not have any direct impact on market participation. We use the interaction of the number of maize seed groups and long-term annual average rainfall as an instrument. As discussed in Section 2.2, the number of seed groups varies across villages.[9] The rationale for interacting seed group number with rainfall is to identify farmers whose adoption decisions were influenced by technology availability and maize growing conditions. Our argument is that technology availability and growing conditions simultaneously determine technology adoption. For instance, two villages might have the same number of maize seed groups and yet they may vary in terms of adoption rate owing to (un)conducive growing conditions. Variation in rainfall alone is insufficient to induce HYV adoption because technology availability is crucial to facilitating adoption.

The instrument meets the instrument relevance condition (discussed in the next section). The instrument is exogenous[10] because both rainfall and number of seed groups are not determined by farmers. The number of seed groups in a village was not correlated with any pre-program village characteristics (see discussion in Appendix S3). Hence, the unobserved characteristics of the farmers that influence technology adoption (such as motivation, risk preference) are most likely to be uncorrelated with the instrument. It can be argued that households self-select their place of living by moving to a village where rainfall is abundant. However, this seems highly unlikely given that most internal migration in Timor-Leste is characterised by rural to urban in-migration and is predominantly driven by factors unrelated to farming such as marriage, education and employment (Kumar et al., 2018). Further, conditional on the inclusion of all relevant observed factors, the instrument meets the exclusion restriction as it is not expected to have any direct impact on farmers' market participation. Variation in long-term (30-year) annual average rainfall (unlike rainfall shock) is unlikely to have any direct effect on market participation (Mather et al., 2013). The number of seed groups may exert some direct influence on farmers' market participation when the seed groups are engaged in commercial activities such as the commercial seed groups. A commercial seed group was present in 6 of the 60 sampled villages (Appendix S2). The rest of the groups were community seed producer groups, present in 46 villages, with almost no commercial activity. Since we control for the presence of the commercial seed producer group in the regression, the direct effect of seed groups on market participation is not a cause for concern. Additionally, we undertake a two-step test for exclusion restriction following Bound and Jaeger (1996) to rule out the possible violation of the exclusion restriction (see Appendix S4).

We fit two-stage least squares (2SLS) regression models to our data. Formally, our specification can be written as:

$$Y_i = A_i\beta_1 + X'\beta_2 + \lambda_r + u_i \tag{1}$$

[9]A list of the sampled villages and their corresponding maize seed group numbers is presented in Appendix S2.

[10]We cannot statistically test for exogeneity as we have a single instrumental variable.

$$A_i = Z_j\pi_1 + X'\pi_2 + \lambda_r + v_i \quad (2)$$

where, Y_i is the market participation outcome and A_i represents the endogenous adoption treatment variable for a household i. Z_j represents the interaction of the number of maize seed groups and rainfall in village j. X' is a vector of additional control variables at the household, farm and village levels. λ_r represents region fixed effects. u_i and v_i represent the error terms.

The estimates from our models provide the local average treatment effect (LATE) of HYV adoption on market participation. This is because the instrument may not affect the adoption decision of all farmers. The treatment effect is, therefore, averaged over only a subset of farmers whose adoption decision is altered by the instrument.

6 | RESULTS

6.1 | Main regression results

Table 3 presents the ordinary least square (OLS) and IV regression results for the total amount of maize sold. The treatment variables and the IV are strongly correlated as is evident from the first-stage F-statistic, which is greater than or close to 10 across all models. The OLS estimates

TABLE 3 Effect of maize HYV adoption on the quantity of maize sold

	Maize HYV adopter		% of cropland under maize HYV	
	OLS	2SLS-IV	OLS	2SLS-IV
Ln (quantity of maize sold[a])	0.079	2.545**	0.001	0.040**
	(0.137)	(1.214)	(0.002)	(0.020)
Household controls	Y	Y	Y	Y
Farm controls	Y	Y	Y	Y
Village controls	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
First-stage F-statistics		12.799		7.507
R-squared	0.130	0.088	0.125	0.105
Observations	631	631	630	630

Notes: Full results are available in Appendix S6 (Table A6). First-stage regression results are presented in Appendix S5 (Table A5).

Robust standard errors are in parentheses.

Household controls: household head's age, age squared, gender and education, number of household members engaged in agriculture, household size; Farm controls: agricultural asset index, crop diversity index, distance from the district capital, ownership status of agricultural land, total farm area under food crops, number of farm animals died last year; Village controls: size, number of commercial maize seed groups, irrigated land as a % of total farm land.

Abbreviations: 2SLS-IV, two-stage least square instrumental variable; HYV, high-yielding variety; OLS, ordinary least square.

[a]This information was missing for about 10% (n = 68) of the sample.

**p < 0.05.

presented in columns (1) and (3) are negative and statistically insignificant. Columns (2) and (4) report the LATE estimates for the two endogenous treatment variables. The LATE estimates of HYV maize adoption on quantity of maize sold is positive and significant at the 5% level. The coefficient presented in column (2) shows that, all else equal, farmers who adopted maize HYVs, on average, sold 254 percentage points higher quantity of maize compared to those farmers who grew only local varieties.

Tables 4 and 5 present the probit and IV-probit regression results for the second and third outcomes (i.e., only sells maize and maize revenue is the main source of income). We report average marginal effects from the probit and IV-probit regression models.[11] The average marginal effects generated from the probit model are insignificant but the average marginal effects reported from IV-probit regressions are positive and statistically significant at the 1% level in Tables 4 and 5. The average marginal effects presented in columns (2) and (4) of Table 4 suggest that, all else equal, the adoption of HYVs increases the probability of farmers selling maize in the market. The coefficient presented in column (2) suggests that the farmers who grew maize HYVs, on average, had a 34.7 percentage points higher likelihood of selling maize in the market compared to the farmers who grew only local maize varieties. The coefficient presented in column (4) shows that the likelihood of selling maize increased by 0.4 percentage points, on average, as the proportion of maize HYV cultivation area increased by 1 percentage point.

TABLE 4 Effect of maize HYV adoption on market participation as sellers (average marginal effects)

	Maize HYV adopter		**% of cropland under maize HYV**	
	Probit	**IV-probit**	**Probit**	**IV-probit**
Only sells maize	0.007	0.347***	2.41×10^{-5}	0.004***
	(0.031)	(0.079)	(0.0004)	(0.001)
Household controls	Y	Y	Y	Y
Farm controls	Y	Y	Y	Y
Village controls	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
First-stage F-statistic		16.233		12.139
R-squared		0.093		0.102
Observations	689	699	687	697

Notes: Full results are available in Appendix S7 (Table A7). First-stage regression results are presented in Appendix S5 (Table A5). First-stage statistics for IV-probit regressions are obtained by estimating 2SLS regressions.

Robust standard errors are in parentheses.

Household, farm and village controls: same as Table 3.

Abbreviations: 2SLS, two-stage least square; HYV, high-yielding variety; IV-probit, instrumental variable probit.

***$p < 0.01$.

[11] IV-probit regressions do not produce a first-stage F-statistic. As an indication of instrument relevance, we present F-statistics obtained from 2SLS regressions for these dummy outcomes.

TABLE 5 Effect of maize HYV adoption on farmers' reliance on maize income (average marginal effects)

	Maize HYV adopter		% of cropland under maize HYV	
	Probit	IV-probit	Probit	IV-probit
Maize revenue is the main source of income	0.039	0.436***	2.90×10^{-5}	0.005***
	(0.037)	(0.035)	(0.0004)	(0.001)
Household controls	Y	Y	Y	Y
Farm controls	Y	Y	Y	Y
Village controls	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
First-stage F-statistic		15.402		11.403
R-squared		0.091		0.102
Observations	699	699	697	697

Notes: Full results are available in Appendix S8 (Table A8). First-stage regression results are presented in Appendix S5 (Table A5). First-stage statistics for IV-probit regressions are obtained by estimating 2SLS regressions.

Robust standard errors are in parentheses.

Household, farm and village controls: same as Table 3.

Abbreviations: 2SLS, two-stage least square; HYV, high-yielding variety; IV-probit, instrumental variable probit.

***$p < 0.01$.

Consistent with the findings obtained for net quantity of maize sold and the likelihood of only selling maize, a significant positive relationship is observed between HYV adoption and having market participation as the main source of a household's income. From Table 5, column (2), it is observed that farmers who grew maize HYV were, on average, 43.6 percentage points more likely to report maize revenue as their main source of income. Likewise, the coefficient presented in column (4) shows that a 1 percentage point increase in the cultivation area under maize HYVs increased the probability of reporting maize revenue as the main source of income on average by 0.5 percentage points.

6.2 | Heterogeneity analysis

Table 6 presents heterogeneity analysis results of the treatment effect on market participation across women's participation in agriculture. The rationale for undertaking heterogeneity analysis across gender composition of agricultural labour is that the petty trading and informal agricultural commerce in rural Timor-Leste are predominantly performed by women (Hedditch & Manuel, 2010).

We divide the sample into two groups based on the relative share of female family labour participation in the total agricultural labour hours. We find that the treatment effect is significant for 'only sells maize' and 'maize revenue is the main source of income' at the 1% level for households where women supply 50% or more of the total agricultural labour hours. For 'ln of quantity of maize sold', the IV coefficient is not significant at the 10% level but it is close

TABLE 6 Heterogeneity analysis of the impact of maize HYV on market access based on gendered composition of the agricultural labour force

	Women's involvement as a % of total agricultural labour			
	Maize HYV adopter		% of cropland under maize HYV	
	Low	High	Low	High
Panel A: Ln (quantity of maize sold[a])	1.275	2.310	0.019	(0.035)
	(1.228)	(1.565)	(0.018)	(0.023)
Observations	274	357	274	356
Panel B: Only sells maize[b]	0.185	0.431***	0.0009	0.0005
	(0.242)	(0.012)	(0.0009)	(0.0009)
Observations	304	395	303	395
Panel C: Maize revenue is main source of income[b]	0.474***	0.403***	0.001	−0.0002
	(0.017)	(0.067)	(0.001)	(0.001)
Observations	304	395	303	394
Household controls	Y	Y	Y	Y
Farm controls	Y	Y	Y	Y
Village controls	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y

Notes: Low (high) means women comprise less (more) than or equal to 50% of the total agricultural labour of the household.

Robust standard errors are in parentheses.

Household, farm and village controls: same as Table 3.

Abbreviation: HYV, high-yielding variety.

[a]This information was missing for about 10% ($n = 68$) of the sample.

[b]Reported coefficients are average marginal effects.

***$p < 0.01$.

($p = 0.125$). The effects of the proportion of cropland under maize HYV adoption on all outcomes of market participation are insignificant for all households.

6.3 | Mechanisms

Drawing upon the literature, our hypothesis for market participation as sellers to be driven by technology adoption, is that the adopters must produce more than the non-adopters. To confirm this, we estimate the causal effect of maize HYV adoption on maize productivity measured as kilogram of maize per hectare of land. The estimated coefficient presented in Table 7, column (1), suggests that the difference in maize productivity between adopters and non-adopters is 23.8 percentage points. This number is lower than the yield advantage (40–50%) estimated in research stations and farmers' fields (Seeds of Life, 2014). From column (2), we observe that if the household, firm and village characteristics are controlled for, the

TABLE 7 Effect of maize HYV adoption on maize productivity

	Maize HYV adopter			% of cropland under maize HYV		
	OLS	**OLS**	**2SLS-IV**	**OLS**	**OLS**	**2SLS-IV**
Ln (maize production/hectare)	0.238**	0.108	1.628*	0.003***	0.001	0.024*
	(0.101)	(0.098)	(0.869)	(0.001)	(0.001)	(0.0136)
Household controls	N	Y	Y	N	Y	Y
Farm controls	N	Y	Y	N	Y	Y
Village controls	N	Y	Y	N	Y	Y
Region fixed effects	N	Y	Y	N	Y	Y
First-stage F-statistic			7.507			7.507
R-squared	0.009	0.150	0.105	0.013	0.151	0.105
Observations	632	631	631	630	630	630

Notes: Robust standard errors are in parentheses.

Household, farm and village controls: same as Table 3.

Abbreviations: 2SLS-IV, two-stage least square instrumental variable; HYV, high-yielding variety; OLS, ordinary least square.

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

difference in maize productivity between adopters and non-adopters disappears. In column (3), when endogeneity in maize HYV adoption is addressed, the difference in maize productivity between adopters and non-adopters is 162.8 percentage points ($p < 0.10$). This number is higher than the estimated yield advantage in research station and farmers' fields. However, this is expected as the LATE coefficient is generally higher than the OLS estimate. This is because the LATE coefficient is averaged over only a subset of farmers whose adoption decision is altered by the IV. The results remain robust for the second indicator of maize HYV adoption (i.e., the proportion of cropland under maize HYV adoption) as presented in columns (4), (5) and (6) of Table 7.

7 | DISCUSSION AND CONCLUSION

We study the impact of maize HYV adoption on farm households' market participation in a subsistence-based rural economy of Timor-Leste which is characterised by an underdeveloped rural agricultural market. This is the first study that establishes a causal connection between technology adoption and market participation. Our results show a significant impact of HYV adoption on maize farmers' market participation rate. These findings support Barrett's (2008) theoretical proposition that the promotion of advanced agricultural technology can act as a catalyst for market participation of smallholder farmers. These findings are highly promising because the intervention made no explicit attempt to increase farmers' market access. The enhanced market participation was a spillover effect of higher agriculture production that made its way through despite the prevalence of unfavourable market access conditions.

Our findings support the hypothesised pathway between adoption of improved variety and household welfare, more specifically income and food security (Bezu et al., 2014; Kassie et al., 2011, 2014; Shiferaw et al., 2014). Although not explicitly tested before, an obvious pathway through which the welfare effects of improved variety adoption manifests is market participation. In terms of the effect size, our results are consistent with the existing estimates. For example, Bezu et al. (2014) report that, in Malawi, a 1 percentage point increase in the area planted under modern varieties increases farmers' income by 0.48 percentage points. Our results reveal that a 1 percentage point increase in cropland under maize HYV increases the likelihood of crop income becoming the main source of household income by 0.5 percentage points. Shiferaw et al. (2014) report that a 1 percentage point increase in area under improved wheat variety in Ethiopia is associated with a marketed surplus of 4.5 kg of wheat. Our estimate reveals that an increase in 1 percentage point area under maize HYV increases maize sale by 4 percentage points (approximately 1.12 kg). Additionally, our results are consistent with the findings on the positive association between increased productivity of cereal crops and farmers' market participation (Benfica et al., 2017).

The estimates obtained from the heterogeneity analysis suggests that maize HYV adoption may create opportunity for women's empowerment. As households with a higher proportion of female labour appear more likely to adopt maize HYV and participate in market activities, and given that in Timor-Leste petty trading is largely women's responsibility, the adoption of HYV has the potential to augment women's access to and control over income. This finding is consistent with previous studies in Timor-Leste which show that women's greater access to agricultural extension programs relative to men increases households' cropping intensity (Akter et al., 2020). Additionally, increased use of HYVs can substantially enhance the income and welfare of smallholder farmers. Although the adoption of improved crop varieties in Timor-Leste increased considerably between 2011 (13%) and 2016 (43%), there is still potential for further growth in adoption (Seeds of Life, 2016). Our study reveals that availability of technology is an important determinant of technology adoption. Continued efforts to support seed multiplication and dissemination activities are, therefore, important to increase the access of smallholder farmers to HYV seeds, thus lowering this barrier to adoption.

The findings of our study highlight the need for a comprehensive design of agricultural intervention programs that promote sustainable access to HYVs and strengthen farmers' integration into the market and agricultural value chain. The focus of most agricultural intervention programs has traditionally been on the development and dissemination of HYVs without emphasis on market access and value chain development. Although market linkage is crucial, merely linking the farmers to the market will help them in the short to medium term by allowing them to sell surplus produce. Value chain development which includes improved market access but goes beyond it by helping farmers to add value to their produce through post-harvest value addition, is a longer-term and more sustainable pathway to poverty alleviation.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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