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RESEARCH ARTICLE

Market Participation of Small-Scale Rice Farmers in Eastern Bolivia

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Abstract
Using a double-hurdle approach, we assess factors associated with the extent of participation in the rice market with data for small-scale farmers drawn from a nationally representative dataset. The results suggest that larger endowments and assets, animal farming and commercialization, and alternative off-farm income make farmers less likely to participate. Conversely, having access to credit, larger farm sizes, and being part of a farmers' association all increase the likelihood of participation. Farms with better technological resources are also those with higher sales volumes. Further understanding market participation dynamics should prove useful for deriving evidence-based policy recommendations to strengthen this Bolivian sector.

Keywords: Bolivia; Rice; Market participation; Transaction costs; Double-hurdle model

JEL classifications: D23; O13; Q12

Introduction

Rice (*Oryza sativa* L.) is among the most consumed crops in Bolivia, third only to wheat and maize. Although the country evidenced an aggressive expansion of industrial crops like soybeans in the 2010s, rice kept a significant share of the national agricultural acreage by 2020 (INE, 2023). Yet, production faces several challenges of decreasing prices, low yields (FAO, 2022), limited technology adoption (Martinez et al., 2021), and poor harvest and postharvest practices (Ortiz and Soliz, 2007). Furthermore, although most farmers are small-scale and their livelihoods rely on the crop heavily, the rate of market participation of rice farmers is remarkably low (Ortiz and Soliz, 2007). Limitations on transitioning into market participation are suggested by local experts as the main causes of recent reductions in the share of small-scale farmers in the sector.

Agricultural development research views the transition from subsistence to commercial agriculture as an improvement mechanism for agricultural households' welfare and to stimulate growth within their sectors (Timmer, 1998). In theory, farming households can specialize in the good for which they have a comparative advantage, thus benefiting from trade. However, market frictions and barriers to entry create inequalities of opportunity to access markets, thus disproportionately affecting small- and medium-scale farmers (Alene et al., 2008; Barrett, 2008; Boughton et al., 2007; Gebremedhin and Jaleta, 2010; Olwande et al., 2015). In the case of Bolivian rice farmers, however, this dynamic remains unexplored.

Studies covering the drivers of market participation have focused on transaction costs among semi-subsistence farming households (Bellemare and Barrett, 2006; Goetz, 1992; Holloway, Barrett, and Ehui, 2001; Jagwe, Machethe, and Ouma, 2010; Key, Sadoulet, and De Janvry, 2000;

Makhura, Kirsten, and Delgado, 2001; Omamo, 1998; Omiti et al., 2009; Ouma et al., 2010). Meanwhile, another branch of the literature suggested that constrained endowments of agricultural assets are among the main factors behind market participation, that is, farmers under a certain asset threshold face a *poverty trap* keeping them out of trade feasibility (Boughton et al., 2007). More recent research jointly considers transaction costs, asset endowment, and technology readiness (Achandi and Mujawamariya, 2016; Alene et al., 2008; Martey, Al-Hassan, and Kuwornu, 2012; Mather, Boughton, and Jayne, 2013; Musah, Bonsu, and Seini, 2014; Ohen, Etuk, and Onoja, 2013; Olwande and Mathenge, 2012; Olwande et al., 2015; Reyes et al., 2012; Woldeyohanes, Heckeley, and Surry, 2017), and some analyze how decisions on becoming sellers, buyers, or autarkic producers occur simultaneously (Muricho, Kasie, and Obare, 2015; Ouma et al., 2010; Zanello, 2012).

However, research with a focus on small-scale rice farmers' market participation is rather scarce (Achandi and Mujawamariya, 2016; Barrett and Dorosh, 1996; Ohen, Etuk, and Onoja, 2013), while there are several studies focused on maize production, especially in sub-Saharan Africa (Alene et al., 2008; Barrett, 2008; Boughton et al., 2007; Martey, Al-Hassan, and Kuwornu, 2012; Muricho, Kasie, and Obare, 2015; Musah, Bonsu, and Seini, 2014; Ohen, Etuk, and Onoja, 2013; Olwande and Mathenge, 2012; Olwande et al., 2015; Omiti et al., 2009). Despite the relevance of agriculture in South American countries, the poverty (or vulnerability to poverty) and market frictions faced by most small-scale producers, and rice farming's potential as a crop for food security and income generation in the region, research on this intersection is still a void in the literature. Our research exploring the case of Bolivia contributes to this gap, studying the drivers of market participation of smallholder agricultural households.

With data from small-scale rice producers drawn from a nationally representative sample in Bolivia, we use a double-hurdle model to study the drivers of (1) market participation and (2) total sales of paddy rice among smallholder farming households. Our results reveal membership in a producer organization – which might work as a mechanism to decrease transaction costs – is positively correlated with both the probability of market participation and total sales. Also, the use of practices such as fertilization and mechanization is strongly correlated to market participation, suggesting that the technological gap in the sector is connected with market participation. We discuss how strategies to promote and strengthen producers' associations should be followed, as this would foster an increase in the bargaining power of farmers. Also, agriculture policymakers should push for mechanisms to disseminate technologies and increase their adoption within the sector, thus improving productivity.

The remainder of the document is as follows: Section 2 provides a brief background on the Bolivian rice sector. Section 3 presents the theoretical framework of the analysis, while Section 4 presents the data and the empirical approach. Section 5 presents the statistical analysis results, followed by a discussion of its implications in Section 6. A seventh section concludes.

Background: Rice in Bolivia and Market Participation

By 2011, rice cultivation accounted for 6.3% of all Bolivian agricultural lands, with 95% of its production in the tropical region, specifically in the departments of Santa Cruz, Beni, and Cochabamba, which constitute the crop's most suitable environment (Degiovanni, Martínez, and Motta, 2010). By 2020, rice still covered roughly 5% of the national agricultural acreage (INE, 2023). Production is mainly intended for human consumption in domestic markets, with exports representing less than 1% of the overall national output (FAO, 2022). Also, rice is one of the nine prioritized for food security and rural development policies by the government (MDRyT–INE, 2012). Ultimately, rice production remains a highly relevant agricultural output in the Bolivian rural sector.

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The sector is not exempt from major setbacks. Average farm gate prices for paddy rice have systematically decreased for several years now (FAO, 2022). Annual production increases were evidenced as a result of new dedicated lands, yet yields remain among the lowest on the continent (FAO, 2022). The latter follows from low technology adoption in the Bolivian rice sector, with most producers relying on manual farming and traditional crop varieties (Martinez et al., 2021). Nevertheless, Bolivia has followed several steps toward the improvement of its rice sector. Since the crop is not native to the country, all available genetic resources are introduced (Nguyen and Tran, 2002), but the country followed a process of population improvement with the objective of developing varieties more properly suited to the national conditions (Taboada, Guzmán, and Hurtado, 2000). Over 15 modern improved varieties have been released in the country since 2004 (Martinez et al., 2021; Taboada and Viruez, *personal communication*, March 2023). This work is done by the Centro de Investigación Agrícola Tropical (CIAT-Bolivia), which also delivers technologies like biofortified rice varieties (Viruez et al., 2016) and recommendations on input use (Viruez and Taboada, 2013). Yet again, their adoption is not as widespread as desired (Martinez et al., 2021)

Bolivian farmers participate in the market either through direct sales of unprocessed (paddy) rice or via a transformation stage in which they polish and process the rice (at their farms or their farmers' association or by outsourcing) for the final consumption market. The latter, however, is the exception rather than the rule. Paddy rice sales can be assisted by associations or cooperatives, or rather take place as direct sales in local markets, which is the most common case. Such sales occur in major meeting points called "*playas*," in which producers and buyers trade rice, soy, maize, and livestock, among many other agricultural products. The largest *playas* are located in Montero, San Juan de Yapacaní, Portachuelo, and Mineros, all municipalities in the department of Santa Cruz.

Paddy rice buyers are usually representatives of milling companies or private intermediaries, who bargain with the producers until a price is settled. However, conditions make the price not necessarily competitive and highly volatile (Bauguil, 2003). Reports suggest that mills' representatives push practices that place rice producers under unfavorable conditions. For instance, prices offered to farmers might be artificially decreased by claiming a need for arbitrary levels of grain humidity that do not necessarily reflect the actual quality of the rice lot. This can further increase the difference between paddy trade prices and final consumption prices, thus increasing the odds of farming households going rice-autarkic (De Janvry, Fafchamps, and Sadoulet, 1991; Fafchamps, 1992), since their shadow price makes it optimal to neither sell nor buy.

Unable to transition from subsistence to commercial agriculture, the share of small-scale farmers has started to gradually reduce (Ortiz and Soliz, 2007). Vulnerable farmers are increasingly finding themselves forced to abandon their agricultural vocation and relocate to cities in an attempt to cover their needs (Taboada and Viruez, *personal communication*, March 2023). Meanwhile, a few large farmers are starting to take over. Thus, agricultural policymakers are facing a highly complex scenario, in which production is further concentrated in the hands of a few, while the livelihoods of small-scale farmers are becoming increasingly vulnerable – that is, studying the factors behind market participation becomes of the utmost importance.

Theoretical Framework

Following Key, Sadoulet, and De Janvry (2000), we bring fixed and variable costs into the basic agricultural household model to analyze market participation. Bolivia is characterized by its slow regulatory systems and high-friction labor markets (Calvo, 2006). Rural markets are not exempt from labor frictions, with increasing cases of unavailability of agricultural workers (Ortiz and Soliz, 2007) that are not rare in South America (White, Labarta, and Leguía, 2005). Hence, we expect that market failures are highly likely in this context and thus set a scenario with non-separability between decisions on production and consumption (De Janvry and Sadoulet, 2006). As we take the case of rice farming, our model considers households that must decide on consumption and production levels, how much of their output to use for the next production cycle, and the extent of rice sales (or purchases). For that purpose, under an assumption of rationality, households maximize their utility subject to a series of restrictions. Focusing our analysis on rice, the representative household preferences are described by a utility function that depends on the consumption of rice (C_r), other bought goods (C_i^o, for $i = 1, \ldots, L$), and exogenous shocks (Z_u). Specifically, the household problem is

$$\max_{C_r, \mathbf{C}_o \in \mathbb{R}_+^L} U(C_r, \mathbf{C}_o, Z_u) \tag{1}$$

subject to

$$\sum_{i=1}^{L} p_i^o C_i^o + S \leq p_r(v_r - C_r) + T \tag{2}$$

$$F(q_r; \mathbf{x}_r, Z_r^p) \leq 0 \tag{3}$$

$$C_r + x_r^* + v_r \leq q_r + D_r, \tag{4}$$

which are budgetary, production, and resource balance restrictions. The budgetary restriction (Eq. 2) tells us that the value of rice sales net of household consumption ($p_r(v_r – C_r)$), with v_r sales and C_r consumption) plus other income (T), such as off-farm jobs, remittances, and subsidies, is large enough to cover for monetary savings (S) and the cost of other goods consumed ($\sum_i p_i^o C_i^o + S$). As the household is capable of producing rice, the functional representation of the production plan (Eq. 3) refers to the technological capacities used in the crop, connecting the output of rice (namely, q_r) with the inputs used for its production ($\mathbf{x}_r \in \mathbb{R}^H$) and exogenous production shocks (Z_j^p). Finally, the resource equilibrium (Eq. 4) shows that the household consumption of rice, plus the amount left as productive supply (x_r*) and the quantity sold, cannot exceed the quantity produced plus the initial endowment of rice ($q_r + D_r$).

Households face different market relations as some have production surplus, hence selling part of their output (Key, Sadoulet, and De Janvry, 2000). Conversely, others have a shortfall as they produce and must buy (net buyers), whereas others do not even participate in markets (self-sufficiency). An explanation of such differences lies in transaction costs, which can be either proportional or fixed. The first kind is the case of unit costs (e.g., transportation costs and imperfect information) that affect both the decision to participate and the trading volume. The second kind of cost does not vary with the amount of the purchased good, as in the case of searching for buyers, infrastructure, credit, etc. Hence, the latter affects only the decision to participate in markets. Finally, another important effect of transaction costs on market participation is the degree of specialization or diversification. Agricultural households facing high transaction costs are usually more diversified, hence having less surplus for sale. Otherwise, they will become more specialized in a specific crop to become market-oriented (Larochelle and Alwang, 2015).

We consider market participation as a choice variable, thus introducing transaction costs into the household's maximization problem. Now, the decisions solve not only for optimal consumption, inputs, and production but also for market participation (and thus the optimal level of sales or purchases). Following Zanello (2012), we introduce proportional (t_p^q) and fixed (t_f^q) transaction costs, where $q \in \{s, b\}$ for *seller* or *buyer*, so the budget constraint now follows:

$$\sum_{i=1}^{L} p_i^o C_i^o + S - [\delta^s[(p_r - t_p^s(z^s))v_r - t_f^s(z^s)] - \delta^b[(p_r + t_p^b(z^b))C_r + t_f^b(z^b)]] - T \leq 0 \tag{5}$$

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hence maintaining purchases and sales as separate. Note that, in the specification of equation (5), market participation as a seller or a buyer of rice is a choice variable represented by δ^s and δ^b, respectively. Hence, $\delta^s = 1$ if a strictly positive amount of rice is sold (i.e., whenever $v_r > 0$), and zero otherwise. Likewise, $\delta^b = 1$ whenever $C_r > 0$, and zero otherwise. The presence of proportional transaction costs causes the price perceived by the seller to be lower than the market price (by an amount of t_p^s), whereas the real price paid by the buyer is higher than the market price (by an amount of t_p^b). On the other hand, t_f^s and t_f^b are fixed sale and purchase transaction costs, respectively. Note that the transaction costs are not directly observable by the researcher. Nonetheless, these can be represented as a function of external characteristics that can be observed (e.g., transportation costs, labor supervision costs, and travel time), hence allowing them to be proxied by other related variables. In the model, these external characteristics are represented by z^s and z^b for sellers and buyers, respectively.

Therefore, the final household's problem is to determine whether to participate in the market, and with how much to participate (as seller or buyer), thus obtaining its maximum feasible utility, under restrictions (3), (4), and (5). For that purpose, the household compares the expected utility between selling or buying rice to the expected utility of being in autarky (self-sufficiency). Formally, assuming a well-behaved utility and production plans, the household's problem is the Karush–Kuhn–Tucker (KKT) solution to

$$\begin{aligned} L(C_r, v_r, \delta^b, \delta^s, \mathbf{C}_o) &= U(C_r, \mathbf{C}_o, Z_u) + \mu(q_r - x_r^* + D_r - v_r - C_r) \\ &+ \psi F(q_r; \mathbf{x}_r, Z_r^p) + \lambda \left\{ \sum_{i=1}^{L} p_i^o C_i^o + S - \left[\delta^s \left[\left(p_r - t_p^s(z^s) \right) v_r - t_f^s(z^s) \right] \right. \right. \\ &\left. \left. - \delta^b \left[\left(p_r + t_p^b(z^b) \right) C_r + t_f^b(z^b)) \right] \right] - T \right\} \end{aligned} \tag{6}$$

where μ, ψ, and λ are, respectively, the Lagrange multipliers associated with the resource equilibrium (Eq. 4), technological (Eq. 3), and budgetary constraints (Eq. 5).

Introducing fixed costs creates a discontinuity in the optimization (Key, Sadoulet, and De Janvry, 2000), which must be broken down into two steps. First, an optimal conditional solution to the market participation regime (seller, buyer, or autarkic) follows from the KKT conditions with respect to C_r, q_r, x_r^*, and v_r (Key, Sadoulet, and De Janvry, 2000; Ouma et al., 2010). Then, the second step is the decision on participation that makes the farmer better off, comparing the achievable indirect utility function under each regime. In our study, we are interested in market participation and total sales, so, from utility maximization, it follows that with $\delta^{s^*} \in \{0, 1\}$ an index of participation:

$$\begin{aligned} \delta^{s*} &= \delta^s(p_r, t_f^s(z^s), Z_r^p, Z_u) \\ v_r^* &= \delta^{s*} \times f(p_r, t_p^s(z^s), t_f^s(z^s), Z_r^p, Z_u) \end{aligned} \tag{7}$$

so that sales are nonzero if and only if participation occurs. More importantly, participation depends only on fixed transaction costs, whereas total sales depend on fixed and proportional costs. Thus, we are interested in modeling how a factor h can affect market participation (i.e., $\partial\delta^s/\partial h$) and total sales (i.e., $\partial v_r/\partial h$), where the latter effect can be either be unconditional (i.e., including the potential changes on participation) or strictly focused among those participating in the market ($\partial v_r/\partial h | \delta^s = 1$).

From the non-separability of the setting, we would expect demographic and non-production farm-level variables to affect participation and total sales significantly.[1] Also, we would expect that factors associated with transaction costs are strongly correlated with market participation and

[1]Nevertheless, this is not equivalent to a separability test. The theoretical framework, however, is flexible enough to make any significant effects (on participation or sales) be consistent with the scenario of non-separability.

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total sales. Since participation in the paddy market follows a rational decision, whenever a farm does not engage in trade, we are in a situation of corner solution (sales are zero) instead of sample selection for the outcome of the total sales (sales are unobserved). Therefore, corner solution methods such as truncated regression should be preferred. We further discuss our data and empirical methods in the following section.

Materials and Methods

Data

We use information from a cross-sectional collected across the rice-producing regions of Bolivia in 2013–2014 to measure the adoption of improved rice varieties. These surveys were collected at the farm level after interviewing the members of the household in charge of managing the rice crops and other agricultural activities done on the farm. This allowed us to capture information both from the household and from the productive activities at the plot level. We used a multistage sampling framework across the rice-producing regions, so that:

a. communities were selected as the primary sampling unit (PSU);
b. within every PSU, a sample of farming households was selected (optimal cluster size aimed at 12–15 households per community);
c. via a clustered sampling strategy, a design effect was estimated to correct the minimum sample size to compensate for the loss of variance from collecting data within communities (clusters);
d. finally, we used a design effect-adjusted, simple random sampling to determine the minimum number of observations needed to achieve national representativeness.

Although medium- and large-scale producers were also interviewed, we focus our attention on small-scale rice farmers as they represent the vast majority of farmers and are the ones facing the most barriers to linking to markets (Ortiz and Soliz, 2007). Bolivian experts' definition of small-scale farmers covers *all farmers with farms under 50 ha and rice production under 20 h*a (Ortiz and Soliz, 2007). After selecting farms with under 50 ha (462 observations), we keep in our subsample farmers with up to 5 ha of rice since this is the largest rice area found in the sample among non-sellers,[2] thus keeping a sample of 358 cases (133 sellers and 225 non-sellers) out of a national sample of 802 observations. Following what we previously discussed, our response variables of interest are a binary variable that takes the value of 1 if the household is a net seller of rice (zero otherwise) and tons of paddy rice sold for the 2012–2013 season.

In Table 1, we summarize the covariates included in the model. We include household demographics based on the head of the household and other household-level covariates, like the number of working-age persons and the number of dependents. We also bring in variables reflecting financial capital and tangible assets, including sales of animals or other crops, off-farm employment, and the total size of the farm. We add a Household Asset Index proposed by Filmer and Pritchett (2002), a standardized, principal component analysis index based on the household ownership of durable goods like television, fridge, and backpack sprayer, among other appliances for household and farming activities. In addition, following Barrett (2008), we include binary variables of technology adoption for rice production, namely agrochemical use (for pest, weed, or disease control), fertilization, and the use of improved rice varieties. Improved varieties follow the

[2]We also performed the estimation using a subsample of farmers that follows the definition of Ortiz and Soliz (2007) (i.e., 462 farmers, with 51% of market participation) which inflates the coefficient point estimates of most covariates. We report those estimations as additional results in the supplementary materials. Nevertheless, as producers beyond 5 ha are always market participants, we argue that keeping farmers with comparable rice areas provides a more suitable estimation of average partial effects. Therefore, we base our interpretations on the estimations derived from the further constrained sample.

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Table 1. Explanatory variables included in the double-hurdle model of market participation and rice sales of small-scale rice farmers in Eastern Bolivia, 2014

Variable	Definition and motivation
Household demographics and human capital	
Sex of head of the household	(1 = Woman) Gender gaps may constrain market participation from women, as they usually face harsher restrictions to access credit and have limited assets compared to men (Lowe, 2013; Ouma et al., 2010; Sigei, 2014).
Age of head of the household	(Measured in years) We expect an ambiguous correlation. Older farmers might be more experienced in bargaining prices in the market. Nevertheless, aging farmers tend to decrease their production scale, thus limiting their likelihood of engaging in trade (Alene et al., 2008; Sigei, 2014).
Years of experience producing rice by the head of the household	Gained experience makes farmers more efficient at managing their crops and more aware of market needs. However, further seasoned farmers might be more reluctant to transition into modern practices, thus potentially reducing the potential of sales. We include a quadratic term to account for feasible nonlinearities.
Number of working-age persons in the household	(Number of people with ages from 15 to 65 years) This is a proxy variable for the in-household availability of labor force, which might be associated with cost reductions that can facilitate market participation.
Number of dependents in the household	(Number of people under 14 years of age and senior persons) As this measures an additional demand for household needs, the literature suggests that this would bring about a decrease in the likelihood of market participation, as well as in total sales.
Education of the head of the household	(Years of schooling) This serves as a proxy for human capital, although the effect might be ambiguous. Although additional education can correlate with more proper knowledge of technology and strategies for crop management, it also opens an opportunity for the generation of off-farm income, thus decreasing the probability of participating in the market (Martey et al., 2012).
Food scarcity in the household	(1 = Food scarcity in the past three months) Incomplete nutrition can negatively affect overall production and thus the likelihood of participation, or sales if the produce was still enough to engage in trade.
Household's tangible assets and financial capital	
Size of the farm	(Farm size in hectares) As having additional land makes it more feasible to reach a production surplus (net of consumption), we anticipate this variable to have a positive effect on market participation and total sales.
Titled land	(1 = Land is owned and titled to a member of the household) Having *de facto* and *de jure* land tenure makes farmers more likely to invest in the crop, thus positively correlated with the probability of market participation (Olwande et al., 2015; Ouma et al., 2010).
Household Asset Index	Following the results of Filmer and Pritchett (2002), we use the method of principal component analysis to build an index, with over 11 variables of durable goods tenancy and house attributes that serves as a proxy for wealth. Therefore, we expect it to be positively correlated with market participation.

(*Continued*)

Table 1. (*Continued*)

Variable	Definition and motivation
Off-farm employment	(1 = Persons in the household do income-generating activities outside of the farm) Additional income entering the household could help improve the production infrastructure (thus increasing the probability of participation), but, if the share of income generated off-farm systematically satisfies the needs of the household, then a productivity scale reduction might take place (Alene et al., 2008; Larochelle and Alwang, 2015).
Sold crops other than rice	(1 = Yes) Similar to off-farm employment, the likelihood of additional income might help improve the technology (via investment) dedicated to the production of rice, hence increasing the probability of participation.
Sold animals	(1 = Yes) The rationale here is the same as for other crop sales – diversification might decrease participation, thus driving farmers toward autarkic rice production.
Acquired credit	(1 = Received credit over the last production season) Following that this variable represents additional liquidity available for investment, we expect it to be positively correlated with investments in technology and inputs (Barrett, 2008).
Technology adoption in rice crops	
(a) Improved rice varieties (*rice varieties released up to 10 years before the survey*) (b) Agrochemicals (*i.e., insecticides, herbicides, or disease controls*) (c) Fertilization (d) Mechanization (*for planting or harvesting*)	411 cm. (1 = Used the mentioned technology) Farms that include technological improvements in their production systems are better equipped to reach higher productivity; thus, they would have a higher probability of participating in the market and larger-than-average total sales (Barrett, 2008).
Transaction costs	
Extension or training	(1 = Received extension services or training in rice production) A positive effect should be expected on participation, in the same way as with technology adoption, since training can facilitate access to technologies by decreasing the costs of information about technologies themselves.
Part of rice farmers' association or cooperative	(1 = Yes) Being part of a network of farmers is likely a mechanism to decrease transaction costs, as this improves the position of farmers when facing the market by facilitating access to commercialization networks.
Travel Effort Index	(Adjusted kilometers) This variable serves as a proxy for the minimum distance to markets. Starting with the exact location of farmers, we use GIS software to calculate a *drag coefficient*, which measures an index of the needed effort to reach the closest agricultural market. The index uses data from publicly available shape files of Bolivia, including information on elevation, slope, populations, water channels, and roads. Since this is directly connected to distance to markets, we expect a negative correlation with participation – that is, the higher the effort needed to *directly* access the market, the lower the likelihood of participating in it.
Department	
(a) Beni (b) Cochabamba (c) Santa Cruz	Control dummies to capture differences by fixed attributes specific to each department.

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Table 2. Acreage, productivity, and poverty vulnerability of small-scale rice farmers in Eastern Bolivia, 2014

		All farms		Sellers		Non-sellers		
Variable	Unit	Mean	SD	Mean	SD	Mean	SD	DM[a]
Area with rice	ha	1.45	1.26	2.23	1.55	0.98	0.75	0.000
Paddy rice yield	ton/ha	1.91	1.34	2.41	1.41	1.62	1.21	0.000
Poverty Probability Index[b]	PPI Score	43.74	16.83	40.63	16.85	45.55	16.58	0.008

[a]Reporting *p*-values of difference in means test. The null hypothesis is no difference in means.
[b]The PPI measures the probability that a surveyed household falls below the poverty line.

definition of *modern improved rice varieties* (Martinez et al., 2021), which are materials selected or developed by the national crop improvement initiative. Other varieties were introduced in the country without validation of their suitability. Also, we consider the use of mechanization as a technology enhancement measure. This determines whether a farm used (rented) a mechanized (service) for either establishing or harvesting the crop. Finally, we add variables related to transaction costs, namely the membership in a rice farmers' association, having received extension or training in rice production, and an adjusted measure of distance to markets.

Based on our theoretical framework, we expect participation in the market to be welfare-enhancing. As a proxy for this, we consider the Poverty Probability Index, which measures the probability of a household falling under the national poverty line. We summarize this measure in Table 2, along with rice acreage and yield metrics. The average farm has a probability of poverty of 43.7%, but non-sellers are roughly 5 percentage points more likely to be poor than market participants, thus consistent with our rationale. Although the range of rice acreage is the same between groups, we find that average non-sellers dedicate roughly 1 ha of land to rice production. On the other hand, their counterparts dedicate an average of 2.23 ha to production. Differences also translate to productivity, with market participants having yields of 2.41 tons/ha, thus closer to the national average[3] than non-sellers who report a yield of 1.62 tons/ha.

Descriptive Statistics of Variables included in the Model

Of the 358 selected small-scale rice farming households, 37.2% participate in the paddy market, and on average, they sold 4.29 tons of rice in the previous season (2013). We report the mean and median of the variables part of the analysis in Table 3. There are no statistical differences in most household demographics and human capital variables between sellers and non-sellers. The share of female-led households, age of the household head, schooling, incidence of food scarcity, number of working-age persons, and number of dependants are statistically the same between groups. Interestingly, net sellers have fewer years of experience with the crop on average (13 years vis-à-vis 18.8 years among non-sellers), which could be connected to newer farmers being more likely to adopt technologies, thus being more productive. Although the number of dependents, on average, is statistically equivalent between sellers and non-sellers, the latter have a slightly larger mean, which translates into additional food demand pressures.

In terms of tangible assets and financial capital, we observe that, as expected, the average farm size differs significantly between sellers and non-sellers (24.31 vis-à-vis to 14.3 ha). Likewise, the former nearly double the likelihood of having their land titled (45.9% of the cases vs. 23.6%), whereas the latter are more likely to have income perceived from off-farm employment (50.2% vs. 36.8%). Non-seller households reported acquiring credit in 4% of the cases, whereas the figure is 15% among those who engage in the paddy rice market. This difference is not unexpected,

[3]The production season of the sample is 2013–2014, which is compared to a 2.7 tons/ha yield at the national level as reported in FAOSTAT (FAO, 2022).

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Table 3. Descriptive statistics of variables included in the double-hurdle model of market participation and rice sales of small-scale farmers in Eastern Bolivia, 2014

		All farms			Sellers			Non-sellers			
Variables		Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	DM*
Participates in the market (1 = Yes)	%	37.2%		0.48	100.0%		0	0.0%		0	–
Total paddy rice sales	tons	1.59	0	3.49	4.29	2.21	4.60	0.00	0	0	0.0000
Household demographics and human capital											
Sex of the head of the household (1 = Woman)	%	4.2%		0.20	5.3%		0.22	3.6%		0.19	0.4359
Age of the head of the household	years	44.91	45	12.07	44.14	44	11.57	45.37	45	12.36	0.3427
Years of experience producing rice	years	17.26	15	11.94	14.59	10	10.17	18.83	15	12.63	0.0006
Number of working-age persons in the household		3.01	3	1.51	2.98	2	1.58	3.03	3	1.46	0.7840
Number of dependents in the household		1.91	2	1.63	1.77	1	1.65	2.00	2	1.62	0.1948
Education of the head of the household (schooling)	years	5.59	5	3.42	5.72	5	3.12	5.52	5	3.59	0.5687
Food scarcity in the household (1 = Yes)	%	48.9%		0.50	45.1%		0.50	51.1%		0.50	0.2726
Household's tangible assets and financial capital											
Size of the farm	ha	18.00	9.5	19.69	24.23	16	19.94	14.31	4	18.63	0.0000
Titled land (1 = Yes)	%	31.8%		0.47	45.9%		0.50	23.6%		0.43	0.0000
Household Asset Index		0.25	0.18	0.21	0.26	0.19	0.22	0.25	0.18	0.20	0.614
Off-farm employment (1 = Yes)	%	45.3%		0.50	36.8%		0.48	50.2%		0.50	0.0140
Sold crops other than rice (1 = Yes)	%	25.1%		0.43	36.1%		0.48	18.7%		0.39	0.0002
Sold animals (1 = Yes)	%	27.9%		0.45	24.1%		0.43	30.2%		0.46	0.2092
Acquired credit (1 = Yes)	%	8.1%		0.27	15.0%		0.36	4.0%		0.20	0.0002
Technology adoption in rice crops											
Improved rice varieties (1 = Yes)	%	30.7%		0.46	33.1%		0.47	29.3%		0.46	0.4575
Agrochemicals (1 = Yes)	%	56.1%		0.50	68.4%		0.47	48.9%		0.50	0.0003
Fertilization (1 = Yes)	%	7.0%		0.26	12.8%		0.34	3.6%		0.19	0.0009
Mechanization (1 = Yes)	%	16.8%		0.37	25.6%		0.44	11.6%		0.32	0.0006
Transaction costs											
Extension or training (1 = Yes)	%	18.4%		0.39	25.6%		0.44	14.2%		0.35	0.0075
Part of a rice farmers' association or cooperative (1 = Yes)	%	8.4%		0.28	18.0%		0.39	2.7%		0.16	0.0000

(*Continued*)

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Table 3. (*Continued*)

Variables		All farms			Sellers			Non-sellers			
		Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	DM*
Travel Effort Index	km	81.80	51.66	81.83	55.20	36.46	52.64	97.53	63.46	91.49	0.0000
Department where the farm is located											
Beni	%	46.4%		0.50	28.6%		0.45	56.9%		0.50	0.0000
Cochabamba	%	16.8%		0.37	20.3%		0.40	14.7%		0.35	0.1679
Santa Cruz	%	36.9%		0.48	51.1%		0.50	28.4%		0.45	0.0000
Number of observations		358			133			225			

**p*-Value for test for difference in means between net sellers and non-sellers. Pearson Chi-square test for binary covariates.

considering the previously mentioned differences in land endowments and titling. Nevertheless, we do not observe any significant difference in the cases of the Household Asset Index or income-generating animal sales. Also, sellers have a more likely diversified production schedule, with 36.1% of households earning income from other crops, while non-sellers only reported sales of other crops on 18.7% of the cases.

There are strong asymmetries on most dimensions of technology adoption except that of improved varietal use, depending on whether the household engages in rice trade – with non-sellers being on the less intensive side of adoption. Some of the detected differences, however, are stronger than others. For instance, net sellers are more likely to use agrochemicals than non-sellers by roughly 19.5 percentage points, while that change is about 9 percentage points for fertilization. Meanwhile, mechanization reports a difference in adoption of slightly over 14 percentage points (25.6% for sellers and 11.6% for non-sellers).

Finally, from the side of factors affecting transaction costs, non-seller households report having received training or extension services for rice production over the past production season (2013) 14.2% of the time, whereas sellers reported receiving that 25.6% of the time. Also, the difference in associativity is striking: while 18% of farming households that engage in rice trade are part of a producers' association or cooperative, that metric is only 2.7% among non-selling farming households. Similarly, it is worth noting that the average distance to markets – captured in the Travel Effort Index – reveals that the effective absolute distance more than doubles when comparing sellers and non-sellers. The highlighted differences between sellers and non-sellers across demographic, financial, and technological dimensions further support the need for a systematic analysis to understand how these factors jointly drive market participation and final sales.

Econometric Approach

Empirically, we observe whether a rice farming household participates in the market and total paddy sales. However, the total sales are zero if a farmer does not enter the market; hence, the nature of the data makes a linear specification inadequate to model the expected value (Mather, Boughton, and Jayne, 2013; Wooldridge, 2010). Although one might easily confuse this problem with one of sample selection (Heckman, 1979) within the data – that is, taking no sales as a "missing value" rather than zero – we are departing from a principle of maximization in which making no sales ($v_r = 0$) reflects a rational decision (corner solution) from the farming household (Alene et al., 2008; Boughton et al., 2007; Makhura, Kirsten, and Delgado, 2001; Olwande et al., 2015). We use the two-part extension of the type I Tobit model formulated by Cragg (1971), usually referred to as the truncated normal hurdle (or double-hurdle) model (Wooldridge, 2010). This allows the underlying coefficients of the probability of participation to differ from those of the extent of sales.

Let ω be a binary variable that takes the value of 1 if a household engages in trade and 0 otherwise. Also, let y be the total paddy rice sales that follow

$$\begin{gathered} y = \omega y^* \\ y^* = \mathrm{x}\boldsymbol{\theta} + \varepsilon \end{gathered} \tag{8}$$

where y^* is a nonnegative latent variable, $\mathrm{x}' \in \mathbb{R}^k$ contains observed attributes of the household, and $D(\epsilon|\mathrm{x})$ is truncated normal with a lower bound at $-\mathrm{x}\boldsymbol{\theta}$ and variance σ^2 (Wooldridge, 2010). Moreover, with $\mathrm{m}' \in \mathbb{R}^j$ also a set of household attributes, define the probability of market participation as:

$$P(\omega = 1|\mathrm{m}) = \Phi(\mathrm{m}\boldsymbol{\beta}) \tag{9}$$

in which Φ is the standard normal CDF, and let ω and y^* be conditionally independent over a set of explanatory variables that are in both x and m. Then, when market participation occurs ($y > 0$), the conditional density of y is

$$f\left(y|\mathrm{x}, \mathrm{m}, y > 0\right) = \left(\frac{1}{\sigma}\right)\frac{\phi\left(\frac{y-\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)}{1-\Phi\left(\frac{-\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)} = \left(\frac{1}{\sigma}\right)\frac{\phi\left(\frac{y-\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)}{\Phi\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)} \tag{10}$$

while the conditional density for *all possible values* of y is

$$f\left(y|\mathrm{x}, \mathrm{m}\right) = [1-\Phi(\mathrm{m}\boldsymbol{\beta})]^{1[y=0]}\left[\Phi(\mathrm{m}\boldsymbol{\beta})\left(\frac{1}{\sigma}\right)\frac{\phi\left(\frac{y-\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)}{\Phi\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)}\right]^{1[y>0]}, \tag{11}$$

so, we can obtain consistent estimates $\widehat{\boldsymbol{\theta}}$ and $\widehat{\boldsymbol{\beta}}$ by quasi-maximum likelihood (QMLE).[4]

Partial Effects

In this nonlinear scenario, we see how the coefficient estimates $\widehat{\boldsymbol{\theta}}$ and $\widehat{\boldsymbol{\beta}}$ would provide us with information about the *direction* of an effect, but of real importance are the partial effects[5] of the covariates. The partial effects from the Probit model are straightforward and are directly connected with our theoretical model through $\partial\delta^s/\partial h$. On the other hand, there are two kinds of conditional expected values of y that are of particular interest – and thus their related partial effects. Namely, we will have the expected value when $y > 0$ and for all possible values of y. These follow:

$$E\left(y|\mathrm{x}, \mathrm{m}, y > 0\right) = \mathrm{x}\boldsymbol{\theta} + \sigma\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right) \tag{12}$$

$$E\left(y|\mathrm{x}, \mathrm{m}\right) = \Phi(\mathrm{m}\boldsymbol{\beta})\left[\mathrm{x}\boldsymbol{\theta} + \sigma\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)\right], \tag{13}$$

where $\lambda(\cdot)$ is the inverse of the Mills ratio. Then, the related partial effects are as follows:

[4]Although the estimates from maximum likelihood (MLE) and QMLE are always identical, the efficiency of standard errors from MLE only occurs whenever both the conditional mean and distribution(s) are correctly specified. Conversely, QMLE only requires a correctly specified conditional mean and then uses a robust estimator of the asymptotical variance, which can be either a sandwich estimator or derived from bootstrapping (see Wooldridge (2010), Ch. 12, 13).

[5]Although these derivatives are defined as partial effects from a statistical point, they should not be considered as *causal effects*, since the changes in covariates cannot be assumed as random.

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$$\frac{\partial E\left(y|\mathrm{x}, \mathrm{m}, y>0\right)}{\partial h}=\theta_h\left[1-\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)\left[\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}+\sigma\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)\right]\right] \tag{14}$$

$$\frac{\partial E\left(y|\mathrm{x}, \mathrm{m}\right)}{\partial h}=\phi(\mathrm{m}\boldsymbol{\beta})\beta_h\left[\mathrm{x}\boldsymbol{\theta}+\sigma\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)\right]+\Phi(\mathrm{m}\boldsymbol{\beta})\theta_h\left[1-\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)\left[\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}+\sigma\lambda\left(\frac{\mathrm{x}\boldsymbol{\theta}}{\sigma}\right)\right]\right], \tag{15}$$

which are directly liked with our theoretical correlations of interest, namely $\partial v_r/\partial h$ and $\partial v_r/\partial h|\delta^s=1$. Thus, while conditional (on $y>0$) average partial effects (*CAPE*) consider only those who did nonzero sales, unconditional average partial effects (*UAPE*) consider the potential effect within the whole sample (Mzyece, 2016).

Although a Tobit model can also be used under our setting, the double-hurdle approach provides greater flexibility: while the Tobit approach requires that $\mathrm{x}=\mathrm{m}$ and $\boldsymbol{\theta}=\boldsymbol{\beta}$, the double hurdle allows $\boldsymbol{\theta}$ and $\boldsymbol{\beta}$ to vary freely and allows for x and m to be in different vector spaces. Therefore, the double hurdle brings fewer assumptions into the empirical strategy. If, for instance, attribute h appears only in the Probit model of market participation, then $\theta_h=0$. Conversely, if h is only a covariate for total sales, then we have $\beta_h=0$. Either way, partial effects are largely simplified when a variable is part of only *one* side of the model.

Finally, due to the two-part nature of the analysis, we rely on cluster-bootstrapping for retrieving valid standard errors[6] (Wooldridge, 2010). Other flexible estimation methods are based on the Tobit II and the log-normal double-hurdle models, but our specification tests suggested that QMLE based on the truncated normal double-hurdle should be the preferred estimator (see Supplementary Materials A.1.).

Results

We report the estimated partial effects of interest in Table 4. The average partial effect (*APE*) of the covariates on the probability of market participation are those in column (1), while columns (2) and (3) present their conditional and unconditional (on participation) average partial effects on total paddy rice sales (i.e., *CAPE* and *UAPE*), respectively. From the side of market participation, we find that, as the household head is older, the probability of participating in the market increases. Although weakly significant, an additional year of age is correlated with a 0.5 percentage point increase in the probability of participation. Such a finding is similar to that of Goetz (1992), suggesting that older leaders in the household are better connected and more experienced in dealing with intrinsic aspects of local markets. However, other demographic and human capital variables show no significant effect on participation.

In terms of assets and financial capital, our results suggest that farm size is not correlated with market participation. On the other hand, farming households that acquired credit were 22.7 percentage points more likely to participate in the market than those who did not access credit. Conversely, when sales of crops other than rice take place, these are correlated to a 9.4 percentage point (weakly significant) increase in the probability of participation. When it is found that a household receives income from animal sales or off-farm employment, the probability of market participation decreases by roughly 9.5 and 11.9 percentage points, respectively. Our findings are in line with those of Alene et al. (2008), Barrett (2008), and Musah, Bonsu, and Seini (2014), which point to credit access as a mechanism to further invest in production, hence increasing the probability of market participation. However, differing from the findings of Boughton et al. (2007) that suggest that animal-derived income positively correlates with participation, we estimate a

[6]Since the double-hurdle model implements a first-stage Probit regression, then there is a potential problem of estimation error within the second-stage standard errors. Also, as the primary sampling unit is a community cluster, we implement a cluster bootstrap that does resampling at the community level. Hence, the standard errors are robust to cluster correlation and distributional misspecification.

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Table 4. Average partial effects on the probability of market participation and total paddy rice sales from the double-hurdle model for small-scale farmers in Eastern Bolivia, 2014

	(1)	(2)	(3)
	Probability of participation	Total sales	Total sales
Variables	*APE*[a]	*CAPE*[a]	*UAPE*[a]
Household demographics and human capital			
Sex of the head of the household (1 = Woman)	0.014	−1.781*	−0.461
	(0.115)	(1.000)	(0.523)
Age of the head of the household (years)	0.005*	−0.034	0.004
	(0.002)	(0.038)	(0.017)
Years of experience producing rice	−0.006	−0.199*	−0.087*
	(0.010)	(0.119)	(0.049)
Years of experience producing rice (square)	−5.6E-5	0.004	0.001
	(2.2E-4)	(0.003)	(0.001)
Number of working-age persons in the household	0.003	−0.473*	−0.144
	(0.013)	(0.262)	(0.096)
Number of dependents in the household	−0.009	−0.589**	−0.225**
	(0.015)	(0.232)	(0.114)
Education of the head of the household	0.007	0.276***	0.114**
	(0.007)	(0.105)	(0.052)
Food scarcity in the household (1 = Yes)	−0.016	−0.559	−0.234
	(0.048)	(0.894)	(0.351)
Household's tangible assets and financial capital			
Size of the farm (in logarithmic scale)	0.028	0.977***	0.414**
	(0.017)	(0.359)	(0.166)
Titled land (1 = Yes)	0.059		0.197
	(0.067)		(0.261)
Household Asset Index	−0.211*		−0.698
	(0.113)		(0.439)
Off-farm employment (1 = Yes)	−0.119***		−0.399**
	(0.036)		(0.141)
Sold crops other than rice (1 = Yes)	0.094*		0.316*
	(0.050)		(0.185)
Sold animals (1 = Yes)	−0.095**		−0.319*
	(0.041)		(0.177)
Acquired credit (1 = Yes)	0.227***	0.798	1.09**
	(0.074)	(0.825)	(0.493)
Technology adoption in rice crops			
Improved rice varieties (1 = Yes)	0.017	1.046	0.419
	(0.056)	(0.663)	(0.379)

(*Continued*)

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Table 4. (*Continued*)

Variables	(1) Probability of participation *APE*[a]	(2) Total sales *CAPE*[a]	(3) Total sales *UAPE*[a]
Agrochemicals (1 = Yes)	0.092*	2.536**	0.975**
	(0.049)	(1.284)	(0.398)
Fertilization (1 = Yes)	0.133	1.081	0.901*
	(0.089)	(0.731)	(0.546)
Mechanization (1 = Yes)	0.030	2.099***	0.858
	(0.072)	(0.759)	(0.477)
Transaction costs			
Extension or training (1 = Yes)	0.035	−1.705***	−0.414
	(0.074)	(0.644)	(0.277)
Part of a rice farmers' association or coop. (1 = Yes)	0.271***	3.195***	2.747**
	(0.086)	(0.986)	(0.874)
Travel Effort Index	−0.000		−0.001
	(0.000)		(0.002)
Department controls			
Cochabamba	−0.081	1.468	0.201
	(0.113)	(1.555)	(1.126)
Santa Cruz	0.036	2.938*	1.029
	(0.073)	(1.639)	(0.811)
Number of observations	358	133	358

Probit regression: Wald test $\chi^2(24) = 96.64$, p-value $= 0.000$.
Truncated regression: Wald test $\chi^2(18) = 69.96$, p-value $= 0.000$.
Cluster bootstrap standard errors (1,000 reps.) in parentheses. *$p < 0.1$; ** $p < 0.05$; ***$p < 0.01$.
[a]Reporting average partial effects (*APE*), average partial effects conditional on market participation (*CAPE*), and unconditional average partial effects (*UAPE*).

negative effect. Nonetheless, our finding is feasible within the theory – diversification on small scales can lead to autarkic production – and by empirical results of Woldeyohanes, Heckeley, and Surry (2017) and Makhura, Kirsten, and Delgado (2001), with the latter pointing to the demand for in-household labor from other activities as a source of the negative effect. Also, as we derive our analysis from a cross section, we cannot consider, for instance, the seasonality of variables correlated with profits from animal sales.

Technology adoption is partially correlated with market participation. We find a weakly statistically significant average partial effect for the case of agrochemicals correlated to an increase in the probability of participation by 9.2 percentage points. Finally, among the factors associated with transaction costs, there are no significant partial effects from extension or training on participation, nor the distance to markets, as captured by the Travel Effort Index. Nevertheless, a significant partial effect arises from being part of an association or cooperative: on average, this is correlated to an increase in the probability of participation by roughly 27.1 percentage points. This further highlights the crucial role played by associativity in the Bolivian rice sector, which favors technological dissemination (Martinez et al., 2021; Ortiz and Soliz, 2007) and market participation, according to our findings.

Now, we focus on total sales of paddy rice, for which we have both conditional and unconditional average partial effects – reporting the latter in parentheses in what follows. An additional year of education by the household head increases sales of paddy rice, on average, by roughly 0.276 tons (0.114 tons). The literature often points to a lack of education as a barrier to entering markets (Musah, Bonsu, and Seini, 2014; Olwande et al., 2015; Sigei, 2014), and it is also true that higher education allows farmers to make better choices according to market conditions, thus likely making more efficient sales. On the other hand, for each additional dependent in the household, total sales are expected to be reduced by roughly 0.589 tons (0.225 tons), on average. Also, on average, sales are expected to be reduced for each additional working-age person in the household, although the effect is weakly significant (and insignificant in the unconditional case), likely reflecting additional food demand in the household. We do not detect any difference in sales based on food scarcity or the age of the household head. However, we find that the average effect of an additional year of experience producing rice is weakly connected to a total sales reduction of 0.199 tons (0.08 tons). Also, female-led households that participate in the market sell 1.78 tons less than other farmers, on average. In terms of assets and financial capital, we find that a 10% increase in farm size is related to an increase of 0.097 tons (0.041 tons) of paddy rice sales, so larger capacities are naturally connected to larger sales. Credit is only related to sales on the unconditional case (i.e., the estimated potential effect across *all* in-sample farmers), suggesting an increase of 1.09 additional tons of sales when credit is available. Our finding on farm size and credit availability is consistent with previous findings in developing countries (Abera, 2009; Alene et al., 2008; Olwande et al., 2015; Woldeyohanes, Heckeley, and Surry, 2017).

Among the factors associated with transaction costs, we find a negative effect from extension or training (although in the unconditional effect is insignificant). Our analysis suggests that, on average, those who received extension or training sell, on average, about 1.7 tons less than those who did not receive such services. Although counterintuitive at first hand, the result should not be unexpected. It is worth asking *who makes use of that kind of service* from the start, which reveals that those who received (accessed) training and extension were likely in the lower bound of crop expertise beforehand[7] – even if they produced enough to enter the market. Finally, our findings point to the crucial relevance of membership in a farmers' association to reduce transaction costs, thus increasing sales. On average, members of an association sell an additional 3.19 tons (2.74 tons) than non-associated farmers.

From the side of technological enhancements, we find that agrochemicals and mechanization use are correlated with total sales, although weakly. Respectively, these imply differences in the average total sales of 2.53 and 2.09 tons each compared to those who do not use those technologies. The unconditional effect is only significant in the case of agrochemicals. These findings are consistent with previous results of two-part model analyses found in Musah, Bonsu, and Seini (2014), Reyes et al. (2012), and Barrett (2008), revealing that technology implementations are related to productivity increases that are correlated with both increased probabilities of market participation and intensity of sales, especially across small-scale farmers (Alene et al., 2008; Olwande et al., 2015). Finally, farms located in the department of Santa Cruz vastly exceed the average sales of farms (additional 2.93 tons in the *CAPE*, although insignificant for the *UAPE*) that are either in the Beni or Cochabamba departments. Given that Santa Cruz is the department with the highest concentration of *playas*, the result is consistent with the local conditions and likely explains the apparent no-correlation of sales with distance to markets (i.e., most distance effect is pooled into the Santa Cruz binary control).

[7]Another reading could go along the way of "*extension and training decrease total sales*," but we restrain ourselves from making such a claim as there is no exogenous variation to categorize it as that kind of causal effect.

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Discussion

As one of Bolivia's most consumed and produced agricultural products, rice has become a strategic crop to achieve objectives of food security and improved livelihoods in rural areas. Policy efforts to bring change into a crop's productive sector via technological transformation and increased market participation are common in the developing world (Olwande et al., 2015), including Bolivia (Larochelle and Alwang, 2015), but these may not be as successful as expected, especially among small farmers (Barrett, 2008). Although small-scale production represents the vast majority of rice-producing households in Bolivia, only a fraction of them engage in trade (Ortiz and Soliz, 2007), which, in addition to the existence of market failures, further limits the extent to which their welfare can be improved via production enhancement. Based on a nationally representative sample, nearly half of the rice farmers are producing only for self-consumption. Also, within a subsample of comparable rice acreage, we find that market participants are more productive and are less vulnerable to poverty. We provide results pointing to feasible factors and mechanisms that can increase the probability of participation and the extent of market participation, thus serving as potential recommendations for public policy targeting.

Our analysis suggests that participation is highly correlated with factors of financial capital, technology adoption, and determinants of transaction costs. Factors such as the acquisition of credit and alternative income sources play an important role in affecting the market participation of rice farmers. Specifically, income generated from the sales of animals (or their by-products) significantly decreases the probability of participation, whereas sales of other crops are correlated positively with participation. Credit acquisition remains an important channel to keep farmers enrolled in production, so efforts toward a more robust and accessible market for agricultural finance are likely to help increase the market participation of smallholder farmers. Farmers' connectedness through producers' associations or cooperatives is also a major driver of market participation, and we argue that its relevance comes through a channel of decreasing transaction costs. Such a finding builds on recent evidence around the Bolivian rice sector that highlights the strong incidence of associativity in technological enhancement. Strengthening the national and regional systems of association is, therefore, a strong mechanism for leveling the ground for producers when bargaining prices in regional *playas* in addition to their potential to disseminate technologies.

Finally, we find that determinants of total paddy rice sales are mostly found on the side of the relative productive scale, potential household food demands, and transaction costs – mainly through membership in farmers' associations. Using agrochemicals (pest and disease controls) and mechanization significantly increase the expected total sales from small-scale farmers. Therefore, our results further highlight the need to foster technological adoption, which is reportedly limited in the Bolivian rice sector (Martinez et al., 2021). Larger and steadier participation in the market serves not only to increase producers' revenues but also to provide local systems with sufficient production, which can help in the stabilization of consumer prices. Altogether, the results also support previous findings on the Bolivian rice sector: even when focused on small-scale rice farmers, market participation and extent of participation are strongly influenced by the size of the productive land. Following the existence of market failures, participation is not fully determined by land availability or prices, so efforts to better target and engage producers with less land – even *within* the segment of small-scale farming – are needed for guaranteeing equitable growth.

Our findings provide additional and valuable insight into the landscape of rice farming in Bolivia, with a focus on small-scale farming. Our data suggest that, although the adoption of modern improved varieties is rather low, efforts from the Bolivian rice breeding program have been able to reach both commercial and self-consumption farmers. This means that although further efforts to promotion are needed to reach higher levels of adoption, these will likely reach all scales of production, thus opening a window for potential impacts not only on productivity but

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also in nutrition with the dissemination of biofortified materials (Viruez et al., 2016). Also, we find that rice farmers' associations play a crucial role in increasing participation and total sales, thus highlighting a channel that should be strengthened by public policies. As suggested by Markelova et al. (2009), these organizations increase the bargaining power of their associates, serving as a bridge to resolve coordination and market inefficiencies. Unfortunately, under the conditions that define the structure of the Bolivian paddy rice market – highly volatile prices, suboptimal pricing, and high transaction costs (Taboada and Viruez, *personal communication*, March 2023) – additional incentives are driving small-scale farmers to venture out of selling paddy rice, with many reported cases (especially subsistence farmers) being forced to abandon their rural vocation. Our results, thus, cast light on potential channels that can be strengthened to revert such a trend, providing paths for increasing participation, production, and welfare of small-scale Bolivian rice farmers.

Although our findings provide relevant insights based on the only available nationally representative sample of rice farmers in the country, there are limitations that should be considered and addressed in future research. First, our analysis is based on partial correlations that cannot be asserted as causal. Therefore, although our estimates are qualitatively appealing, the exact magnitude of the effects remains to be explored. Studies exploiting exogenous variations on factors connected to proportional and fixed transaction costs would prove useful in quantifying the causal effects on market participation. Second, despite the suggestions from experts pointing to the available data as still representative of local conditions, more recent data are crucial for validating our analysis. Third, detailed and representative information on market-level data should be brought into the analysis. While our analysis exploits all available information at the farmer level, the dynamics of bargaining between farmers and sales intermediaries remain insufficiently explored and should be considered in future analyses.

Conclusion

Despite the relevance of rice farming as an income and food security crop in Bolivia, the market participation of small-scale rice farmers remains low. This limits the potential for welfare enhancement that can be achieved by national research programs aiming at the technological improvement of the crop. Our findings suggest that strengthening credit channels can increase market participation and sales. A central finding of our analysis is the strong relevance of membership in a farmer association in increasing the probability of market participation and final sales, likely by means of improving coordination and bargaining power. Overall, our finding suggests that efforts to promote the joint expansion of credit channels, technology adoption, and collective action are key to improving the livelihoods of small-scale Bolivian rice farmers.

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Data availability statement. Implemented data and replication codes will be provided by the corresponding author upon request.

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Competing interests. The authors declare none.

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