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**Article**

# Assessing the benefits of green super rice in Sub-Saharan Africa: Evidence from Mozambique

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## Abstract

In Mozambique, smallholder farmers commonly grow rice under rainfed systems with limited fertilizer application; thus, productivity remains very low. Moreover, the adoption rate of improved rice varieties is as low as 3 per cent, partly because these varieties usually require an irrigated environment with the use of fertilizer. Green super rice (GSR) varieties are expected to sustain high yield potential under severe stress conditions. This article used farm-level survey data collected in Mozambique to assess the benefits of the adoption of a GSR variety (*Simão*) on the yield and cost efficiency of smallholder rice producers. The econometric approach involves propensity score matching and a simultaneous equation model with endogenous switching regression to account for observable and unobservable factors that affect adoption and outcome variables. The results indicate positive and significant benefits from adopting GSR on rice yield and cost efficiency for adopters. These benefits are observed not only in irrigated environments where fertilizer is applied together with some more advanced farming practices (i.e. Gaza province), but also in Nampula and Sofala provinces where farmers grow rice under rainfed conditions with no fertilizer application. Our findings suggest that GSR varieties have the potential to bring some positive changes in the development of rice production in Mozambique.

**Keywords:** Impact assessment, Rainfed rice production, Endogenous switching regression

**JEL codes:** O1, O3, Q0, Q1

## 1. Introduction

In Mozambique, about 98 per cent of the rice cultivation area is operated in unirrigated conditions (Kajisa and Payongyong 2011), with an average productivity of 0.8–1.2 t/ha (Ministry of Agriculture 2009). The average irrigated yield remains 1.6–2.0 t/ha (Larson *et al*. 2020) because of limited chemical application. According to ACI (2005), only 2.5 and 5.2 per cent of farmers use fertilizer and pesticide, respectively. Lack of irrigation and the absence of fertilizer use are the main constraints to rice production (Kajisa 2016), along with the increasing variability of climate stresses (Balasubramanian *et al*. 2007).

Given the above constraints and challenges, one solution resides in promoting new rice varieties that can sustain high and stable yields under limited chemical inputs and rainfed systems. Examples of such varieties include green super rice (GSR) varieties. GSR varieties have been disseminated in several provinces of Mozambique since 2012. In this study, we aim to assess the benefits of adopting the GSR varieties and discuss their potential role in enhancing Mozambique's rice production.

The existing evidence on the performance of GSR in Africa is limited to the yield advantage revealed by experimental agronomic trials (Dessie *et al.* 2020; Yu *et al.* 2020). The impact evaluation of GSR varieties on the African continent, in general, and Mozambique has not been explored using household-level data. To our knowledge, no existing impact assessment studies use rigorous econometric techniques to assess the impact of GSR varieties on farm performance in Africa. This study therefore fills part of this large research gap by examining the effects of the adoption of GSR varieties on rice yield and the cost efficiency of smallholder Mozambique farmers. We use cross-sectional data from a survey conducted in three provinces of Mozambique. The study uses the propensity score matching (PSM) technique combined with the endogenous switching regression (ESR) method to control for observable and unobservable factors that might affect the adoption of GSR varieties and the resulting outcomes. The study finds that smallholders who adopted GSR (*Simão*) increased their rice yield by about 10.0 per cent on average. In the case of non-adopters, rice productivity would have increased by 9.8 per cent if they had adopted GSR. The GSR growers improved their cost efficiency by 26.4 per cent by adopting *Simão*. Non-adopters would have improved their cost efficiency by 45.7 per cent had they adopted *Simão*. Additionally, we find regional heterogeneity of the impact of GSR adoption on rice productivity and cost efficiency.

The rest of the article is structured as follows. The following section provides background information on the country's situation regarding production, consumption, import of rice and the adoption of improved rice varieties including GSR. The econometric method used for assessing the benefit of GSR on yield and cost efficiency is presented next, followed by data description. After presenting our results and discussion with some recommendations for future studies, the article ends with some conclusions.

## 2. Background

### 2.1. Production, consumption, and import of rice

A recent report by Nigatu *et al.* (2017) shows that consumer preferences and consumption patterns in Sub-Saharan Africa (SSA) are changing from traditional foods to rice because of economic growth and urbanization. According to the authors, SSA's total rice consumption is projected to reach 36 million tons by 2026, and the region is likely to become the leader in global rice imports (Nigatu *et al.* 2017). In Mozambique, rice consumption increased rapidly from 86,000 tons in 1990 to 884,000 tons in 2021 (USDA 2021). However, local rice production reportedly provides only one-third of the consumption requirement, indicating that national rice production has not been able to keep up with consumer demand (Kajisa 2016). Figure 1 shows the increasing trend in rice consumption and imports in Mozambique from 1990 to 2021. Despite efforts to raise productivity and increase local production, the self-sufficiency ratio remains around 30 per cent (USDA 2021).

With increasing rice prices in the world market and the threat of climate change to production, rice consumers—particularly those dependent on imported rice—may face increasingly limited accessibility to rice, and this could adversely affect food security (cf. Balasubramanian *et al.* 2007).

### 2.2. Adoption of improved rice varieties

The adoption rate of improved rice varieties in Mozambique is low, about 3 per cent (USAID 2017). Most farmers use either traditional rice varieties or improved varieties developed in

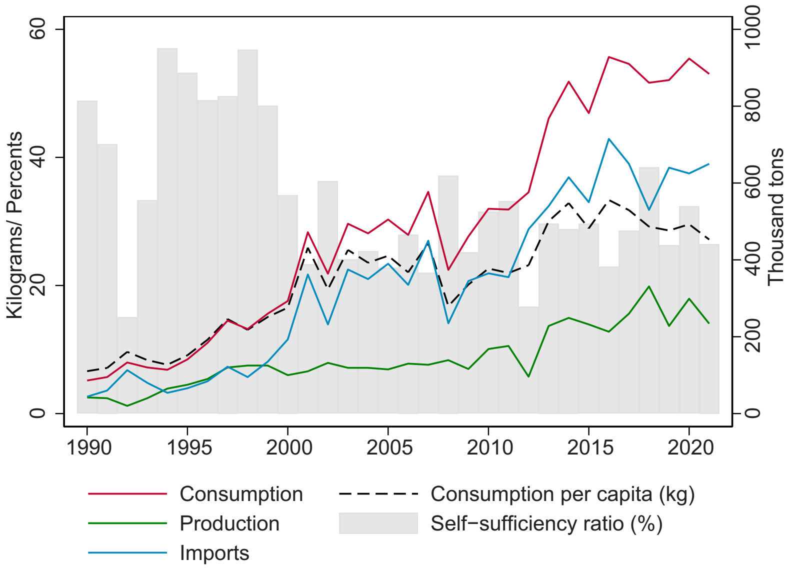


**Figure 1.** Production, consumption, and imports of rice in Mozambique, 1990–2021 (source: USDA 2021).

the 1970s or earlier (ACI 2005). The low adoption rate has its roots in the agronomic conditions for rice production. In Mozambique, most farming lands are located in lowland areas and rely on rainwater. The lack of irrigation systems forces farmers to stick to traditional varieties adapted to rainfed conditions. Only 3 per cent of the potential agricultural land in Mozambique is irrigated (FAO 2019), and only 2.3 per cent of the total rice area is estimated to be under irrigation (Kajisa and Payongyong 2011). Therefore, rice farmers face uncertainties on weather shocks such as drought (FAO 2019). As traditional varieties are more robust to climate stress in general, adopting new improved varieties involves risks for rainfed lowland and upland farmers.

Mozambique has the potential to increase rice area to 900,000 ha, accounting for 35 per cent of the total cultivated area. Most of the rice production is concentrated in five provinces: Gaza (south Mozambique), Zambezia and Sofala (central Mozambique), and Nampula and Cabo Delgado (north Mozambique). Rice farmers face several problems in rice production, including the lack of technology, improved seeds and fertilizer, irrigation facilities, extension services, and government support. Gaza remains the only exception, with irrigation facilities established across the province. Most farmers in other parts of the country follow traditional cultivation practices (i.e. no chemical application) under rainfed lowland or upland ecosystems. The low fertilizer use is due to households' inadequate financial resources (FAO 2019) and market failure factors (such as lack of access to credit, banks, output markets, and market integration).[1] The poorly organized seed system also represents a major constraint to farmers in having access to improved seeds. In Mozambique, most farmers use leftover seeds from the previous harvest or buy seeds from a local informal supplier (FAO 2019). Currently, the private sector produces and commercializes only improved seeds for irrigated ecosystems (USAID 2017). Therefore, improved varieties that sustain higher yields under rainfed conditions and that can be multiplied by farm households are needed.

## 2.3. GSR varieties

GSR varieties were developed by integrating genomic resources, molecular biology technologies, and breeding processes while targeting desirable traits

(Zhang 2007; Yu *et al.* 2020). These varieties have numerous properties such as high efficiency of fertilizer use, drought tolerance, submergence tolerance, biotic stress resistance (to pests and diseases), good grain quality, and increased yield potential (Li and Ali 2017). These properties are expected to enable farmers to bring about sustainable production in economic terms appropriate for rice cultivation in rainfed and/or limited-input conditions (Yu *et al.* 2020). The rainfed lowland ecosystem, which accounts for about 33 per cent of the global rice-growing area (GRiSP 2013), is where GSR varieties can positively impact rice production and farmer income. Rainfed lowland rice production is often exposed to multiple abiotic and biotic stresses, conditions in which modern rice varieties designed for irrigated ecosystems—typically with tolerance for only one abiotic stress such as drought—have a limited advantage in productivity. Moreover, modern rice varieties require fertilizer and chemical inputs for higher and more stable production, which smallholder farmers in rainfed ecosystems usually cannot afford (Li and Ali 2017).

The relative advantage of GSR varieties compared with other released varieties in the same ecosystem (i.e. irrigated and rainfed conditions) has been evaluated in experimental trials. For instance, Dessie *et al.* (2020) showed that GSR variety *Yungeng 31 (Selam)*, whose characteristics include high yield, cold tolerance, and disease resistance, outperformed the best available varieties by 1.2 t/ha in Ethiopia in a rainfed ecosystem. Likewise, other GSR varieties, such as *Okile* in Uganda and *Buryohe* in Rwanda, outperformed the best available varieties by more than 1 t/ha in an irrigated environment (Yu *et al.* 2020).

The development of GSR varieties in Mozambique involved the screening of elite lines. After evaluating 88 promising GSR cultivars using adaptation trials, two varieties, *Simão* and *Hua564*, were officially released.[2] These two varieties are tolerant of drought and low input, have pest and disease resistance, and are suitable for rainfed ecosystems. Their growth duration is 133 and 127 days, respectively. They are medium- and long-grain varieties with lodging resistance, milling recovery of 74 per cent, good threshing ability, and yield potential of 10 t/ha (in irrigated environments) and 4–5 t/ha (in rainfed environments). More GSR materials were subsequently developed and underwent multi-environment trials (Yu *et al.* 2020) in the major rice ecosystems. From 2013 to 2018, 138 tons of *Simão* and *Hua564* seeds were produced and distributed in Maputo, Gaza, Inhambane, Sofala, and Zambezia to ensure seed availability for farmers. In 2019, seed production for these two varieties was further expanded to include the provinces of Cabo Delgado and Nampula.

Seed dissemination was complemented by information campaigns about GSR technologies (i.e. production techniques, fertilizer use, and weeding methods). Note that these campaigns did not involve any provision of chemical fertilizer or pesticide. The information campaigns included workshops for farmer groups and extension agents in Gaza province, extension agent training sessions, and demonstration plots in 68 farmer association fields and 15 research stations. These efforts reached more than 330 extension agents and about 2,500 farmers. Moreover, mass media outlets (i.e. radio and television) broadcast information about GSR varieties to farmers in target ecosystems throughout the country. Several GSR cultivars are disseminated in several regions of Mozambique, including the areas where farmers used to cultivate only traditional varieties under traditional farming practices, and Gaza province, where rice farming is mainly conducted with irrigation facilities and fertilizer applications. In 2019, the estimated area under GSR varieties was about 84,000 hectares, thus accounting for about 20 per cent of the rice-growing area (USDA 2021).

## 3. Econometric method

To investigate the effects of GSR adoption on yield and cost efficiency, we combined two econometric approaches for impact assessment: PSM and ESR. Farm households that grow GSR varieties are the treatment group, whereas the control group consists of farm households that use non-GSR varieties (other improved and traditional varieties).

Farm households that grow GSR varieties were exposed to the dissemination program and may have self-selected into the treatment group. Their socioeconomic and farm characteristics are likely to have a sample selection bias (Heckman 1979). Thus, the treatment is endogenous. Although the PSM approach accounts for selection bias due to observed characteristics, ESR has the advantage of accounting for selection bias due to both observed and unobserved characteristics (Mishra *et al.* 2017). However, ESR imposes relatively strong assumptions on the covariance matrix for identification and is sensitive to outliers (Greene 2012). We alleviate such concerns by excluding outliers in the PSM framework and referring to the statistical tests. This justifies the choice of combining the two econometric approaches in this article.

PSM has been frequently employed to assess the impact of technology adoption (e.g. Hossain *et al.* 2006; Crost *et al.* 2007; Yorobe *et al.* 2016). The PSM technique can only alleviate selection biases arising from observable factors (selection on observables) but cannot mitigate biases caused by unobservable factors (selection on unobservables). As Cameron and Trivedi (2005) discussed, PSM compares 'similar' individuals among the treatment and control groups based on observed characteristics. A probit model is first estimated using observed socioeconomic and farm characteristics as determinants of GSR adoption in the PSM approach. Second, the control and treatment groups are matched using the estimated probability from the probit model. We consider the nearest neighbor (NN) matching with replacement outlined in Caliendo and Kopeinig (2008).[3,4] Compared with other matching techniques, NN matching nearly always estimates the average treatment effects (ATEs) on the treated, ATT, which is a critical estimate in our ESR estimation (Stuart 2010). The NN matching with replacement increases the matching quality and minimizes bias by only using samples with the most similar characteristics (Smith and Todd 2005). After removing the observations that fall outside the range of common support, the remaining sub-sample (GSR adopters and GSR non-adopters) is then used in the ESR estimation. We use farm and household characteristics as controls in the PSM.

The ESR framework follows a procedure that involves a joint estimation of a selection equation and an outcome equation (cf. Fuglie and Bosch 1995; Di Falco *et al.* 2011; Mishra *et al.* 2017). In the ESR model, the expected utility of growing a GSR variety, $A^*_{i,\ T}$, is compared with the expected utility of non-adoption, $A^*_{i,\ C}$. Farmers grow GSR varieties if $A^*_{i,\ T} > A^*_{iC}$ and do not adopt if otherwise. Let $Z_i$ be a set of factors that affect their choice of adoption (expected utility of adoption), $\gamma$ a parameter to be estimated, and $\varepsilon_i$ an error term with mean zero and variance $\sigma^2$. A binary choice selection equation is then defined as

$$A^*_i = Z'_i\,\gamma + \varepsilon_i, \tag{1}$$

with $A^*_i$ being a latent variable that determines farmers' adoption and $A_i$ as

$$A_i = \begin{cases} 1 \text{ iff } A^*_{i,T} > A^*_{iC}\ , \\ 0 \text{ iff } A^*_{iT} < A^*_{iC}\ . \end{cases} \tag{2}$$

Although ordinary least squares estimates of equation (1) will be biased because $A_i$ is a binary choice variable, a limited dependent variable model such as a probit model can consistently estimate the equation (Maddala 1986).

In the outcome equation, a two-regime equation is estimated, where Regime 1 explains the outcome variables of interest (i.e. logarithm of yield and cost efficiency) for adopters and Regime 2 estimates the same for non-adopters. Let $Y_i$ be the outcome variable, $X_i$ a set of factors that affect the outcome, and $\beta$ the parameters to be estimated. The error terms $u_{1i}$ and $u_{2i}$ are assumed to be normally distributed with zero mean and constant variances, $u_{1i} \sim N(0,\ \sigma_1^2)$ and $u_{2i} \sim N(0,\ \sigma_2^2)$.[5] The two regime equations are defined as

$$\text{Regime 1}: Y_{1i} = X'_{1i}\,\beta_1 + u_{1i} \text{ iff } A_i = 1, \tag{3.1}$$

$$\text{Regime 2: } Y_{0i} = X'_{2i}\,\beta_2 + u_{2i} \text{ iff } A_i = 0. \tag{3.2}$$

A covariance matrix of $u_{1i}$, $u_{2i}$, and $\varepsilon_i$ is given as

$$\text{Cov } (u_{1i},\ u_{2i},\ \varepsilon_i) = \begin{bmatrix} \sigma_1^2 & & \\ . & \sigma_2^2 & \\ \sigma_{1\varepsilon} & \sigma_{2\varepsilon} & \sigma^2 \end{bmatrix}. \tag{4}$$

We cannot identify the covariance between $u_1$ and $u_2$ because Regimes 1 and 2 are not observed simultaneously (Greene 2012). The covariances between $u_{1i}$ and $\varepsilon_i$ and between $u_{2i}$ and $\varepsilon_i$ ($\sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$) are non-zero, which represent fundamental assumptions for ESR models (Maddala 1986). The variable $Z_i$ is allowed to overlap with $X_i$, but at least a unique variable should be included, which would work as an instrument (Cameron and Trivedi 2005). As instruments, we use two distance variables—walking distance from the seed source and from the extension office—that are not used in the PSM. We conducted a falsification test by Di Falco *et al.* (2011) to confirm the instruments' validity.

Given the above-described assumptions, the ESR model includes inverse Mills ratios (IMRs) in the two-regime equations. The IMRs evaluated at $Z'_i\gamma$ are used to control selection bias. The IMRs in Regimes 1 and 2, $\lambda_1$ and $\lambda_2$, respectively, are given as

$$\lambda_1 = \frac{\phi\left(Z'_i\gamma\right)}{\Phi\left(Z'_i\gamma\right)} \text{ and } \lambda_2 = \frac{-\phi\left(Z'_i\gamma\right)}{1-\Phi\left(Z'_i\gamma\right)}, \tag{5}$$

where $\phi$ and $\Phi$ are the probability density and cumulative distribution function, respectively. The maximum likelihood method is used to estimate the parameters (Greene 2012). The expectation of outcomes with and without adoption, conditioned on actual adoption and non-adoption, is formulated as

(i) GSR farmers with adoption (observed)

$$E\ [Y_{1i}|Z_i, A_i = 1] = X'_{1i}\,\beta_1 + \sigma_1\rho_1\lambda_1, \tag{6.1}$$

(ii) GSR farmers without adoption (counterfactual)

$$E\ [Y_{0i}|Z_i,\ A_i = 1] = X'_{2i}\,\beta_2 + \sigma_2\rho_2\lambda_1, \tag{6.2}$$

(iii) Non-GSR farmers with adoption (counterfactual)

$$E\ [Y_{1i}|Z_i,\ A_i = 0] = X'_{1i}\,\beta_1 + \sigma_1\rho_1\lambda_2, \tag{6.3}$$

(iv) Non-GSR farmers without adoption (observed)

$$E\ [Y_{0i}|Z_i,\ A_i = 0] = X'_{2i}\,\beta_2 + \sigma_2\rho_2\lambda_2, \tag{6.4}$$

where $\rho_1$ and $\rho_2$ are the correlation coefficients between $u_{1i}$ and $\varepsilon_i$ and between $u_{2i}$ and $\varepsilon_i$, respectively (Lokshin and Sajaia 2004). With these equations, the ATE on the treated, ATT $(= E[Y_{1i}|\ Z_i,\ A_i = 1] - E[Y_{0i}|\ Z_i,\ A_i = 1])$, and on the untreated, ATU $(= E[Y_{1i}|\ Z_i,\ A_i = 1] - E[Y_{0i}|\ Z_i,\ A_i = 1])$, can be consistently estimated.

## 4. Data and descriptive statistics

The data used in this study comes from a farm survey conducted in Mozambique from June to November 2018. The survey covered three rice-producing provinces (Gaza, Sofala, and Nampula), where GSR varieties have been disseminated (Fig. 2).

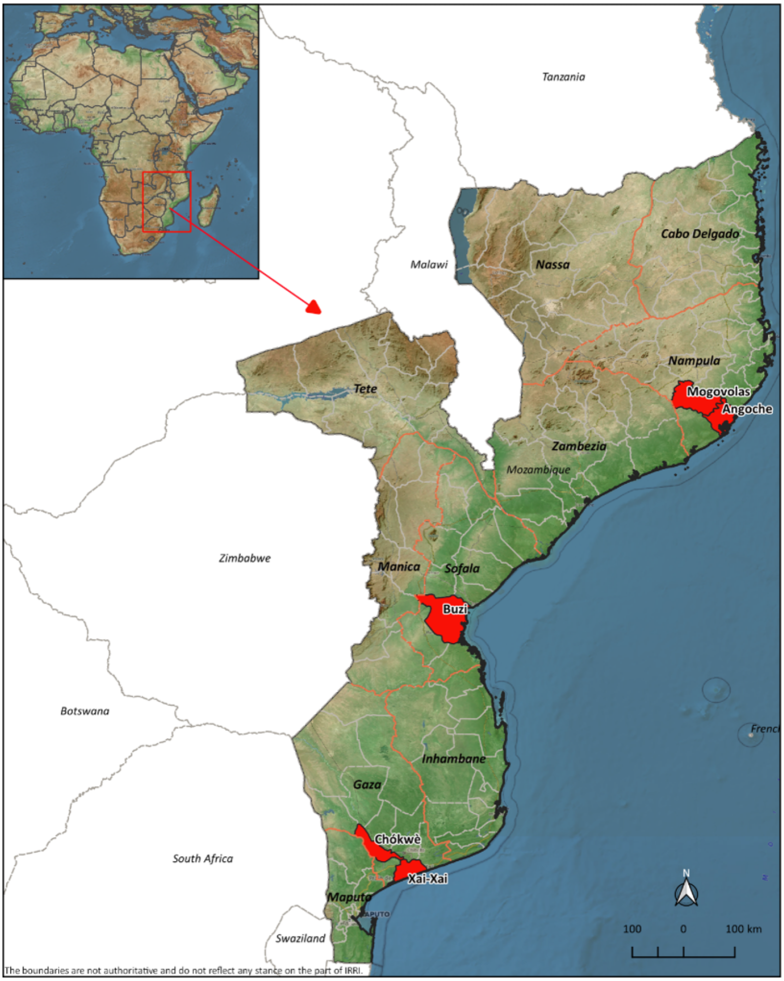


**Figure 2.** Map of study sites.

The three provinces were selected based on their potential for rice production as indicated by the National Agricultural Survey and GSR variety dissemination coverage. A multi-stage sampling technique was then used to select the districts, the administrative posts (APs), and the respondent farmers for the survey. In Gaza province, which has 13 districts, only Chokwe and Xai-Xai have rice producers who received GSR varieties, whereas in Sofala province, which has 12 districts, Dondo and Buzi districts have significant rice production, but GSR varieties were disseminated only in Buzi. Nampula province has 20 districts, and only Mogovolas, Angoche, and Moma have significant rice production, but GSR varieties were disseminated only in Mogovolas and Angoche. The districts with GSR dissemination were all selected (Chokwe, Xai-Xai, Buzi, Mogovolas, and Angoche). In each of these districts, we purposely selected the APs with the help of extension agents.[6] In each of the selected APs, smallholder rice farmers were randomly selected using the list of rice farmers. The sample size for each AP was determined based on the percentage of rice farmers. The study's total sample is 378 randomly selected farm households, of which 61 are from Chokwe, 38 from Xai-Xai, 129 from Buzi, 63 from Mogovolas, and 87 from Angoche. Interviews were conducted using a structured questionnaire, including household socioeconomic information,

**Table 1.** Climate conditions, main stresses, and cultivated varieties at study sites.

| Province | Climate classification | Annual rainfall range (mm) | Constraints to rice production | Types of varieties |
|---|---|---|---|---|
| Gaza | Dry semi-arid/dry sub-humid | 800–1,200 mm | Low soil fertility; bird damage | Improved non-GSR, GSR (*Simão*) |
| Nampula | Tropical humid of savannah | 1,000–1,100 mm | Low soil fertility; pests and diseases | Traditional, GSR (*Simão*) |
| Sofala | Dry sub-humid | 800–1,200 mm | Low soil fertility; pests and diseases | Improved non-GSR, traditional, GSR (*Simão*) |

landholding and land profile, land use pattern and rice varieties grown, inputs–outputs in rice production, knowledge and perceptions on GSR varieties, and seed exchange and income sources.

Table 1 presents some information on the study sites: climate, annual rainfall range, and some constraints to rice production. The sites are characterized mainly by dry and sub-humid climates. Gaza and Sofala have the lowest average annual precipitation. Low soil fertility is a typical constraint to rice production at all the study sites. Pests and diseases also cause significant damage in Sofala and Nampula. Damage caused by birds is prominent in Gaza, and this is a common stress in rice production in SSA (De Mey et al. 2011).

The survey results revealed that *Simão* is the only GSR variety grown at the study sites. We therefore refer to *Simão* as the GSR variety in the rest of the article. Gaza province is known for growing only improved rice varieties (including *Simão*). In Nampula, *Simão* is the only improved variety grown in addition to traditional varieties, whereas in Sofala, *Simão*, other improved varieties and traditional ones are present. Online Appendix Table A1 shows the list of improved and traditional varieties grown at the study sites and their characteristics.

Table 2 shows the descriptive statistics for all provinces combined and individually. Although several similarities can be noticed among the three provinces, some sharp differences are also revealed. The higher overall rice yield performance in Gaza could be attributed to the progressive nature of agriculture (i.e. openness to improved varieties, technologies, and agronomic processes; irrigated conditions and fertilizer use). In Gaza, only improved rice varieties (including *Simão*) are grown with enhanced access to irrigation and fertilizer application for rice production. Our survey indicates that 73.7 per cent of the farmers in Gaza plant rice in irrigated lowland conditions. In contrast, most farmers in the other two provinces produce rice in rainfed lowlands with minor to no fertilizer application.[7] Rice farmers in Gaza province grow improved varieties under better conditions, and, in particular, 44 per cent of the sample in that province grows *Simão*. Rainfed farmers tend to choose *Simão,* but irrigated farmers grow conventionally improved varieties. This trend is consistent with the properties of *Simão* (Li and Ali 2017).

In contrast, a lack of irrigation facilities in Nampula drives farmers to stick with the robust low-yielding traditional varieties. Perhaps the conventional improved varieties are not suitable for the growing environment of Nampula. Some farmers in that province use *Simão* because of its stress tolerance. With the severe stress conditions prevailing in Sofala province, 17.8 per cent of the farmers plant improved varieties, and *Simão* stands out as the most commonly adopted variety (62 per cent). The variety adoption presented here refers to those varieties grown in the largest plot. Still, most farmers in our sample usually planted the same variety in their other plots when they had multiple plots. Online Appendix Table A2 provides more insight into the pattern of varietal choice by farmers in their plots.[8]

**Table 2.** Descriptive statistics, rainy season 2017–2018, in Mozambique.

| | All | Gaza | Nampula | Sofala |
|---|---|---|---|---|
| Outcomes: | | | | |
| Yield (kg/ha) | 1596.824 | 2918.410 | 1202.004 | 1041.678 |
| | (1403.420) | (1654.064) | (991.101) | (847.804) |
| Cost efficiency (MZN/kg) | 13.942 | 9.622 | 12.166 | 19.394 |
| | (1403.420) | (1654.064) | (991.101) | (847.804) |
| Inputs: | | | | |
| Area (ha) | 0.820 | 1.159 | 0.461 | 0.977 |
| | (0.739) | (0.870) | (0.608) | (0.580) |
| Seed input (kg/ha) | 171.774 | 98.189 | 262.612 | 121.267 |
| | (181.606) | (80.390) | (243.355) | (79.261) |
| Fertilizer input (kg/ha) | 17.734 | 67.334 | 0.250 | 0.000 |
| | (57.657) | (96.991) | (3.062) | (0.000) |
| Hired labor input (MZN/ha) | 4151.553 | 5492.072 | 2394.768 | 5165.557 |
| | (7234.286) | (5976.622) | (6623.986) | (8347.205) |
| Farm characteristics: | | | | |
| Irrigated lowland (= 1, if yes) | 0.354 | 0.737 | 0.173 | 0.271 |
| | (0.479) | (0.442) | (0.380) | (0.446) |
| Rainfed lowland (= 1, if yes) | 0.505 | 0.242 | 0.553 | 0.651 |
| | (0.501) | (0.431) | (0.499) | (0.478) |
| Upland (= 1, if yes) | 0.140 | 0.020 | 0.273 | 0.078 |
| | (0.348) | (0.141) | (0.447) | (0.268) |
| Transplanted rice (= 1, if yes) | 0.365 | 0.293 | 0.633 | 0.109 |
| | (0.482) | (0.457) | (0.484) | (0.312) |
| Sandy soil (= 1, if yes) | 0.235 | 0.172 | 0.387 | 0.109 |
| | (0.425) | (0.379) | (0.489) | (0.312) |
| Clay soil (= 1, if yes) | 0.680 | 0.818 | 0.507 | 0.775 |
| | (0.467) | (0.388) | (0.502) | (0.419) |
| Loam soil (= 1, if yes) | 0.085 | 0.010 | 0.107 | 0.116 |
| | (0.279) | (0.101) | (0.310) | (0.322) |
| Household characteristics: | | | | |
| Male household head (= 1, if yes) | 0.677 | 0.616 | 0.800 | 0.581 |
| | (0.468) | (0.489) | (0.401) | (0.495) |
| Education (year) | 4.270 | 4.040 | 3.613 | 5.209 |
| | (3.994) | (4.150) | (3.571) | (4.185) |
| Farm experience (year) | 8.701 | 7.717 | 10.007 | 7.938 |
| | (10.591) | (9.725) | (10.242) | (11.511) |
| Household size (#) | 5.354 | 5.747 | 5.047 | 5.411 |
| | (2.154) | (2.366) | (1.971) | (2.149) |
| Distances: | | | | |
| Distance from seed source (minutes) | 57.387 | 69.960 | 42.319 | 65.258 |
| | (98.152) | (133.923) | (80.625) | (81.395) |
| Distance from extension office (minutes) | 78.110 | 89.310 | 78.451 | 69.131 |
| | (132.364) | (168.612) | (143.908) | (72.367) |
| Cultivated varieties: | | | | |
| GSR variety (*Simão*) (= 1, if yes) | 0.439 | 0.424 | 0.293 | 0.620 |
| | (0.497) | (0.497) | (0.457) | (0.487) |
| Improved non-GSR variety (= 1, if yes) | 0.211 | 0.576 | 0.000 | 0.178 |
| | (0.409) | (0.497) | (0.000) | (0.384) |
| Traditional variety (= 1, if yes) | 0.348 | 0.000 | 0.707 | 0.202 |
| | (0.477) | (0.000) | (0.457) | (0.403) |
| Observations | 379 | 99 | 150 | 129 |

*Notes*: Standard deviations are in parentheses. 1 USD is equal to 73.10 MZN.

**Table 3.** Results of probit regression of GSR (*Simão*) adoption.

| | Gaza | Nampula | Sofala |
|---|---|---|---|
| Rainfed lowland | 0.663* | 0.138 | −0.141 |
| | (0.342) | (0.326) | (0.273) |
| Upland | 1.681* | 0.273 | −0.673 |
| | (1.000) | (0.354) | (0.485) |
| Clay soil | 0.052 | −0.026 | −0.707 |
| | (0.371) | (0.394) | (0.514) |
| Loam soil | | −0.282 | 0.078 |
| | | (0.399) | (0.388) |
| Transplanted rice | −1.097*** | −0.114 | −0.727* |
| | (0.363) | (0.243) | (0.424) |
| Male household head | 0.467 | −0.693** | −0.070 |
| | (0.325) | (0.299) | (0.271) |
| Education | −0.001 | 0.050 | −0.024 |
| | (0.035) | (0.032) | (0.032) |
| Farm experience | −0.027 | −0.010 | 0.010 |
| | (0.017) | (0.011) | (0.012) |
| Household size | −0.161** | 0.017 | 0.132** |
| | (0.069) | (0.063) | (0.060) |
| Constant | 0.704 | −0.116 | −0.069 |
| | (0.470) | (0.571) | (0.574) |
| Log-likelihood $\chi^2$ | 29.920 | 11.004 | 16.115 |
| Pseudo $R^2$ | 0.222 | 0.061 | 0.094 |
| Observations | 99 | 150 | 129 |

*Notes*: Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. Standard errors of estimated coefficients are in parentheses. 'Irrigated lowland' and 'loam soil' are used as references. In Gaza, 'clay soil' is also a reference because only one 'loam soil' farmer was observed in our data. Estimated coefficients for district dummies are not shown.

In Gaza, landholdings are larger than in other provinces, and more area is used for rice production. On average, the total cultivated area was 2.29 ha (Gaza), 1.34 ha (Nampula), and 1.42 ha (Sofala). During the 2018 wet season, 78.3 (Gaza), 71.8 (Nampula), and 97.0 per cent (Sofala) of the area were used for rice production. Our survey indicates that more seed inputs are used in Nampula than in Gaza and Sofala. The traditional beliefs may drive farmers to think that overusing seeds allows maximizing output. Farmers in Gaza and Sofala spend twice as much on hired labor as their counterparts in Nampula. Transplanted rice as the crop establishment method is more common among Nampula farmers than among Gaza and Sofala farmers. In all three provinces, clay-type soil is dominant in rice fields, with a noticeably higher proportion in Gaza. The households surveyed for this study are relatively large (7–10 members) and headed mainly by a male with 3–5 years of education. These households live relatively far from their source of seeds (42–70 min) and the extension office (78–89 min), which may constrain adopting new varieties.

## 5. Propensity score matching

### 5.1. Adoption of GSR (*Simão*)

A probit model was estimated to examine the drivers of *Simão* adoption. The estimated coefficients are presented in Table 3. In Gaza province, rainfed and upland farmers are more likely to adopt *Simão* than irrigated farmers. This reflects the fact that conventional improved varieties usually require an irrigation system to maintain a high yield. In addition, farmers who practice direct seeding are more likely to adopt *Simão*, which may decrease farmers' labor input for transplanting. This significant effect of direct seeding is also seen in Sofala province. Female household heads have a higher probability of adopting *Simão* in

**Table 4.** Farmers' perceptions on GSR varieties and its adoption.

| | Gaza | | Nampula | | Sofala | |
|---|---|---|---|---|---|---|
| | Observations | Share | Observations | Share | Observations | Share |
| Awareness and adoption of the GSR varieties | | | | | | |
| Heard of GSR—adopted | 42 | 0.42 | 38 | 0.25 | 82 | 0.64 |
| Heard of GSR—did not adopt | 33 | 0.33 | 34 | 0.23 | 46 | 0.63 |
| Did not hear of GSR | 28 | 0.28 | 78 | 0.52 | 1 | 0.01 |
| Total | 99 | 1.00 | 150 | 1.00 | 129 | 1.00 |
| Non-adopter: reason for non-adoption | | | | | | |
| Did not trust the GSR variety | NA | | NA | | 10 | 0.20 |
| Did not want to take any risk | NA | | NA | | 5 | 0.10 |
| Already prepared the seedbed | NA | | NA | | 5 | 0.10 |
| Seeds not available | NA | | NA | | 5 | 0.10 |

*Notes*: Only non-adopters in Sofala province were asked the reasons for not adopting the varieties. Share denotes the number of farmers who raised the reason over the number of non-adopters (which is 49 in Sofala).

Nampula. According to Table 4, 52 per cent of Nampula farmers never heard about GSR varieties. Although we did not use the perception about a GSR variety as an explanatory variable in the probit regression because of its endogeneity, it should be seen as a major determinant of adoption. Other variables, such as household size, also appear as significant determinants of adoption in Gaza and Sofala. Given that the GSR variety (*Simão*) requires less hired labor input for irrigation maintenance and transplanting (see Online Appendix Table A3), its adoption remains beneficial for households with a small size by decreasing hired labor costs. In Sofala, however, where a reverse trend is observed, with limited irrigation facilities, households with large size can use family labor for other activities such as crop establishment and weeding. Therefore, adopting *Simão* is perhaps beneficial.

## 5.2. Matching results

Table 5A shows the results of *t*-tests on means between adopters and non-adopters of *Simão* in the original sample before PSM. In all three provinces, significant differences are noticed in the mean comparison between adopters and non-adopters of *Simão* for farm and household characteristics. This indicates the likely presence of selection bias. Therefore, the mean comparison of outcomes (yield and cost efficiency) between adopters and non-adopters is biased. Thus, this justifies our choice of PSM to account for selection bias due to observable farm and household characteristics. A PSM was conducted for the three provinces to obtain a balanced sample of adopters and non-adopters of *Simão*. NN matching was considered using propensity scores from the probit model presented in Table 3. The propensity score distribution balance test confirms the good quality of the matching.[9] Figure 3 shows the distribution before and after the matching when all provinces are combined. These results remained robust under alternative matching techniques. After the matching, the balanced samples of adopters and non-adopters are as follows: 64 farmers in Gaza, 84 in Nampula, and 98 in Sofala.

Results of *t*-tests on means between adopters and non-adopters of *Simão* after the matching are presented for each province individually in Table 5B. Unlike the results shown in Table 5A, there are no significant differences in farm and household characteristics between adopters and non-adopters after PSM. Still, in Gaza, a few differences persist (seed, fertilizer, and hired labor inputs). In Gaza province, adopters apply significantly larger amounts of seed and fertilizer than non-adopters even after PSM. The optimal fertilizer application rate in this area is about 50 kg/ha (Kajisa and Payongyong 2011), and the adequate amount of seed is 40–100 kg/ha (IRRI 2022). For hired labor, *Simão* shows

**Table 5A**. Difference in sample means: before the matching.

| | Gaza province | | | Nampula province | | | Sofala province | | |
|---|---|---|---|---|---|---|---|---|---|
| | Adopters | Non-adopter | Mean diff. | Adopters | Non-adopter | Mean diff. | Adopters | Non-adopter | Mean diff. |
| Outcomes: | | | | | | | | | |
| Yield | 3411.967 | 2554.737 | 857.230* | 1250.660 | 1181.807 | 68.852 | 1089.927 | 962.903 | 127.024 |
| Cost efficiency | 9569.796 | 9661.015 | –91.219 | 10,780.504 | 12,745.992 | –1965.488 | 15,782.735 | 25,143.234 | –9360.499** |
| Inputs: | | | | | | | | | |
| Seed input | 116.980 | 84.672 | 32.308* | 289.450 | 251.472 | 37.978 | 116.649 | 128.866 | –12.217 |
| Fertilizer input | 114.848 | 32.325 | 82.523*** | 0.000 | 0.354 | –0.354 | 0.000 | 0.000 | 0.000 |
| Hired labor input | 4006.447 | 6586.743 | –2580.295* | 1735.391 | 2668.471 | –933.081 | 4710.259 | 5908.900 | –1198.641 |
| Farm characteristics: | | | | | | | | | |
| Irrigated lowland | 0.571 | 0.860 | –0.288** | 0.136 | 0.189 | –0.052 | 0.275 | 0.265 | 0.010 |
| Rainfed lowland | 0.405 | 0.123 | 0.282** | 0.523 | 0.566 | –0.043 | 0.675 | 0.612 | 0.063 |
| Upland | 0.024 | 0.018 | 0.006 | 0.341 | 0.245 | 0.096 | 0.050 | 0.122 | –0.072 |
| Transplanted rice | 0.095 | 0.439 | –0.343*** | 0.614 | 0.642 | –0.028 | 0.062 | 0.184 | –0.121* |
| Clay soil | 0.190 | 0.158 | 0.033 | 0.455 | 0.358 | 0.096 | 0.062 | 0.184 | –0.121* |
| Loam soil | 0.810 | 0.825 | –0.015 | 0.432 | 0.538 | –0.106 | 0.825 | 0.694 | 0.131 |
| Other soil | 0.000 | 0.018 | –0.018 | 0.114 | 0.104 | 0.010 | 0.113 | 0.122 | –0.010 |
| Household characteristics: | | | | | | | | | |
| Male household head | 0.667 | 0.579 | 0.088 | 0.682 | 0.849 | –0.167* | 0.575 | 0.592 | –0.017 |
| Education | 4.238 | 3.895 | 0.343 | 4.136 | 3.396 | 0.740 | 4.975 | 5.592 | –0.617 |
| Farm experience | 5.476 | 9.368 | –3.892* | 8.705 | 10.547 | –1.843 | 7.737 | 8.265 | –0.528 |
| Household size | 5.190 | 6.158 | –0.967* | 4.909 | 5.104 | –0.195 | 5.713 | 4.918 | 0.794* |
| Distances: | | | | | | | | | |
| Distance from seed source | 58.643 | 38.509 | 20.134* | 48.280 | 39.844 | 8.435 | 58.041 | 46.735 | 11.307 |
| Distance from extension office | 63.402 | 44.553 | 18.849* | | 83.917 | –19.506 | 60.132 | 56.268 | 3.864 |
| Cultivated varieties: | | | | | | | | | |
| Improved non-GSR variety | | 1.000 | | | 0.000 | | | 0.469 | |
| Traditional variety | | 0.000 | | | 1.000 | | | 0.531 | |
| Observations | 42 | 57 | 99 | 44 | 106 | 150 | 80 | 49 | 129 |

*Notes*: 'Mean Diff.' denotes the difference between means of adopters and non-adopters. To compare the means, the *t*-test is used for a continuous variable and the test for equality of proportions is used for binary variables. Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. 1 USD is equal to 73.10 MZN.

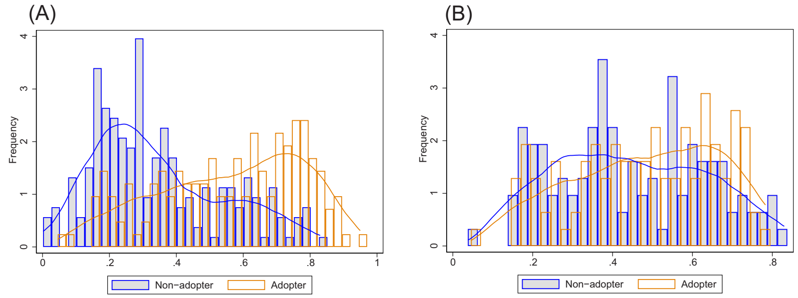


**Figure 3.** Distribution of propensity score: before (left) and after (right) the matching—all provinces.

a significant advantage over the other varieties. Adopters incur some savings in hired labor costs related to crop establishment and irrigation maintenance, harvesting, threshing, and bird control (Online Appendix Table A3).

Given that significant differences still exist in input use (seed, fertilizer, and hired labor) between adopters and non-adopters, even after the matching, some remaining selection bias is likely to exist because of unobservable characteristics related to farmers' input management. This reinforces the choice of an econometric approach, such as ESR, to address those remaining selection bias issues.

The following section presents the econometric results of the effects of *Simão* adoption on yield and cost efficiency based on ESR estimations.

## 6. Yield and cost efficiency effects of GSR variety adoption

The results of ESR estimations for the effects of GSR adoption on yield and cost efficiency are shown in Tables 6 and 7. We examined the GSR variety's impact for all the provinces combined and for each province individually to obtain more specific insights. In each of these estimations, the sub-sample of adopters and non-adopters of *Simão*, obtained after applying PSM, is used to estimate the ESR.

### 6.1. Selection equation

The estimated selection equation shows the significant impacts of distance variables on *Simão* adoption (Table 6A). The falsification test confirms the exclusion restriction and relevance conditions of these variables (Online Appendix Table A4). As we expect, farmers with better access to an extension office have a higher probability of adoption. Interestingly, adopters live farther away from a seed source than non-adopters. Perhaps this relates to the fact that, unlike other improved varieties (i.e. non-GSR), *Simão* can be multiplied by farmers. The results show that other factors related to *Simão* adoption are fertilizer, seed, and hired labor inputs. Our results confirm that fertilizer use is positively associated with growing *Simão*. Cultivation practices for traditional rice varieties do not usually involve the use of fertilizer in Mozambique (Kajisa and Payongayong 2013). The province-specific selection equations are presented in Online Appendix Table A5.[10]

### 6.2. Effects on yield

The estimated two-regime equation (Table 6A) shows that the null hypothesis that all estimated coefficients are equal to zero is rejected given the Wald test's significance. More importantly, the IMR coefficients came out positive and significant, confirming that the estimates would be biased if the correction were not performed. The likelihood ratio (LR) test with $\chi^2(1)$ is significant, rejecting the null hypothesis of independence of outcome equations.

**Table 5B.** Difference in sample means: after the matching.

| | Gaza province | | | Nampula province | | | Sofala province | | |
|---|---|---|---|---|---|---|---|---|---|
| | Adopters | Non-adopter | Mean diff. | Adopters | Non-adopter | Mean diff. | Adopters | Non-adopter | Mean diff. |
| Outcomes: | | | | | | | | | |
| Yield | 3195.508 | 2322.464 | 873.044* | 1272.070 | 1571.401 | –299.332 | 1048.408 | 962.903 | 85.505 |
| Cost efficiency | 10,421.286 | 12,735.742 | –2314.456 | 10,239.551 | 10,135.926 | 103.625 | 17,309.562 | 25,143.234 | –7833.672 |
| Inputs: | | | | | | | | | |
| Seed input | 127.619 | 77.083 | 50.536* | 290.865 | 221.523 | 69.343 | 113.026 | 128.866 | –15.840 |
| Fertilizer input | 104.644 | 22.057 | 82.587*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Hired labor input | 4453.775 | 7948.375 | –3494.600* | 1775.749 | 2801.647 | –1025.899 | 5159.045 | 5908.900 | –749.854 |
| Farm characteristics: | | | | | | | | | |
| Irrigated lowland | 0.750 | 0.750 | 0.000 | 0.140 | 0.093 | 0.047 | 0.265 | 0.265 | 0.000 |
| Rainfed lowland | 0.219 | 0.219 | 0.000 | 0.535 | 0.651 | –0.116 | 0.653 | 0.612 | 0.041 |
| Upland | 0.031 | 0.031 | 0.000 | 0.326 | 0.256 | 0.070 | 0.082 | 0.122 | –0.041 |
| Transplanted rice | 0.125 | 0.219 | –0.094 | 0.628 | 0.488 | 0.140 | 0.082 | 0.184 | –0.102 |
| Clay soil | 0.250 | 0.188 | 0.062 | 0.442 | 0.465 | –0.023 | 0.082 | 0.184 | –0.102 |
| Loam soil | 0.750 | 0.781 | –0.031 | 0.442 | 0.488 | –0.047 | 0.755 | 0.694 | 0.061 |
| Other soil | 0.000 | 0.031 | –0.031 | 0.116 | 0.047 | 0.070 | 0.163 | 0.122 | 0.041 |
| Household characteristics: | | | | | | | | | |
| Male household head | 0.656 | 0.625 | 0.031 | 0.698 | 0.698 | 0.000 | 0.612 | 0.592 | 0.020 |
| Education | 4.406 | 4.344 | 0.062 | 4.070 | 3.442 | 0.628 | 5.755 | 5.592 | 0.163 |
| Farm experience | 6.500 | 5.875 | 0.625 | 8.884 | 6.814 | 2.070 | 8.143 | 8.265 | –0.122 |
| Household size | 5.781 | 5.906 | –0.125 | 4.884 | 4.558 | 0.326 | 4.755 | 4.918 | –0.163 |
| Distances: | | | | | | | | | |
| Distance from seed source | 49.844 | 43.062 | 6.781 | 48.937 | 40.442 | 8.495 | 67.061 | 46.735 | 20.327 |
| Distance from extension office | 60.190 | 46.096 | 14.094 | 65.444 | 67.077 | –1.633 | 68.193 | 56.268 | 11.925 |
| Cultivated varieties: | | | | | | | | | |
| Improved non-GSR variety | | 1.000 | | | 0.000 | | | 0.469 | |
| Traditional variety | | 0.000 | | | 1.000 | | | 0.531 | |
| Observations | 32 | 32 | 64 | 43 | 43 | 86 | 49 | 49 | 98 |

*Notes*: 'Mean Diff.' denotes the difference between means of adopters and non-adopters. To compare the means, the *t*-test is used for a continuous variable and the test for equality of proportions is used for binary variables. Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. 1 USD is equal to 73.10 MZN.

**Table 6A.** Parameter estimates of ESR: yield (kg/ha) effect, all provinces combined.

| Yield, log | Regime equation GSR (*Simão*) | Regime equation Non-GSR | Selection equation |
|---|---|---|---|
| Seed, log | –0.134 | –0.054 | 0.372** |
| | (0.128) | (0.107) | (0.114) |
| Fertilizer, log | 0.085** | 0.074 | 0.124** |
| | (0.032) | (0.044) | (0.035) |
| Hired labor, log | 0.039* | 0.034 | –0.068** |
| | (0.020) | (0.021) | (0.022) |
| Area, log | –0.078 | –0.196* | 0.065 |
| | (0.084) | (0.090) | (0.100) |
| Rainfed lowland | –0.234 | –0.152 | 0.092 |
| | (0.171) | (0.173) | (0.209) |
| Upland | –0.167 | –0.421* | 0.144 |
| | (0.243) | (0.256) | (0.289) |
| Transplanted rice | –0.103 | 0.168 | 0.093 |
| | (0.182) | (0.173) | (0.207) |
| Clay soil | 0.516 | 0.099 | –0.378 |
| | (0.271) | (0.330) | (0.347) |
| Loam soil | 0.333 | –0.319 | –0.301 |
| | (0.251) | (0.310) | (0.324) |
| Distance (seed source), log | | | 0.208** |
| | | | (0.067) |
| Distance (extension office), log | | | –0.169* |
| | | | (0.077) |
| Constant | 8.015*** | 7.043*** | –2.725** |
| | (1.213) | (0.854) | (1.029) |
| Wald test | $\chi^2 = 42.856$*** | | |
| LR test of independent equation | $\chi^2 = 6.092$*** | | |
| $\sigma_1^2/\sigma_2^2$, log | –0.275* | –0.156 | |
| | (0.141) | (0.107) | |
| Transformed $\sigma_{1\epsilon}^2/\sigma_{2\epsilon}^2$ | –0.557 | –0.453 | |
| | (0.490) | (0.385) | |
| IMR | 0.705*** | 0.690*** | |
| | (0.028) | (0.028) | |
| Observations | 123 | 123 | 246 |

*Notes*: Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. Standard errors of estimated coefficients are in parentheses. 'Irrigated lowland' and 'loam soil' are used as references. District dummies were not used in the ESR framework because farmers' input decisions are highly correlated with their locations (i.e. district and province).

The estimated coefficients in Table 6A show some interesting findings. The coefficient of fertilizer inputs was positive for both GSR and non-GSR growers (significant only for the GSR regime), denoting the importance of fertilizer inputs for rice productivity. One per cent increase in fertilizer input increases yield by 0.085 per cent for GSR growers and by 0.074 per cent for non-GSR growers. The effects of hired labor are also positive but significant only for GSR adopters. Based on the estimations, planting non-GSR rice varieties under rainfed upland conditions is disadvantageous for rice yield. This may be related to the difficulty in growing rice in rainfed upland conditions in general. However, our estimates show that, for GSR growers, upland conditions do not constrain productivity.

Table 6B summarizes the expected yield for adopters with adoption (observed), adopters without adoption (counterfactual), non-adopters with adoption (counterfactual), and non-adopters without adoption (observed). The table presents the ATE on both the treated (ATT) and untreated (ATU) groups. If we refer to the percentile change, the smallholder

**Table 6B.** Treatment effect on yield (kg/ha), log.

| | Observations | GSR (*Simão*) Mean | GSR (*Simão*) Standard deviation | Non-GSR Mean | Non-GSR Standard deviation | Treatment effect | % change |
|---|---|---|---|---|---|---|---|
| All provinces | | | | | | | |
| Adopters | 124 | 7.096 | 0.466 | 6.448 | 0.409 | ATT: 0.405*** | 10.044 |
| Non-adopters | 124 | 7.647 | 0.322 | 6.964 | 0.364 | ATU: 0.683*** | 9.810 |
| Gaza province | | | | | | | |
| Adopters | 32 | 7.744 | 0.427 | 6.760 | 0.360 | ATT: 0.983*** | 14.553 |
| Non-adopters | 32 | 7.921 | 0.409 | 7.120 | 0.385 | ATU: 0.801*** | 11.259 |
| Nampula province | | | | | | | |
| Adopters | 42 | 6.899 | 0.268 | 6.633 | 0.266 | ATT: 0.266*** | 4.016 |
| Non-adopters | 42 | 7.755 | 0.254 | 7.022 | 0.370 | ATU: 0.732*** | 10.435 |
| Sofala province | | | | | | | |
| Adopters | 49 | 7.066 | 0.323 | 6.365 | 0.215 | ATT: 0.700*** | 11.011 |
| Non-adopters | 49 | 7.845 | 0.278 | 6.861 | 0.226 | ATU: 1.985*** | 14.354 |

*Notes*: Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. Based on the coefficients estimated from the ESR model, the predicted yields are shown in log form. Because the dependent variables in the model are the log of yields (kg/ha), the predicted yields are also given in the log form. Converting the mean back to kilogram would lead to inaccuracies due to the inequality of arithmetic and geometric means.

rice farmers who adopted GSR (*Simão*) increased yield by about 10.0 per cent on average. This result indicates the steady and positive effects on yield brought about by the adoption of *Simão*. For the non-adopters, the estimation shows that they would have increased productivity by 9.8 per cent if they had adopted GSR. These results confirm the overall benefits of GSR adoption on yield.

To obtain further insights into these results, we also estimated the ESR for each province individually. The estimated parameters are presented in Online Appendix Table A5. Although sample sizes are smaller when ESR is estimated for individual provinces, the results are similar to those obtained for the combined estimation. The ATE on the treated (ATT) and untreated (ATU) groups presented in Table 6B shows that adopters as well as non-adopters benefit from adopting the GSR variety. The change in productivity associated with adoption (for the adopters) is much higher in Gaza (14.5 per cent), followed by Sofala (11.0 per cent) and Nampula (4.0 per cent). For the non-adopters, the productivity increase associated with adoption is much higher in Sofala (14.4 per cent), followed by Gaza (11.3 per cent) and Nampula (10.4 per cent).

## 6.3. Effects on cost efficiency

Table 7A presents ESR estimation results on the cost efficiency (MZN/kg) effects of GSR adoption over other varieties. As in the estimation for the yield effect, the Wald test is significant, indicating that the null hypothesis that all estimated coefficients are equal to zero is rejected. Similarly, the positive and significant coefficients in the IMRs confirm that the estimated coefficients would have been biased without the correction. The LR test is significant, and therefore, the null hypothesis of independence of outcome equations is rejected.

**Table 7A.** Parameter estimates of ESR: cost efficiency (MZN/kg) effect, all provinces combined.

| Cost efficiency, log | Regime equation GSR (*Simão*) | Regime equation Non-GSR | Selection equation |
|---|---|---|---|
| Seed, log | 0.600*** | 0.524*** | 0.372** |
| | (0.132) | (0.106) | (0.114) |
| Fertilizer, log | 0.014 | –0.013 | 0.124** |
| | (0.033) | (0.038) | (0.035) |
| Hired labor, log | 0.048* | 0.070** | –0.068** |
| | (0.019) | (0.022) | (0.022) |
| Area, log | 0.107 | 0.161 | 0.065 |
| | (0.087) | (0.094) | (0.100) |
| Rainfed lowland | 0.047 | 0.061 | 0.092 |
| | (0.177) | (0.181) | (0.209) |
| Upland | –0.096 | 0.185 | 0.144 |
| | (0.249) | (0.263) | (0.289) |
| Transplanted rice | 0.156 | –0.225 | 0.093 |
| | (0.187) | (0.180) | (0.207) |
| Clay soil | –0.338 | 0.101 | –0.378 |
| | (0.282) | (0.341) | (0.347) |
| Loam soil | —0.110 | 0.483 | –0.301 |
| | (0.263) | (0.322) | (0.324) |
| Distance (seed source), log | | | 0.208** |
| | | | (0.067) |
| Distance (extension office), log | | | –0.169* |
| | | | (0.077) |
| Constant | –3.264** | –2.173* | –2.725** |
| | (1.238) | (0.889) | (1.029) |
| Wald test | $\chi^2$= 46.033*** | | |
| LR test of independent equation | $\chi^2$= 8.679*** | | |
| $\sigma_1^2/\sigma_2^2$, log | –0.169 | –0.094 | |
| | (0.173) | (0.110) | |
| Transformed $\sigma_{1\epsilon}^2/\sigma_{2\epsilon}^2$ | 1.016** | –0.674 | |
| | (0.454) | (0.417) | |
| IMR | 0.699*** | 0.696*** | |
| | (0.027) | (0.028) | |
| Observations | 123 | 123 | 246 |

*Notes*: Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. Standard errors of estimated coefficients are in parentheses. 'Irrigated lowland' and 'loam soil' are used as references. District dummies were not used in the ESR framework because farmers' input decisions are highly correlated with their locations (i.e. district and province).

The estimated correlation between the error term of the Regime 1 equation and the selection equation is positive and significant. This suggests that, if the non-GSR farmers plant *Simão*, they will be more cost efficient than the adopters, controlling for all other variables in the regime equations.

Some interesting findings are also obtained with the two-regime estimation. First, seed input and hired labor use appear as significant drivers of cost efficiency. A one per cent decrease in seed input results in 0.52–0.60 per cent improvement in cost efficiency for GSR and non-GSR farmers. Second, the production environment (irrigated, rainfed lowland, and upland) does not significantly affect cost efficiency. For instance, although farmers in the irrigated environment tend to have a higher yield, part of the advantage is offset by the expenses they have to incur in maintaining irrigation facilities.[11]

Table 7B presents the ATE on the treated (ATT) and untreated (ATU) groups for GSR (*Simão*) and non-GSR growers. The GSR growers improved their cost efficiency by 26.4 per

**Table 7B.** Treatment effect on cost efficiency (MZN/kg), log.

| | | GSR (*Simão*) | | Non-GSR | | | |
|---|---|---|---|---|---|---|---|
| | Observations | Mean | Standard deviation | Mean | Standard deviation | Treatment effect | % change |
| All provinces | | | | | | | |
| Adopters | 126 | 2.305 | 0.487 | 3.131 | 0.614 | ATT: –0.825*** | –26.366 |
| Non-adopters | 126 | 1.257 | 0.563 | 2.313 | 0.662 | ATU: –1.057*** | –45.674 |
| Gaza province | | | | | | | |
| Adopters | 33 | 2.310 | 0.368 | 3.340 | 0.381 | ATT: –1.030*** | –30.851 |
| Non-adopters | 33 | 1.170 | 0.354 | 2.431 | 0.332 | ATU: –1.260*** | –51.841 |
| Nampula province | | | | | | | |
| Adopters | 42 | 2.146 | 0.552 | 2.650 | 0.490 | ATT: –0.504*** | –19.026 |
| Non-adopters | 42 | 0.307 | 0.639 | 1.819 | 0.678 | ATU: –1.512*** | –83.139 |
| Sofala province | | | | | | | |
| Adopters | 49 | 2.337 | 0.544 | 3.233 | 0.652 | ATT: –0.896*** | –27.713 |
| Non-adopters | 49 | 0.972 | 0.483 | 2.652 | 0.527 | ATU: –1.680*** | –63.347 |

*Notes*: Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. Based on the coefficients estimated from the ESR model, the predicted yields are shown in log form. Because the dependent variables in the model are the log of yields (kg/ha), the predicted yields are also given in the log form. Converting the mean back to kilogram would lead to inaccuracies due to the inequality of arithmetic and geometric means.

cent by adopting *Simão*. Those who did not adopt would have improved their cost efficiency by 45.7 per cent had they adopted *Simão*. The province-specific results also suggest that a positive effect of GSR adoption is observed for cost efficiency. For adopters, the highest improvement in cost efficiency is observed in Gaza (30.8 per cent), followed by Sofala (27.7 per cent) and Nampula (19.0 per cent). For non-adopters, had they switched to the GSR variety, the improvement in cost efficiency would have been higher in Nampula (83.1 per cent), followed by Sofala (63.3 per cent) and Gaza (51.8 per cent). Overall, these results demonstrate the cost-efficiency benefit associated with the adoption of the GSR variety.

## 6.4. Discussion

The results confirm the positive effects of adopting the GSR variety on yield and cost efficiency, not only in irrigated environments where fertilizer is applied together with some more advanced farming practices (i.e. Gaza province), but also in Nampula and Sofala provinces where farmers grow rice under rainfed conditions without fertilizer application. Our estimations suggest that the GSR variety outperforms the existing improved varieties and also the traditional varieties grown under traditional farming practices. The evidence provided in this study confirms the expected benefit of GSR varieties, which is to enable farmers to bring about sustainable production in economic terms appropriate for rice cultivation in rainfed and/or limited-input conditions (see Yu *et al*. 2020).

Table 8 shows farmers' perceptions of the varieties they cultivated: GSR, improved non-GSR, and traditional varieties. First, it is interesting to see that many GSR adopters like *Simão* for its taste/aroma. Second, 40 per cent of the adopters in Gaza are satisfied with its grain yield, whereas 34 per cent of the adopters in Nampula and 65 per cent in Sofala

**Table 8.** Farmers' perception on desirable and undesirable traits of cultivating variety.

| | Gaza | | Nampula | | Sofala | | |
|---|---|---|---|---|---|---|---|
| | GSR (*Simão*) | Improved (non-GSR) | GSR (*Simão*) | Traditional | GSR (*Simão*) | Improved (non-GSR) | Traditional |
| Desirable trait of the variety | | | | | | | |
| Taste/aroma | 26 (0.62) | 31 (0.54) | 28 (0.64) | 63 (0.60) | 17 (0.21) | 10 (0.43) | 9 (0.35) |
| Grain yield | 17 (0.40) | 29 (0.51) | 0 (0.00) | 1 (0.01) | 1 (0.01) | 2 (0.09) | 1 (0.04) |
| Tillering ability | 4 (0.10) | 3 (0.05) | 15 (0.34) | 39 (0.37) | 52 (0.65) | 12 (0.52) | 7 (0.27) |
| Milling quality | 3 (0.07) | 6 (0.11) | 15 (0.34) | 25 (0.24) | 13 (0.16) | 4 (0.17) | 4 (0.15) |
| Tolerance to submerge | 3 (0.07) | 0 (0.00) | 15 (0.34) | 26 (0.25) | 5 (0.06) | 0 (0.00) | 3 (0.12) |
| Pests and diseases | 0 (0.00) | 0 (0.00) | 0 (0.00) | 20 (0.19) | 0 (0.00) | 0 (0.00) | 1 (0.04) |
| Drought | 0 (0.00) | 0 (0.00) | 0 (0.00) | 4 (0.04) | 2 (0.03) | 1 (0.04) | 1 (0.04) |
| Undesirable trait of the variety | | | | | | | |
| Taste/aroma | 0 (0.00) | 9 (0.16) | 0 (0.00) | 2 (0.02) | 0 (0.00) | 0 (0.00) | 2 (0.08) |
| Milling quality | 7 (0.17) | 6 (0.11) | 3 (0.07) | 10 (0.09) | 2 (0.03) | 0 (0.00) | 1 (0.04) |
| Tolerance to submerge | 0 (0.00) | 4 (0.07) | 0 (0.00) | 18 (0.17) | 12 (0.15) | 3 (0.13) | 5 (0.19) |
| Pests and diseases | 14 (0.33) | 14 (0.25) | 24 (0.55) | 64 (0.61) | 13 (0.16) | 7 (0.30) | 6 (0.21) |
| Drought | 2 (0.05) | 4 (0.07) | 15 (0.34) | 38 (0.36) | 20 (0.25) | 11 (0.48) | 1 (0.04) |
| Number of adopters | 42 | 57 | 44 | 105 | 80 | 23 | 26 |

*Notes*: Asterisks (*, **, and ***) denote significance at 10, 5, and 1 per cent levels, respectively. Based on the coefficients estimated from the ESR model, the predicted yields are shown in log form. Because the dependent variables in the model are the log of yields (kg/ha), the predicted yields are also given in the log form. Converting the mean back to kilogram would lead to inaccuracies due to the inequality of arithmetic and geometric means.

prefer its tillering ability. The higher tillering ability is generally associated with a higher grain yield, but it is unclear whether farmers expect this correlation. Third, GSR adopters in Nampula appreciate its submergence tolerance vis-à-vis those who cultivate traditional varieties.[12] Finally, some GSR adopters do not believe the variety is tolerant enough of drought and resistant enough to biotic stresses (pest infestations and diseases), although non-GSR adopters also suffer from such stresses. In this study, we do not assess the stress tolerances of *Simão* in comparison with those of conventional varieties because of the lack of sufficient data, but this point needs further investigation.

Fundamentally, farmers in most regions in Mozambique face unfavorable rice production conditions (such as drought and biotic stresses) with limited access to irrigation and chemical fertilizer. These conditions make improved varieties less profitable and attractive for adoption under traditional farming practices. This concern is what Mozambique and other Sub-Saharan African countries have been struggling with for decades (Evenson and Gollin 2003; Balasubramanian *et al.* 2007; Kajisa and Payongayong 2011). Recognizing the needs of locally suitable improved varieties in SSA (Evenson and Gollin 2003), GSR varieties are expected to adapt to local environments and benefit farmers by sustaining higher yields (cf. Yu *et al.* 2020). Our results revealed the yield and cost efficiency advantages of GSR adoption over the existing conventional improved varieties in both favorable and unfavorable environments.

Although our study revealed some positive and interesting benefits of GSR variety adoption, which established good potential for GSR varieties in Mozambique, we would like to highlight some limitations that should be taken into account by future studies. First, *Simão* is the only GSR variety grown at our study sites, and therefore, the findings cannot be generalized to all GSR varieties. The benefits of other GSR varieties disseminated in the country (for example, *Hua564*) should also be examined. Second, from an econometric perspective, the instruments used in the ESR estimation could possibly be weak. Therefore, new instruments should be explored in future studies, such as a random treatment that induces GSR adoption. Third, given the potential reverse causality between adoption of GSR varieties and yield and cost efficiency, the estimates from our regression could be interpreted only as associations rather than causalities. Fourth, we used a cross-sectional dataset, and thus the results do not suggest any insights into the long-term impacts of GSR adoption. Recurrent surveys will allow examining the impacts of the intensity (duration) of GSR adoption over time in a panel data context. Also, besides yield and cost efficiency, the impact of GSR varieties could further be examined on outcomes such as productivity enhancement, income, etc. Finally, our study is also limited by the lack of data: (i) farmers' risk preferences, locus of control, and societal norms are important determinants of farmers' technology adoption (Abay *et al.* 2017); and (ii) quality differentials in seed, labor, and land may have contributed to the heterogeneity observed in yields. But, unfortunately, these detailed data are not available in our survey. These points need to be addressed in future surveys and studies.

## 7. Conclusions

Several abiotic and biotic stresses characterize rainfed rice areas in Mozambique. Resource-poor smallholder rice farmers in ecosystems across SSA cannot buy the expensive inputs needed to sustain stable yields and income. However, GSR varieties are expected to produce high and stable yields with fewer inputs and could increase yields at a lower production cost in such rice ecosystems. This article aimed to assess the impact of GSR adoption on rice yield and the cost efficiency of smallholder farmers in Mozambique. We used a farm-level survey and a combination of PSM and ESR methods to address selection bias due to observable and unobservable characteristics.

This study found that GSR adoption brings about some positive and significant benefits in rice yield and cost efficiency. These benefits are observed not only in irrigated environments where fertilizer is applied together with some more advanced farming practices (i.e. Gaza province), but also in Nampula and Sofala provinces where farmers grow rice under rainfed conditions with no fertilizer application. The GSR variety is beneficial for farmers who have it already and also for those who would consider switching from the improved and traditional varieties they are currently growing. The benefits were shown in the overall sample (all provinces combined) and also for individual provinces. Our findings suggest that GSR varieties have the potential to bring about some positive changes in the development of rice production in Mozambique, although we recognize that our study has some limitations and future studies may be needed for further investigation.

## Supplementary material

Supplementary data are available at *Q Open* online.

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## Conflict of interest

The authors declare they have no conflicts of interest.

## Data availability

Data used in this article are available in the online supplementary material.

## End Notes

1 Benson and Mogues (2018) noted that missing public goods prevent the development of crop markets that ensure consistent returns to fertilizer and promote fertilizer uptake. They also stress that competitive fertilizer markets need to be fostered.
2 *Simão* and *Hua564* were found to yield the highest among all the GSR varieties and the local check varieties in the national varietal testing program and participatory varietal trials organized by the Agricultural Research Institute of Mozambique (IIAM). They satisfy the local market requirements for grain quality, which are grain shape and size (medium to long slender), amylose content (20–23%), and milling recovery (>65%).
3 NN matching also has the advantage that it allows keeping larger sample sizes for the ESR estimation that controls for selection bias due to observable and unobservable characteristics.
4 Other matching techniques were also considered for robustness checks (caliper matching and kernel matching). Also, the quality of matching was examined using the propensity score distribution balance test.
5 Online Appendix Figure A1 shows that our outcome variables (yield and cost efficiency) are normally distributed. This supports our assumptions on error terms $u_{1i}$ and $u_{2i}$, and justifies our choice of a probit model in the PSM and selection equation in the ESR.
6 In Chokwe district, two APs out of four were selected (Cidade de Chokwe and Lionde), whereas, in Xai-Xai, only Chicumbane was selected among the four APs in the district. In Buzi, which has three APs, we selected Buzi-Sede, which is the only rice-producing AP in the district. In Mogovolas, which has five APs, we selected Nametil-Sede, Ilute, and Muatua. Finally, in Angoche, two out of four APs were selected (Aube and Nametoria).
7 Only a small fraction of Gaza farmers used other chemical inputs (i.e. herbicide, insecticide, pesticide) and no farmers in the other two provinces used any of them.
8 In Gaza, few farmers have multiple plots, and they grow either *Simão* or other improved varieties in the smaller plots. More farmers have multiple plots in Nampula and Sofala. In Nampula, farmers grow mostly traditional varieties in their smaller plots, while mostly improved varieties, including *Simão*, are chosen in Sofala.
9 A 1% significance for Gaza and 5% significance for the other two provinces. When all matched samples are combined, the null hypothesis is rejected at the 1% significance level.
10 The distance variables do not appear significant in Gaza province. Thus, we have a concern about weak instrumental variables when it comes to the estimation for this province. This could be due to the decreased sample size used for the estimations for Gaza. We recognize this as a limitation.
11 This does not necessarily mean that their advantage is offset in terms of net income.
12 In 2018, Nampula province recorded high annual precipitation of 1759 mm (Visual Crossing 2018) and a large fraction of farmers faced submergence.

## References

Abay K. A., Blalock G and Berhane G. (2017) ‘Locus of control and technology adoption in developing country agriculture: evidence from Ethiopia’, *Journal of Economic Behavior & Organization*, 143: 98–115.

ACI. (2005) ‘Development strategy for the rice sector in Mozambique. *Agrifood Consulting International’ Draft Final Report prepared for Cooperazione Italiana*, Maputo, Mozambique.

Balasubramanian V., Sie M., Hijmans R. and Otsuka K. (2007) ‘Increasing rice production in sub-Saharan Africa: challenges and opportunities’, *Advances in Agronomy*, 94: 55–133.

Benson T. and Mogues T. (2018). Constraints in the Fertilizer Supply Chain: Evidence for Fertilizer Policy development from Three African Countries', *Food Security*, 10: 1479–500.

Caliendo M. and Kopeinig S. (2008) 'Some Practical Guidance for the Implementation of Propensity Score Matching', *Journal of Economic Surveys*, 22: 31–72.

Cameron A. C. and Trivedi P. K. (2005) '*Microeconometrics: Methods and Applications*', Cambridge: Cambridge University Press.

Crost B., Shankar B., Bennett R. and Morse S. (2007) 'Bias from Farmer Self-Selection in Genetically Modified Crop Productivity Estimates: evidence from Indian Data', *Journal of Agricultural Economics*, 58: 24–36.

De Mey Y., Demont M. and Diagne M. (2011) 'Estimating Bird Damage to Rice in Africa: Evidence from the Senegal River Valley', *Journal of Agricultural Economics*, 63: 175–200.

Dessie A., Zewdu Z., Berie A. and Atnaf M. (2020) 'GGE Biplot Analysis of Genotype X Environment Interaction of Cold Tolerant Green Super Rice Genotypes in Ethiopia', *International Journal of Research and Review*, 7: 300–5.

Di Falco S., Veronesi M. and Yesuf M. (2011) 'Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia', *American Journal of Agricultural Economics*, 93: 829–46.

Evenson R. E. and Gollin D. (2003) 'Assessing the Impact of the Green Revolution, 1960 to 2000', *Science*, 300: 758–62.

FAO. (2019). *FAO/WFP Crop and Food Security Assessment Mission to Mozambique (Special Report)*. FAO, Rome.

Fuglie K. O. and Bosch D. J. (1995) 'Economic and Environmental Implications of Soil Nitrogen Testing: A Switching-Regression Analysis', *American Journal of Agricultural Economics*, 77: 891–900.

Greene W. H. (2012). *Econometric Analysis*, 7th edn. Upper Saddle River, NJ: Prentice Hall.

GRiSP (Global Rice Science Partnership). (2013). *Rice Almanac*, 4th edn. Los Baños, Philippines: International Rice Research Institute.

Heckman J. J. (1979) 'Sample Selection Bias As a Specification Error', *Econometrica*, 47: 153–61.

Hossain M., Bose M.L. and Mustafi B.A. (2006) 'Adoption and Productivity Impact of Modern Rice Varieties in Bangladesh', *The Developing Economies*, 44: 149–66.

IRRI (International Rice Research Institute). (2022). Seed rate (high). Retrieved from http://www.knowledgebank.irri.org/decision-tools/rice-doctor/rice-doctor-fact-sheets/item/seed-high-rate, accessed 15 April 2020.

Kajisa K. and Payongayong E. (2011) 'Potential of and Constraints to the Rice Green Revolution in Mozambique: A Case Study of the Chokwe Irrigation Scheme', *Food Policy*, 36: 615–26.

Kajisa K. (2016) 'On the Determinants of Low Productivity of Rice Farming in Mozambique: Pathways to Intensification', In: Otsuka, K., Larson, D.F. (eds) *In Pursuit of an African Green Revolution: Views from Rice and Maize Farmers' Fields*, pp. 13–38. New York: Springer.

Kajisa K. and Payongayong E. (2013) 'Extensification and Intensification Process of Rainfed Lowland Rice Farming in Mozambique', In: *The Coalition for African Rice Development (CARD): Progress in 2008—2013*, pp. 121–44. Tokyo: International Cooperation Agency Research Institute.

Larson D. F., Muraoka R. and Otsuka K. (2020) 'Rural Development Strategies and Africa's Small Farms', In: Gomez y Paloma, S., Riesgo, L., and Louhichi, K. (eds) *The Role of Smallholder Farms in Food and Nutrition Security*, pp. 45–77. Gewerbestrasse: Springer.

Li Z. and Ali J. (2017) 'Breeding Green Super Rice (GSR) Varieties for Sustainable Rice Cultivation', In: Sasaki, T. (ed) *Achieving Sustainable Cultivation of Rice. Volume 1: Breeding for Higher Yield and Quality*. Cambridge: Burleigh Dodds Science Publishing.

Lokshin M. and Sajaia Z. (2004) 'Maximum Likelihood Estimation of Endogenous Switching Regression Models', *The Stata Journal: Promoting Communications on Statistics and Stata*, 4: 282–9.

Maddala G. S. (1986) '*Limited-Dependent and Qualitative Variables in Econometrics*'. Cambridge: Cambridge University Press.

Ministry of Agriculture. (2009) '*National Rice Development Strategy Mozambique*', Mozambique's Ministry of Agriculture. Retrieved from https://www.jica.go.jp/english/our_work/thematic_issues/agricultural/pdf/mozambique_en.pdf, accessed 4 April 2020.

Mishra A. K., Khanal A. R. R. and Pede V. O. O. (2017) 'Is Direct Seeded Rice a Boon for Economic Performance? Empirical Evidence from India', *Food Policy*, 73: 10–8.

Nigatu G., Hansen J., Childs N. and Seeley R. (2017) 'Sub-Saharan Africa Is Projected To Be the Leader in Global Rice Imports', Retrieved from https://www.ers.usda.gov/amber-waves/2017/october/sub-saharan-africa-is-projected-to-be-the-leader-in-global-rice-imports/#:~:text=By%202026%2C%20the%20region%20is,surpassing%20number%20one%20importer%20China, accessed 23 Dec 2020.

Smith J. and Todd P. (2005) 'Does Matching Overcome LaLonde's Critique of Nonexperimental Estimators?', *Journal of Econometrics*, 125: 305–53.

Stuart E. A. (2010) 'Matching Methods for Causal Inference: A Review and a Look Forward', *Statistical Science*., 25: 1–21.

USAID. (2017) '*Mozambique Early Generation Seed Report*', Retrieved from https://www.agrilinks.org/sites/default/files/resource/files/mozambique_early_generation_seed_report.pdf, accessed 4 April 2020.

USDA. (2021) 'Production, Supply and Distribution Database', Retrieved from https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery, accessed 23 December 2021.

Visual Crossing. (2018) 'Weather History of Nampula, Mozambique', Retrieved from https://www.visualcrossing.com, accessed 2 April 2021.

Yorobe J.M., Ali J., Pede V.O., Rejesus R.M., Velarde O.P. and Wang H. (2016) 'Yield and Income Effects of Rice Varieties with Tolerance of Multiple Abiotic Stresses: The Case of Green Super rice (GSR) and Flooding in the Philippines', *Agricultural Economics*, 47: 261–71.

Yu S., Ali J., Zhang C., Li Z. K. K. and Zhang Q. (2020) 'Genomic Breeding of Green Super Rice Varieties and Their Deployment in Asia and Africa', *Theoretical and Applied Genetics*, 133: 1337.

Zhang Q. (2007) 'Strategies for Developing Green Super Rice', *Proceedings of the National Academy of Sciences USA*, 104: 16402–9.