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ABSTRACT

Most Sub-Saharan countries implement input subsidy programs (ISPs) in an attempt to increase fertilizer use, crop yields and farmers' income and to improve household food security. Senegal is no exception and has had an ISP in place for the last 15 years. This article assesses how access to subsidized fertilizer under the ISP is associated with changes in fertilizer and manure use and gross margin. Using household-level data from two agro-ecological zones, we employ an endogenous switching regression framework to control for the potential endogeneity of access to subsidized fertilizer. We find that access to subsidized fertilizer is associated with an increase in the total use of fertilizer of +39 % but also with a reduction in the use of commercial fertilizer of 18 %. Access to subsidized fertilizer is also associated with a reduction in the likelihood of using manure of 5 % and an increase in farmers' total gross margin of 11 %. Results are heterogeneous across agroecological zones, with a strong crowding-out of commercial fertilizer where widely available to farmers. In this case, revising the design of the ISP could lead to improved efficiency.

1. Introduction

With an average fertilizer application level of about 20 kg/ha, sub-Saharan Africa (SSA) has the lowest fertilizer use of any region of the world (FAO, 2022). This low level of fertilizer application leads to nutrient mining and soil fertility decline (Morris et al., 2007) and prevents actual yields from reaching their potential (Van Dijk et al., 2017). In this context, increasing fertilizer use is often seen as a necessary, but not sufficient, condition to promote sustainable agriculture intensification in SSA (Falconnier et al., 2023; Jayne et al., 2018). One of the main policy instruments widely used by African governments to increase yields are input subsidy programs (ISPs). Since the mid-2000s, ISPs have become common practice in SSA (Druilhe & Barreiro-Hurlé, 2012) and assessing their impact has received a great deal of attention from agricultural economists (Jayne & Rashid, 2013). ISPs consist in providing farmers with packages of inputs at subsidized prices, mostly focused on fertilizer and seeds, and to a lesser extent agricultural equipment. Their primary objective is to increase total fertilizer and other input uses (depending on the specific input package offered) as a prerequisite to trigger agricultural productivity growth and to improve farmers' income and food security.

A majority of studies that assess the performance of ISPs conclude that they suffer from important design and implementation failures (Holden, 2019). These include unclear or contradictory objectives, the lack of an exit strategy, the late delivery of inputs (Druilhe & Barreiro-Hurlé, 2012), targeting errors (Holden and Lunduka, 2012; Pan & Christiaensen, 2012), the diversion and leakages of inputs (Liverpool-Tasie and Takeshima, 2013), and the crowding-out of commercial fertilizer use.[1] The latter has been observed in Zambia (Mason & Jayne, 2013; Xu et al., 2009) Malawi (Ricker-Gilbert et al., 2011), Kenya (Jayne et al., 2013), and Nigeria (Takeshima & Nkonya, 2014). Only one case found evidence of crowding-in of commercial fertilizer demand, namely a pilot voucher program set up in one Nigerian state (Liverpool-Tasie, 2014). These weaknesses explain the limited impact of ISPs on crop yields, income or food security, and increased program costs. Published studies that directly assess the effects of ISPs on crop yield and gross margin are scarce and have been mainly conducted in Eastern Africa with a focus on maize, the main crop of this region (Chibwana et al., 2014; Mason et al., 2013; Mason et al., 2017; Ricker-Gilbert & Jayne, 2012). One exception is the study of Wossen et al. (2017) which also focuses on maize, but in Nigeria, and assesses the impact of a mobile-based e-voucher program. Overall, these studies show positive, but

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[1] For a detailed literature review, see Jayne et al. (2018) and Holden (2019).

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limited, impact of the program on crop yields and gross margin (Jayne et al., 2018).

Senegal first started implementing an ISP 15 years ago. In this article, we test whether access to subsidized fertilizer via this program is associated with farmers' total and commercial fertilizer use, manure use, and gross margins.

Our analysis contributes to the literature on input subsidies in several ways. First, we focus on a fertilizer subsidy program (FSP) in a West African country, a sub-region of Africa where little attention has been paid to this issue, and where maize is not the main targeted crop.[2] Indeed, the FSP in Senegal has barely been studied at all. Kelly et al. (2011) provides a policy synthesis that covers four countries including Senegal. For Senegal, they found that the subsidy largely benefited a few importing companies that had close ties to government. Seck (2017) is the only existing impact assessment of the program and shows that it had a positive impact on farmers' technical efficiency in the Senegal River Valley. Yet, Seck (2017) focuses on a region that is not representative of the rest of the country as it is the only one that relies on irrigated farming systems with heavy public and private investment. The analysis presented here includes another important but poorer agroecological zone (AEZ) of Senegal that depends mainly on rainfed agriculture.

Second, while most of the papers focus on one specific aspect of the program, either the crowding-out effect or crop yield and income, here we consider both aspects to better understand how the FSP changes farming systems. Third, we expand the analysis to observe how the program relates to manure use. This is relevant as in 2022 the government expanded the inputs covered by the program to include organic fertilizer. Fourth, we examine one of the potential sources of heterogeneity in program performance, namely that of agroecological zones (AEZ). Previous studies have shown the importance of distinguishing different AEZs of a country within the analysis of FSPs, especially there where there are significant regional discrepancies in the importance of the private fertilizer supply sector (Xu et al., 2009). Lastly, from a methodological perspective, we control for the potential endogeneity of access to the FSP using an endogenous switching regression approach. This approach is more flexible than other IV approaches as estimates can vary according to whether households benefit from the ISP or not. Furthermore, we assess the robustness of our findings using alternative instrumental variables (based on Lewbel's (2012) method), using propensity score matching methods and considering the intensity of access to the FSP.

The rest of the article is organized as follows. Section 2 gives a brief overview of the Senegalese ISP. The empirical framework is provided in Section 3 and results are presented in Section 4. Section 5 concludes with the policy implications of the findings.

2. The input subsidy program in Senegal

In response to the global food crisis of 2007/08, but also in a consistent effort to overcome the challenges related to weak agricultural productivity, low availability of inputs, and outdated and inadequate farming equipment, the Senegalese government expanded support for the agricultural sector with the implementation of an ISP. The program gained momentum in 2012 doubling the amount of fertilizer subsidized and included agricultural equipment as an eligible input in some areas of the country. In parallel, the budget allocated to the ISP was increased reaching a total of 91.5 million euros in 2020 (Delegation of the European Union to Senegal, personal communication).[3] Fertilizer subsidies accounted for about 40 % of the ISP's budgetary resources, seed subsidies for around 40 %, agricultural equipment for 5 %, and the remaining resources were used to subsidize phytosanitary products and so-called "special" programs (Seck, 2017). In 2018, the ISP's budget represented around one third of the total budget of the Ministry of Agriculture and Rural Equipment (MARE) and about 0.5 % of GDP, making it the main policy support for farmers in the country.

The ISP's stated objectives are to improve the affordability of the inputs for main domestic crops (groundnut, rice, millet, sorghum, maize, cowpea) in order to significantly increase productivity and achieve self-sufficiency (Ministère de l'Agriculture et de l'Equipement Rural, 2014). The program is implemented as follows. Annually, the MARE sets fertilizer and seed quotas for each region on the basis of regional production targets, crop acreage forecasts and recommended fertilizer doses to achieve crop-specific production targets. The MARE then selects input suppliers following a public call for tenders, resulting in the selection of five private importers responsible for the supply of fertilizers in the country (IPAR, 2015). Each year, the MARE appoints the members of a national committee responsible for supervising, coordinating and ensuring the transparency of agricultural input transport and transfer operations throughout the country. Members are drawn from administrative authorities, civil society and producers' organizations (PO). Similar committees are set up at each administrative level: regional, departmental and local. These local committees, known as *commissions de cession* in French, are in charge of the reception and distribution of inputs at centralized distribution points, the quality control thereof, and the drawing up of a completion report. These reports serve as proof of delivery of the inputs for the suppliers to be paid the subsidy rate (50 % when the field work was carried out). Theoretically conceived as a universal program accessible to all producers, limited input availability leads to a *de facto* selection of farmers by the local committees (IPAR, 2015) with recipients receiving up to three 50-kg bags of fertilizer (Seck, 2017). Given the universal regime of the Senegalese ISP with local targeting whereby no general eligibility criteria have been established beyond "being a full-time smallholder farmer", it can be assumed that various unobservable criteria affect the recipient selection process making access to the ISP likely endogenous.

3. Empirical framework

3.1. Study areas and survey design

The data used in this study comes from a household survey conducted in two Senegalese agroecological zones: the groundnut basin (GB) and the Senegal River Valley (SRV). The GB is composed of four provinces and farm households rely on rain fed agriculture, using extensive or semi-intensive cropping systems mainly based on cereal-leguminous rotation (Sall, 2015). Despite a certain heterogeneity among households, fertilizer use is low and the private input distribution system is known to be weak. In this agroecological zone, groundnut is the main crop targeted by the ISP, which provides groundnut seeds and specific fertilizer (6–20-10). The SRV lies in the northern part of the country close to the Senegal river where farm households cultivate mainly irrigated rice based on an intensive use of fertilizer and where the private input distribution system is more consolidated and dynamic. In this agroecological zone, rice is the main crop targeted by the ISP which provides different types of fertilizer (9–23-30, 16–46-0, and urea). The two AEZ were selected in order to capture extreme cases with regard to current use of commercial fertilizer. From August to October 2021, 936 farmers were surveyed using a stratified two-stage sampling procedure. At the first stage, villages were selected with a probability proportional to size within each district. The villages were randomly drawn from the last available census carried out in 2013. In the second stage, 12 farmers per village were randomly selected from a list of households provided by the chief of the village when the interviews started. Recipients of the ISP and non-recipients were proportionately

[2] Given that we focus in this article on subsidized fertilizer (and not the other subsidized inputs), we refer to FSP rather than to ISP when we analyse this program.

[3] In 2016, the total budget amounted to 54 million euros. Missing information for the other years prevents a broader picture of the total budget allocated to the program.

selected. After excluding 34 households due to missing information or unrealistic outliers, the final sample was reduced to 902 households.[4] Among those 902 households, 441 (49 % of the final sample) obtained either subsidized fertilizer or subsidized seed, or both. Among those 441 households, 74 received only subsidized seeds. The other 367 households received subsidized fertilizer (combined or not with seeds). As there are two main growing seasons in the SRV - the hot dry season (from February to May) and the rainy season (from June to October) – 81 households reported data for both growing seasons and the total sample size came to 983 observations.

3.2. Variables used and descriptive statistics

Following Mason et al. (2017) and Wossen et al. (2017), we investigate how access to subsidized fertilizer relates to other variables by using a binary variable taking the value of 1 if the farmer is a beneficiary of subsidized fertilizer and 0 otherwise. An alternative would be to use a continuous variable that would capture this relationship at the intensive margin (e.g., focusing on how an additional kg of subsidized fertilizer relates to the variables of interest). Given that we are more interested in access rather than in the amount (any additional kg) of subsidized fertilizer used, we will display results from the analysis using the binary variable. Results using the continuous variable are shown in Appendix E. While the ISP also covers seeds, we do not show how access to subsidized seeds is related to the outcome variables for two reasons. First, few households receive only subsidized seeds (8 % of the sample) and, second, it mainly concerns households from the GB since there are no subsidies for rice seeds in the SRV. However, we include access to subsidized seeds in our analysis by using the variable as a (endogenous) covariate (see section 3.3).

We measure the associations between benefiting from the FSP and four output indicators: total amount of nitrogen used (in kg/ha), total amount of commercial nitrogen used (in kg/ha),[5] whether the farmer use manure or not, and gross margin[6] (in FCFA/ha). Output and input prices were directly derived from the questionnaire. For the households that did not sell (buy) any unit of a given output (input), we use the district-level median price. Table 1 presents descriptive statistics for the entire sample and for the recipients and non-recipients.[7]

As expected, we observe significant differences between the two groups for different variables. On average farmers in our sample use 46 kg of nitrogen per hectare (the median is 7 kg), but recipients use 30 kg/ha more nitrogen than non-recipients. Out of the total 46 kg/ha of nitrogen used, 25 kg/ha comes from the commercial channel (the median for the commercial use is 3 kg) while the remainder comes from the ISP. Commercial use of fertilizer is higher for non-recipients (34 kg/ha) than for recipients (11 kg/ha), which suggests ISP crowds-out private fertilizer sales to farmers. Also, while on average 59 % of the farmers use manure, the percentage is slightly higher for non-recipients (63 % against 53 %). Last, average total gross margin of recipients stands at 239 thousand FCFA/ha which is 70 thousand FCFA/ha higher than that of non-recipients. We need to be careful when interpreting the average differences as evidence of impact, as we need to account for the potential selection bias when selecting recipients. Furthermore, output indicators can also be affected by other factors that need to be accounted for. We consider a set of explanatory variables that can affect output indicators which include household characteristics such as age and gender of the household head, if they are literate, the number of adult male equivalents (AME), and the ethnic group of the household. From Table 1, we can observe that beneficiaries of the ISP are slightly older, more literate, belong to households with more members, and include more male-headed and Wolof households (the main ethnic group in Senegal). We also considered some important farm structural variables such as total cultivated area, number of cows for fattening,[8] credit access, if the farmer belongs to a PO, distance to the main road, and distance to the closest input supplier. The last two variables are considered as proxies for transportation costs to access the market and inputs respectively. We also included the number of plots cultivated by the household that are subjectively considered to be of good quality for farming. Furthermore, as mentioned above, we include whether the household was also a recipient of subsidized seeds.

3.3. Empirical strategy

While the FSP is allegedly universal (i.e. accessible to all households) not all households receive it. This might be driven by two reasons. First, even at the subsidized price, some households cannot afford to buy the subsidized inputs or still consider that these inputs are not worth the price. Second, due to the limited amount of subsidized fertilizer available, even households that would be willing to buy fertilizer at subsidized prices might not receive it. The exact criteria for selecting recipients are unknown as they are not specified in official documents. At the village level, fertilizer allocation may be based on crop acreage potential but also on other factors such as political considerations (e.g. Pan & Christiaensen, 2012). Therefore, the (self-)selection of recipients entails a selection bias that needs to be controlled for in order to understand how the FSP is correlated with the output variables. The simple average comparison of the output indicators reported in the previous section may be the result of biased correlations and lead to spurious conclusions.

3.4. Endogenous switching regression

Given the cross-sectional nature of the data, and to account for both observable and unobservable underlying factors explaining the selection of the recipients, the method used in this study is based on an IV approach in order to obtain less biased estimates of the treatment effects of the FSP. Further, to estimate the impact of access to subsidized fertilizer (a dummy variable) an endogenous switching regression (ESR) approach is considered the most adequate for this task. Contrary to other IV approaches, such as the two-stage least-squares regression or the control function approach, ESR is more flexible as the estimates of the outcome equation are estimated independently for each of the regimes: being recipient or not of subsidized fertilizer (Clougherty et al., 2016). The first stage is a probit selection equation where the dummy variable D_i equals to 1 if the farmer is a recipient. The probability of being a recipient of subsidized fertilizer can be expressed as:

$$D_i^* = X_{ij}\phi_1 + Z_{ik}\phi_2 + \varepsilon_{ik} \text{ with } D_i = \begin{cases} 1 if D_i^* > 0 \\ 0 if D_i^* \leq 0 \end{cases}, \quad (1)$$

[4] We omitted 10 households where nitrogen application is reported as highly unlikely (over 600 kg/ha).

[5] We focus on the level of nitrogen in order to assure consistency due to the different types of subsidized fertilizer provided to farmers. However, the analysis using “total amount of fertilizer used” and “commercial fertilizer used” as output variables instead of nitrogen led to very similar results.

[6] Gross margin is defined as the difference between the total value per hectare of production minus unit costs incurred (seed, fertilizer, pesticides, manure, irrigation, off-farm labour, and renting costs of production factors).

[7] We use the term “recipients” to refer to households that received any quantity of subsidized fertilizer.

[8] Senegalese farmers do not like to inform interviewers about their herd size for several reasons. For religious reasons, because they are wary that this information will be used for tax purpose, and because the allocation of animal property rights is complex within the household, making it objectively difficult to establish herd size. Instead, we elicited the number of cows held for fattening. This variable is closely related to the total herd size and can be considered as an indicator of wealth.

Table 1
Descriptive statistics of the variables used in the study for the whole sample and for recipients and non-recipients of subsidized fertilizer sub-groups.

Variables	Definition	Mean (N = 902)	SD	Recipient[1] (N = 367)	Non-recipient (N = 535)	Diff.
Outcome variables:						
Ferti tot	Total use of nitrogen (kg/ha)	46.77	72.27	64.4	34.05	−30.34***
Ferti com	Total use of commercial ntrogen (kg/ha)	25.03	54.89	12.53	34.05	21.51***
Manure use	1 if the household applied manure	0.59	0.49	0.53	0.63	0.09*
Gross margin	Gross margin at farm level (thousand FCFA/ha)	198.15	328.4	239.36	168.42	−70.93**
Explanatory variables:						
Recipient	1 if household received subsidized fertilizer	0.42	0.49			
Age	Age of household head	52.46	12.32	53.6	51.68	−1.92**
Male	1 if household head is a male	0.96	0.19	0.98	0.95	−0.02**
Literacy	1 if household head is literate	0.29	0.45	0.33	0.26	−0.08*
Wolof	1 if ethnic group of the household is Wolof	0.43	0.5	0.47	0.4	−0.07**
AME	Adult male equivalent	6.74	4.43	7.4	6.29	−1.11***
Land	Area of land cultivated (hectare)	4.08	3.79	4.86	3.55	−1.31***
CowFat	Head of cow fattening	0.27	0.6	0.34	0.23	−0.11***
Credit	1 if household got a credit	0.14	0.34	0.17	0.11	−0.06**
PO	1 if household belongs to a PO	0.31	0.46	0.43	0.23	−0.20***
DistRoad	Distance to the main road (km)	2.26	1.14	2.23	2.28	0.05
DistSuppl	Distance to the nearest input supplier (km)	2.57	1.02	2.73	2.46	−0.28***
NumQualPlot	Number of plots of good quality	0.6	0.85	0.68	0.55	−0.13**
SubsSeed	1 if household received subsidized seeds	0.22	0.43	0.39	0.14	−0.24***
PolRol	1 if a member of household has political role or is a member of the local committee	0.19	0.39	0.27	0.14	−0.13***
ShareVillage	Share of total amount of subsidized fertilizer at the village level over the total at district level	0.3	0.23	0.33	0.27	−0.04***

Note: * p<0.1, ** p<0.05, *** p<0.01 (t-tests used for continuous variables and chi2 test for binary variables). [1] A household is labelled as "Recipient" if he obtained any quantity of subsidized fertilizer.
Source: own elaboration based on survey data.

where D_i^* is the latent variable for being recipient of fertilizer. X_{ij} is a vector of control variables for household i in commune k, Z_{ik} is a vector of instruments, and ε_{ik} represents a normally distributed error term associated with selection into the program with mean 0 and variance σ_ε^2. In the second stage, the effect of access to subsidized fertilizer on the outcome of interest Y_{ik} is estimated under the both regimes (recipients [R1] and non-recipients [R2]):

$$\text{R1}: \; Y_{ik}^1 = X_{ij}^1\gamma^1 + \mu_{ik}^1 \text{ if } D_i = 1 \tag{2}$$

$$\text{R2}: \; Y_{ik}^2 = X_{ij}^2\gamma^2 + \mu_{ik}^2 \text{ if } D_i = 0 \tag{3}$$

The error terms ε_{ijk}, μ_{ijk}^1, and μ_{ijk}^2 are assumed to have a trivariate normal distribution with mean vector zero. σ_ε^2 is the variance of the error term in the selection equation, σ_1^2 and σ_2^2 are the variances of the error terms of the equations of R1 and R2 respectively, $\sigma_{2\varepsilon}$ is a covariance of ε_{ijk} and μ_{ik}^2, and $\sigma_{1\varepsilon}$ is a covariance of ε_{ijk} and μ_{ik}^1. If either $\sigma_{1\varepsilon}$ or $\sigma_{2\varepsilon}$ is significant, the null hypothesis that selection bias is absent can be rejected. Conditional expectations of outcome and counterfactual cases can be calculated as follows (Lokshin & Sajaia, 2004):

$$E\left(Y_{ik}^1|D=1\right) = X_{ij}^1\gamma^1 + \sigma_{1\varepsilon}\lambda^1 \tag{4}$$

$$E\left(Y_{ik}^2|D=1\right) = X_{ij}^1\gamma^2 + \sigma_{2\varepsilon}\lambda^1 \tag{5}$$

$$E\left(Y_{ik}^1|D=0\right) = X_{ij}^2\gamma^1 + \sigma_{1\varepsilon}\lambda^2 \tag{6}$$

$$E\left(Y_{ik}^2|D=0\right) = X_{ij}^2\gamma^2 + \sigma_{2\varepsilon}\lambda^2 \tag{7}$$

where λ^1 and λ^2 are the inverse Mills ratios evaluated from the selection equation for the recipients and non-recipients, respectively. Equations (4) and (7) give the observed expected outcomes. Equation (5) gives the counterfactual expected outcome in the case where recipients would not have received any subsidized fertilizer, and equation (6) gives the counterfactual expected outcome in the case where non-recipients would have actually received subsidies. From equations (4) and (5), we estimate the average treatment effect on the treated (ATT) which gives the change in the average output due to the treatment for the treated households (recipients of subsidized fertilizer). The average treatment effect on the untreated can be derived from equations (6) and (7). We focus our analysis on the ATT estimates as the ATU is less relevant for the policy-makers and may lead to unsound policy conclusions. The selection equation and the two outcome equations are simultaneously estimated using the full information maximum likelihood estimator implemented in Stata following Lokshin and Sajaia (2004).

Identification strategy

At least one instrument in the participation equation has to be excluded from the outcome equations. A valid instrument should affect the likelihood of being a recipient of subsidized fertilizer but should not influence outcomes of interest. Our first instrument is selected based on the evidence of the positive relationship between engagement in local politics and access to public funds (Baird et al., 2011; Bardhan & Mookherjee, 2005) and following previous analysis which find measures of socio-political capital an appropriate instrument in the case of ISPs (Jayne et al., 2013; Pan & Christiaensen, 2012; Ricker-Gilbert et al., 2011; Sibande et al., 2015). Therefore, the first instrument is a dummy variable capturing whether a member of the household holds a political role at the district level or below, or is a member of the local committee in charge of the allocation of the inputs to farmers. The underlying hypothesis is that having local political connections may directly or indirectly influence the local committee choices of fertilizer distribution but not the outcome variables.

We also introduced a second instrument that proxies the effect on the likelihood to be a recipient at the village level. This instrument captures the share of the total amount of subsidized fertilizer in each particular village over the total amount of subsidized fertilizer in the region where the village is located. As fertilizer allocation may be based on production potential, larger values of the instrument correspond to areas with greater agricultural potential. As agricultural potential may affect some outcomes of interest, we include district dummies to account for this unobserved heterogeneity.

A falsification test to establish the appropriateness of these instruments (Di Falco et al., 2011) confirms that the two instruments significantly and positively affect the farmer's likelihood to receive subsidized fertilizer while it does not affect the outcomes of interest (see Appendix A). Therefore, while not guaranteeing that instruments are valid, the falsification test rejects that the selected instruments are not valid.

The variable access to subsidized seeds (SubsSeed), used as an explanatory variable, may be endogenous too. To test and control for the potential endogeneity of this variable, we applied the two-stage control function method proposed by Wooldridge (Wooldridge, 2015). We first estimate a reduced form probit model of the variable SubsSeed on all the exogenous explanatory variables plus an instrument. The instrument used is the share of the total value of subsidized seed at the village level over the total value of subsidized seed at the regional level. We also included the district dummies in the first stage probit model. The instrument positively and significantly influences the access to subsidized seeds while it does not affect the access to subsidized fertilizer (See Table A1). The variable and the generalized residuals predicted from the probit model are then added as regressors in the first-stage of the ESR model (eq. (1)).

While being aware of the potential limitations of our identification strategy, which relies on cross-sectional data and the assumed appropriateness of the instruments, we believe that our econometric approach (ESR) will overcome a significant part of the confounding caused by a range of omitted variables and endogeneity problems. However, this is not enough to ensure full causality and therefore we explicitly avoid language referring to causal links (such as treatment effect) and instead refer to associations between the access to subsidized fertilizer and the outcome variables.

4. Results and discussion

Results of the ESR models are displayed for total use of nitrogen and total use of commercial nitrogen (Table 2), and for manure use and gross margin (Table 3). Models for total use of nitrogen, total use of commercial nitrogen, and gross margin follow a log-linear functional specification. For each of the four outcome variables, the first column gives the selection equation estimates while the second and third columns give the estimates of the relationship between covariates and the outcome variable for recipients and non-recipients, respectively. The standard errors are clustered at the village level as it is at this level that residual correlation could be expected.[9]

The significant results of the likelihood ratio test (LR test) and the sigma (σ_j) reported at the bottom of Tables 2 and 3 indicate that for each outcome variable the three equations are jointly dependent, confirming the existence of selection bias. Also, the correlation coefficients (ρ_1 and ρ_2) between the selection equation and the outcome equations are mostly negative but only significant for the commercial fertilizer use output variable. The negative ρ_2 indicates a positive selection bias where non-recipients tend to use more commercial fertilizer than a random household. Additional discussion of the results of the selection equations is included in Appendix B.

4.1. Relationships between access to subsidized fertilizer and the outcome variables

If we look at the estimates of the relationship between main covariates and outcome variables, we observe that the larger the household size (AME), the higher the total use of nitrogen (whether the household is recipient or not). A larger family requires more food, but also provides a higher number of workers that can contribute to the purchase of fertilizer. Farm size shows the opposite correlation. For recipients the number of cows bred for fattening plays a positive role on the use of fertilizer. Wealthier households use a higher amount of fertilizer. Ethnicity (Wolof) also is of influence among recipients. Among the non-recipients, transportation cost (proxied by distance to the main road) has a negative effect on fertilizer use while the number of plots of good quality has a positive influence. The covariates that influence the use of commercial nitrogen among the non-recipients are very similar. Interestingly, the number of plots of good quality positively impacts the use of commercial fertilizer for both recipients and non-recipients. Farmers use more commercial fertilizer when they are endowed with more plots of land perceived as of good quality. Covariates that impact the use of manure among the recipients are the number of cows held for fattening, which is directly related to the production of on-farm manure. Likewise, the higher the distance to the road, the higher the use of manure, which may act as a substitute to mineral fertilizer. Being a member of a PO negatively impacts manure application among the recipients. As we have seen above, PO membership has a strong impact on the access to subsidized fertilizer, which may reduce the incentive to use manure. Last, gross margin is mainly impacted by the number of plots of good quality, and, for non-recipients, by age. The latter result may be related to the role played by experience on the economic performance of farming.

Based on the estimates of the ESR models, Table 4 shows the coefficients reflecting the associations between being recipients of subsidized fertilizer and the four outcomes of interest. As one would expect, we observe a positive relationship between benefiting from the FSP and total use of nitrogen, which increases by 39 % for recipients. However, this increase in fertilizer use would be higher if subsidized fertilizer was not used to substitute commercial fertilizer. Our results show a decrease in commercial fertilizer use of 18 % when households are recipients of the FSP. This negative association between being a recipient of the FSP and commercial fertilizer use suggests the program partially crowds out commercial fertilizer sales. The failure of the program to support the use of commercial fertilizer, and consequently private sector activities, is consistent with evidence from Zambia (Mason & Jayne, 2013; Xu et al., 2009), Malawi (Ricker-Gilbert et al., 2011), and Kenya (Mather & Jayne, 2018). The estimated level of the crowding-out in previous literature ranges from 0.08 kg in Zambia (Xu et al., 2009) to 0.43 kg in Kenya (Jayne et al., 2013). This means that for each additional unit of subsidized fertilizer received total fertilizer use increases by 0.92 kg (Zambia) to 0.57 kg (Kenya).[10] As the methodology used here is different and the identification strategy weaker (we use a cross-sectional dataset), we cannot preform a direct comparison of results. Yet, a crowding-out effect of 18 % suggest that a recipient would reduce their consumption of commercial fertilizer to 0.82 kg, compared to a non-recipient that would use 1 kg. This value is close to the findings of Xu et al. (2009), and is located at the lower end of the range of crowding-out effects reported in similar studies. This can be explained by the fact that subsidized nitrogen accounts for a relatively large share of the total use (81 %), combined with the low level of nitrogen purchased (12.5 kg/ha), which demonstrates the limited development of the commercial fertilizer sector in Senegal and in the GB in particular (see below for an analysis at region level).

Results indicate that being a recipient of subsidized fertilizer is to some extent negatively associated with the likelihood to apply manure (-5%). This signals partial substitution between both sources of nitrogen (mineral and organic), similar to evidence found by Holden and Lunduka (2012) for Malawi and maize. When considering the economic performance of farms, being a recipient of the program is positively associated with the log of gross margin (+11 % in average). Previous studies on the impact of access to subsidized fertilizer on gross margin are rather scant and inconclusive. Mason and Tembo (2015) found that

[9] We also undertook the analysis clustering at the household level as a robustness check. This alternative clustering level does not change the significance of the parameters of interest.

[10] See Xu et al. (2009) for a mathematical definition of the crowding in/out effect in a context of program of fertilizer subsidies.

Table 2
Endogenous switching regression model results for total and commercial fertilizer use.

	Total fertilizer use (log form)			Commercial fertilizer use (log form)		
	Selection equation	Recipients	Non-recipients	Selection equation	Recipients	Non-recipients
Age	0.007*(0.004)	−0.004(0.003)	−0.010***(0.004)	0.008*(0.004)	−0.006(0.006)	−0.012***(0.004)
Male	0.477(0.309)	0.192(0.192)	0.144(0.236)	0.453(0.298)	0.242(0.335)	0.056(0.263)
Literacy	0.089(0.133)	0.052(0.084)	0.170(0.124)	0.081(0.132)	−0.264*(0.147)	0.169(0.131)
Wolof	−0.011(0.141)	0.330***(0.117)	0.057(0.132)	−0.045(0.155)	0.563***(0.202)	0.229(0.146)
AME	0.025*(0.013)	0.014*(0.008)	0.032**(0.015)	0.024*(0.014)	0.018(0.015)	0.036**(0.015)
Land	0.172**(0.085)	−0.301***(0.094)	−0.418***(0.103)	0.171**(0.084)	0.170(0.143)	−0.446***(0.101)
CowFat	0.060(0.094)	0.131**(0.062)	−0.014(0.082)	0.059(0.099)	−0.130(0.113)	0.004(0.089)
Credit	−0.026(0.151)	−0.055(0.115)	0.100(0.213)	−0.032(0.151)	0.170(0.221)	0.123(0.212)
PO	0.561***(0.175)	0.016(0.119)	0.053(0.190)	0.556***(0.181)	0.092(0.197)	−0.035(0.186)
DistRoad	0.055(0.056)	0.058(0.043)	−0.119*(0.063)	0.061(0.057)	−0.028(0.078)	−0.151**(0.062)
DistSuppl	0.068(0.066)	0.063(0.039)	−0.009(0.075)	0.055(0.067)	−0.017(0.093)	0.057(0.078)
NumQualPlot	0.130**(0.062)	0.048(0.064)	0.159**(0.079)	0.125*(0.065)	0.141(0.095)	0.131(0.083)
SubsSeed	0.024(0.742)	−0.136(0.128)	−0.054(0.232)	0.017(0.914)	0.131(0.315)	−0.291(0.218)
PolRol	0.278**(0.127)			0.273**(0.117)		
ShareVillage	0.574*(0.330)			0.575*(0.334)		
Seed subs residuals	0.892**(0.426)			0.894*(0.536)		
Constant	−3.597***(0.590)	2.152*** (0.536)	1.602*** (0.457)	−3.491***(0.589)	1.039 (0.919)	1.766*** (0.444)
σ_1 and σ_2		0.808* (0.092)	1.198*** (0.050)		1.322*** (0.044)	1.245*** (0.049)
ρ_1 and ρ_2		−0.028 (0.122)	−0.091 (0.216)		−0.082 (0.257)	−0.310* (0.183)
Observations	983			983		
LR test	15.54***			26.36***		

Note: Standard errors in parenthesis. All specifications include seasonal and district dummies. * p<0.1, ** p<0.05, *** p<0.01; standard errors are clustered at village level. σ_1 (σ_2) is the square-root of the variance of the error terms in the outcome equation 2 (3). ρ_1 (ρ_2) is the estimated correlation between the selection equation errors and the outcome equation errors for the treated (non-treated). The LR test report if we can reject the null hypothesis of no correlation between the selection equation errors and the outcome equation errors (Ho: rho1= rho2=0).

Table 3
Endogenous switching regression model results for manure use and total gross margin.

	Manure use			Gross margin (log form)		
	Selection equation	Recipients	Non-recipients	Selection equation	Recipients	Non-recipients
Age	0.007*(0.004)	0.002(0.002)	0.001(0.001)	0.008*(0.004)	0.014(0.010)	0.022***(0.007)
Male	0.486(0.311)	0.215(0.164)	−0.003(0.083)	0.456(0.310)	0.776(0.889)	0.269(0.466)
Literacy	0.094(0.135)	0.024(0.044)	0.011(0.034)	0.084(0.133)	−0.187(0.206)	0.242(0.191)
Wolof	−0.016(0.144)	0.062(0.058)	0.060(0.052)	−0.005(0.142)	0.082(0.254)	0.027(0.169)
AME	0.024*(0.014)	−0.003(0.005)	0.018***(0.006)	0.026*(0.014)	0.006(0.018)	−0.012(0.027)
Land	0.170**(0.086)	0.024(0.037)	0.033(0.037)	0.175**(0.086)	0.026(0.192)	0.159(0.159)
CowFat	0.057(0.093)	0.072**(0.029)	0.051*(0.030)	0.062(0.092)	0.095(0.159)	−0.013(0.196)
Credit	−0.026(0.150)	−0.063(0.059)	0.016(0.069)	−0.031(0.150)	0.372(0.259)	0.025(0.294)
PO	0.559***(0.174)	−0.109*(0.059)	−0.044(0.063)	0.569***(0.171)	0.204(0.279)	−0.024(0.377)
DistRoad	0.054(0.056)	0.052***(0.019)	−0.023(0.018)	0.054(0.056)	−0.001(0.074)	0.068(0.076)
DistSuppl	0.068(0.065)	0.010(0.023)	−0.013(0.026)	0.066(0.065)	0.007(0.100)	0.177* (0.094)
NumQualPlot	0.131**(0.063)	−0.000(0.025)	−0.017(0.026)	0.132**(0.062)	0.166*(0.095)	0.162* (0.090)
SubsSeed	0.097(0.714)	0.058(0.095)	0.034(0.074)	−0.021(0.693)	0.105(0.231)	−0.093 (0.164)
PolRol	0.269**(0.125)			0.273**(0.124)		
ShareVillage	0.564*(0.325)			0.537*(0.327)		
Seed subs residuals	0.852**(0.414)			0.917**(0.399)		
Constant	−3.618***(0.585)	0.179(0.306)	0.333(0.213)	−2.378***(0.490)	3.351** (1.185)	2.550***(0.744)
LnS		0.35*** (0.058)	0.393*** (0.040)		1.923*** (0.096)	2.039*** (0.084)
ρ_1 and ρ_2		0.091 (0.295)	−0.010 (0.198)		0.027 (0.116)	−0.133 (0.118)
Observations	983			983		
LR test	13.46***			32.23***		

Note: Standard errors in parenthesis. All specifications include seasonal and district dummies. * p<0.1, ** p<0.05, *** p<0.01; standard errors are clustered at village level. σ_1 (σ_2) is the square-root of the variance of the error terms in the outcome equation 2 (3). ρ_1 (ρ_2) is the estimated correlation between the selection equation errors and the outcome equation errors for the treated (non-treated). The LR test report if we can reject the null hypothesis of no correlation between the selection equation errors and the outcome equation errors (Ho: rho1= rho2=0).

Table 4
Estimated associations between access to subsidized fertilizer and total and commercial fertilizer use, manure use and gross margins.

Outcomes	Mean outcomes		ATT	Change (%)
	Recipients[1] (N = 367))	Non-recipients (N = 535)		
Ferti tot (log form)	3.127	2.241	0.886*** (0.033)	39 %
Ferti com(log form)	1.432	1.748	−0.316*** (0.083)	−18 %
Manure_use	0.531	0.561	−0.029*** (0.008)	−5%
Gross_margin (log form)	5.418	4.867	0.550*** (0.037)	11 %

Note: * p<0.1, ** p<0.05, *** p<0.01 (two-sample t-tests with unequal variances and unpaired sample is applied to test for significance). [1] A household is labelled as “Recipient” if he obtained any quantity of subsidized fertilizer.

in Zambia being a recipient of an FSP increased crop income by 10 %. On the other hand, Mason et al. (2017) found no evidence of impact of the Kenyan FSP on farm income, even if it positively impacted production and the gross value of production.

4.2. Robustness checks

Given that the validity of our results relies on the adequacy of the chosen instruments, we conducted robustness checks to test if the results hold when using alternative methods. Following Lewbel (2012) we built alternative instruments using the heteroscedasticity of the error terms (see Appendix C for more details), which are then included into the ESR framework. In addition, we applied matching techniques that do not require instrumental variables (See Appendix D for more details). As the latter rely on the assumption that access to fertilizer subsidies is based entirely on observed characteristics, which is unlikely in our case, we are more confident in the ESR results. When the analysis is made using alternative instruments following the Lewbel approach (Table 5), the estimated associations confirm the strong positive (negative) relation between subsidized fertilizer receipt and the total use of nitrogen (commercial nitrogen). It also confirms the weak but negative association with manure use as well as the positive one with gross margin. The analysis based on matching techniques also confirms results on total use and commercial use of nitrogen. However, with this approach estimates on manure use and gross margin are not significant, despite having the same sign. This is probably due to the role of unobservable characteristics that are only captured when using instruments. Our analysis focusing on the amount of subsidized fertilizer received also confirms the positive (negative) relationship between being a subsidized fertilizer recipient and the total use of nitrogen (commercial nitrogen). It also confirms the positive association with gross margin (see Appendix E).

Table 5
Estimated associations between access to subsidized fertilizer and total and commercial fertilizer use, manure use and gross margins using heteroscedasticity to identify instruments (Lewbel method).

	ATT (Lewbel)
Ferti tot (log form)	0.999*** (0.033)
Ferti com (log form)	−0.303*** (0.083)
Manure_use	−0.018** (0.008)
Gross_margin (log form)	0.524*** (0.038)

Note: * p<0.1, ** p<0.05, *** p<0.01 (two-sample t-tests with unequal variances and unpaired sample is applied to test for significance).

Table 6
Estimated associations between access to subsidized fertilizer and total and commercial fertilizer use, manure use and gross margins across crops/zones.

Outcomes	Crop (zone)	Obs.	ATT	Change (%)
Ferti tot (log form)	Groundnut (GB)	640	0.593*** (0.040)	49.7 %
	Rice (SRV)	343	0.686*** (0.044)	16 %
Ferti com (log form)	Groundnut (GB)	640	-0.044 (0.036)	n.s
	Rice (SRV)	343	−2.967*** (0.061)	−67.5 %
Gross_margin (log form)	Groundnut (GB)	640	0.415*** (0.024)	8.7 %
	Rice (SRV)	343	0.823*** (0.039)	16.5 %
Yield (kg.ha^{-1} in log form)	Groundnut (GB)	640	0.729*** (0.02)	12.7 %
	Rice (SRV)	343	0.408*** (0.026)	5.2 %

Notes: * p<0.1, ** p<0.05, *** p<0.01 (two-sample t-tests with unequal variances and unpaired sample is applied to test for significance). GB = groundnut basin / SRV = Senegal river basin; n.s: not significant.

4.3. Heterogeneous relationships across crops and agroecological zones

To better understand the role of access to subsidized fertilizer on households, we estimate the associations with the four outcome variables by agroecological zone and by main crop. We ran the same specifications as above for groundnut in the GB, and for irrigated rice in the SRV, separately. As mentioned earlier, given the difference between the two zones in the development of private input distribution systems and crop-specific response to fertilizer, we expect different associations.[11] By focusing on crop specific data, we can also add crop yields as an additional outcome variable. However, given that the information on the application of manure is not recorded at crop level, for this analysis we exclude manure application from the outcome variables of interest. Results presented in Table 6 show that access to subsidized fertilizer in the GB is associated with an increase in total use of nitrogen of 50 % without affecting the use of commercial fertilizer and leads to a smaller, but still statistically significant, increase in gross margins (9 %). This increase of the gross margin is driven both by a reduction in nitrogen unit cost and by an increase in yields, the latter estimated at 13 %. In the SRV, access to subsidized fertilizer is associated with a much more modest increase of fertilizer use (16 %), as crowding out of commercial fertilizer is much higher in this area. In this zone access to subsidized fertilizer reduces the use of commercial nitrogen by 67 %. Consequently and unsurprisingly, the association of the program with rice yield is quite limited (5 % increase). Yet, participation in the program is associated with an increase in gross margins of 16 %, mainly due to reduced input costs (in our dataset, fertilizer purchase is approximately 75 % of total production cost). An important finding from this heterogeneity analysis relates to the association between FSP and commercial fertilizer. While the aggregated crowding out effect was low (-18 %), we see that this is driven by a bi-modal behaviour across AEZ. No crowding-out is found in the GB but there is large crowding-out in the SRV (-67 %). Therefore, while effective for areas where commercial fertilizer access is limited, the strong negative association between the FSP and commercial fertilizer suggests limited additionality of the FSP in areas where commercial fertilizer availability is widespread.

The diverging results between the two zones further stress the fact

[11] From our sample, in the GB the average use of nitrogen from commercial fertilizer is 5 kg/ha while in the SRV the average use is 61 kg/ha.

that the effectiveness of the FSP hinges on the characteristics of the region of implementation. Evidence of such heterogeneity has been reported for many east African countries including Zambia (Xu et al., 2009; Jayne et al., 2013; Mason and Jayne, 2013), Kenya and Malawi (Jayne et al., 2013). In all the studied FSPs these authors find differences in program performance depending on the stage of development of the commercial fertilizer sector. The more developed the commercial fertilizer sector, the lower the additionality of the FSP due to increased crowding-out effects. Our study expands such evidence to FSPs implemented in West Africa.

Focusing on crop yields, the positive association with benefitting from the FSP in the GB is larger than in the SRV and can be partially explained by the absence of crowding-out. The larger share of fertilizer of total costs may explain the stronger association between the FSP and the gross margin observed in the SRV.

4.4. Is the FSP cost-effective?

While a full-fledged cost-benefit analysis of the FSP is beyond the scope of this paper, we attempt to provide a partial analysis of the return on investment for this program. To do so we derived a stylized and partial benefit-to-cost ratio. We define benefits as the difference in gross margin between FSP recipient and non-recipient households. Subsidy costs are calculated as the difference between the market and the subsidized price of fertilizer multiplied by the total amount distributed to, or used by, households. At the sample level, the additional gross income amounts to 10.8 million FCFA while subsidy costs stand at 6.2 million FCFA. The cost falls to 5.1 million FCFA as we focus on fertilizer used rather than on fertilizer distributed. This translates into a return-on-investment ratio of 1.7 or 2.1. As mentioned, these values cannot be interpreted as comprehensive benefit-to-cost ratios. Such an analysis would require economy-wide second order effects and the large direct administrative costs associated with the FSP's implementation, control, enforcement and procurement[12] to be taken into account. Accounting for the latter may considerably reduce the cost-effectiveness of the FSP, but to an unknown extent. Also, because of the narrow set of costs and benefits captured, these ratios cannot be compared to those reported when evaluating other ISPs which report lower ratios, ranging from 0.55 to 1.1 (Jayne et al., 2013; Mason and Jayne, 2013; Wossen et al., 2017).

5. Conclusions and policy implications

This paper evaluates whether access to the Senegalese FSP is associated with increased input use (fertilizer and manure) and increased gross margin at the household level. We use ESR models based on primary data collected in 2021 from a randomly selected sample of 936 farmers in the two main agricultural zones of the country. ESR models have been used to address the potential selection bias arising from both observed and unobserved factors. To investigate the robustness of our findings, additional ESR models were estimated using alternative instrumental variables (based on the Lewbel method), and matching approaches were also run. Finally, we tested the robustness of our findings by considering access to the FSP at the intensive margin (accounting for the amount of fertilizer received). All these alternative methods provided similar results.

Our results indicate a positive association between access to subsidized fertilizer and total nitrogen use (+39 %), but a negative association with commercial nitrogen use (-18 %).[13] Access to subsidized fertilizer also seems to be negatively associated with the likelihood to use manure by 5 %, and increase the farmers' total gross margin by 11 %. Our results show important discrepancies according to the AEZ studied. In the SRV, where the private input distribution system is active, we observe a strong crowding-out of commercial fertilizer (-67 %) while in the GB no crowding-out is observed. This latter finding is consistent with previous assessments made in East Africa where crowding out is contingent on the initial level of private input distribution. The stronger the initial network of private retailers, the higher the crowding out and the more limited the impact on the total use of fertilizer, which is detrimental to the development of profitable private input distribution systems. However, targeting areas based on the intensity of farmers' fertilizer use and on the activity level of private sector retailers may raise equity and political issues. It would mean that some households living in non-targeted areas would not receive subsidized fertilizer, while they could have made a better use of it than those recipients located in targeted areas that would have otherwise purchased commercial fertilizer. Furthermore, efficient targeting should not only rely on selecting specific areas but should also consider other aspects, such as for instance the level of household wealth which could influence the crowding-out of commercial fertilizer (Xu et al., 2009; Mason et al., 2013). Besides, minimizing crowding-out by selecting areas with fewer private retailers and poorer farmers does not mean that it would necessarily maximize production gains. A weak private sector supply of fertilizer is not necessarily an indicator of market failure but could be an indication of low crop-responses to fertilizer application (Burke et al., 2020). In our sample, more than half of the farmers stated that they would have bought the same amount of fertilizer if available at commercial prices (56 % in the GB and 63 % in the SRV). Those that declared that they would not buy commercial fertilizer mostly argued lack of liquidity (78 % and 53 % in the GB and SRV respectively). Moreover, in SRV, 20 % of the respondents argued that commercial fertilizer prices are too high and cannot be covered by the additional yields obtained, a reason nearly absent in the GB (9 %). These responses suggest that in the GB, at the current level of fertilizer use and fertilizer-crop price ratios, most of the farmers may limit the amount of commercial fertilizer they buy due to liquidity constraints (and unavailability) rather than a lack of fertilizer profitability. On the contrary, in the SRV, given the already high use of fertilizer, the marginal productivity of this input might be low. Additional analysis is needed to confirm this hypothesis.

After more than 15 years of existence, there is an increasing debate among Senegalese agricultural stakeholders regarding the need to revise the FSP and this study can inform its potential re-design. In areas of the country where the private input distribution is well developed and fertilizer use is already high, alternative policy designs should be investigated. These could involve changing the way the FSP is implemented or providing support in other domains. The FSP could use redeemable vouchers (such as in Nigeria with the Growth Enhancement Support Scheme) (Wossen et al., 2017) to foster the further development of the commercial fertilizer market or by improving the crop-response to fertilizer through public investments in research, extension services, or the distribution of complementary inputs, etc. Broader infrastructure development (roads, warehouses) could also be used to reduce farmer's commercial fertilizer costs. In areas where the commercial fertilizer sector is less developed, a step-wise approach could be developed where the original FSP is accompanied by market friendly measures that would enable the development of such a sector before moving towards an approach similar to that of the SRV.

From a methodological perspective, despite having undertaken robustness checks that support the soundness of our results, we reiterate that these should be interpreted as associations as we base our analysis on cross-sectional data. Repeating the data collection process to obtain a panel and employ fixed-effect estimators would provide a more accurate assessment of the Senegal's FSP.

[12] Data on these costs are not available from the MARE.

[13] In this study, we do not consider potential diversion of program fertilizer (which refers to subsidized fertilizer that are diverted from the normal government subsidy program distribution channels and re-sold to farmers at (close to) commercial prices) while it has been shown to diminish the estimated impacts of the program on the total use of fertilizer (Jayne et al., 2013).

CRediT authorship contribution statement

Aymeric Ricome: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jesus Barreiro-Hurle:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Cheickh Sadibou Fall:** Writing – review & editing, Visualization, Project administration, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Verification of instrumental variables

Table A1
Probit models for access to subsidized fertilizers (Recipients) and access to subsidized seeds (SubsSeed) including the instruments used in the ESR modelling as independent variables.

	Recipients	SubsSeed
Age	0.007	0.009**
	(0.108)	(0.069)
Male	0.476*	−0.083
	(0.098)	(0.728)
Literacy	0.079	0.002
	(0.460)	(0.986)
Wolof	0.02	0.281**
	(0.868)	(0.056)
AME	0.022**	0.029**
	(0.045)	(0.014)
Land	0.139*	−0.008
	(0.071)	(0.926)
CowFat	0.081	0.18**
	(0.339)	(0.054)
Credit	−0.022	−0.088
	(0.868)	(0.617)
PO	0.489***	0.33**
	(3.594)	(0.022)
DistRoad	0.041	−0.073
	(0. 386)	(0.137)
DistSuppl	0.063	0.096
	(0. 264)	(0.157)
NumQualPlot	0.118**	0.089
	(0.034)	(0.153)
PolRol	0.272**	
	(0.022)	
ShareVillage	0.457*	
	(0.091)	
Instrument for SubsSeed	−0.169	1.555***
	(0.564)	(0.000)
Intercept	−2.177***	−1.468***
	(0.000)	(0.002)
Observations	983	983
Pseudo R2	0.164	0.161

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. standard errors clustered at village level. p-values in parenthesis. All specifications include district and seasonal dummies.

Table A2
OLS regressions for the four output variables including instruments used in the ESR modelling as independent variables.

	Ferti tot (log form)	Ferti com (log form)	Manure use	Gross margin (log form)
PolRol	0.076	0.075	0.065	0.329
	(0.708)	(0.707)	(0.239)	(0.130)
ShareVillage	0.259	0.26	−0.032	−0.401
	(0.350)	(0.350)	(0.761)	(0.423)
Adjusted R2	0.59	0.57	0.34	0.13
Observations	571	571	571	571

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. standard errors clustered at village level. p-values in parenthesis. All specifications include district and seasonal dummies. Parameters for the control variables are not reported for brevity.

Appendix B. Additional discussion on results of the step 1 of the ESR estimations

Results from the selection equations (step 1 of the ESR estimations) showed in Tables 2 and 3 are very similar for all four outcome variables considered and confirm that the two instruments chosen affect positively the likelihood of receiving subsidized fertilizer. Also, the variable that contains the residuals from the reduced-form model of subsidized seeds is significant, showing the relevance to control for the endogeneity of the access to seed subsidies. Other significant determinants of being recipient of subsidized fertilizer include the cultivated area, the number of AME in the household, being member of a PO, and the number of plots of good quality. The role of land size and AME is consistent with previous studies (Xu et al., 2009; Ricker-Gilbert and Jayne, 2017). Interestingly, being recipient of subsidized seeds is not significant. This may be explained by the fact that subsidized seeds mainly target groundnut while subsidized fertilizer focus on a larger scope of crops.

Appendix C. Robustness checks – Details of the Lewbel method

As a robustness check, we use the method proposed by Lewbel (2012) allowing an identification of instruments using heteroscedasticity. With this method, the identification is achieved by having regressors uncorrelated with the product of heteroskedastic errors. We first predict the residuals θ from the first-stage equation where the endogenous variable (being recipient of subsidized fertilizer) is regressed on the exogenous variables X. then, residuals are multiplied as $(X - \overline{X})\theta$ where $\overline{X}$ is the sample mean of X (Lin et al., 2022). As the method assumes that the residuals are heteroskedastic, we applied a Breusch-Pagan test which shows that the null hypothesis of homoscedasticity is indeed rejected.

Appendix D. Robustness checks - results of the matching methods

Matching methods build counterfactuals from observable variables only and do not rely on instruments. They consist in matching treated individuals (here households that received subsidized fertilizer) with similar non-treated individuals. The similarity between two individuals is either directly calculated from the whole set of observable variables considered for the analysis, or from a propensity score (PS) which represents the conditional probability measure of being treated given the observable variables considered (Caliendo & Kopeinig, 2008). After matching, the average treatment on the treated (ATT) is estimated by computing the average difference of the outcome between the matched treated and non-treated individuals (Rosenbaum and Rubin, 1983). Several matching techniques exist and we first used the propensity score matching where the treated individuals are matched with similar non-treated individuals according to their estimated propensity score (PSM-NNM). The five nearest neighbour non-treated individuals were matched with each treated. We also applied three alternative matching techniques to test for robustness of results with regards to the matching technique used: kernel, radius and weighted nearest neighbour (Caliendo & Kopeinig, 2008). The kernel matching uses a nonparametric technique to operate a weighted average of the outcome (the weights are inversely proportional to the distance between the control and the treated observation). The radius matching specifies a maximum PS distance (caliper) by which matches can be made between treated and non-treated observations. A caliper of 0.01 has been applied. The last matching method used is the nearest neighbour matching but where the similarity between subject is not based on the propensity score but rather on a weighted function of the covariates for each observation (weighted-NNM). This latter technique is applied because if it gives similar results to methods relying on the propensity score, the findings are assumed to be more reliable (Khandker et al., 2009). The covariates used are the same as those used for the endogenous switching regression.

Table D1 shows the results of the matching methods. They confirm the positive (negative) association between access to subsidized fertilizer and the total use of nitrogen (commercial nitrogen). The results on the application of manure and the gross margin differs from the results based on the ESR method. Matching techniques provides the same signs but are not significant (gross margin would be significant at the 15 % level). These differences show the importance to account for the unobserved heterogeneity in the analysis.

Table D1
Estimated associations between access to subsidized fertilizer and the outcome variables using different matching techniques.

	Matching techniques			
	PSM-NNM	Kernel	Radius	Weighted-NNM
Ferti tot (log form)	0.926***	0.848***	0.887***	0.665***
	(0.178)	(0.150)	(0.162)	(0.086)
Ferti com (log form)	−0.715***	−0.892***	−0.853***	−1.013***
	(0.162)	(0.149)	(0.140)	(0.149)
Manure use	−0.002	−0.018	−0.015	0.023
	(0.050)	(0.041)	(0.043)	(0.029)
Gross margin (log form)	0.284	0.201	0.203	0.191
	(0.196)	(0.142)	(0.162)	(0.164)

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Abadie-Imbens standard errors for PSM-NNM and Weighted NNM and bootstrapped standard errors for the kernel and radius matching techniques.

The quality of the matching procedure is assessed through several indicators presented in Table D2 that check if the distribution of the covariates is balanced in the treatment and control groups after matching. The likelihood-ratio tests of the joint significance of all regressors in the PS estimation model (probit model) indicate that the null hypothesis can always be rejected before matching ($p > \chi^2 = 0.00$) but never be rejected after matching ($p > \chi^2 = 1.00$). Associated with a low pseudo-R^2 after matching, it implies that there is no systematic difference in the distribution of the covariates between the treated and control groups after matching and satisfies the balancing property of the sample. The standardized percentage bias (column Meanbias), defined as the mean difference in the treated and non-treated sub-samples for all covariates used for the matching reduces from 8 % before matching to 4.5 % in average after matching, which is also an indicator of good matching.

Table D2
Quality of the matching.

	PSM-NNM			Kernel			Radius		
	Pseudo R2	P > chi2	MeanBias	Pseudo R2	P > chi2	MeanBias	Pseudo R2	P > chi2	MeanBias
Unmatched	0.06	0.00	8	0.06	0.00	8	0.06	0.00	8
Matched	0.01	1.00	5.3	0.01	1.00	3.8	0.01	1.00	4.3

Appendix E. Robustness checks – Estimation results when considering the amount of subsidized fertilizer

The core results presented in the article show the associations between the access to subsidized fertilizer (captured by a binary variable) and several outcomes of interest, using the ESR framework. Here, we present the associations where, instead of using a binary variable representing the access, we focus on the magnitude of the access through the continuous variable amount of subsidized fertilizer used per hectare by the household (*Sub ferti use*). We could also have used the amount of subsidized fertilizer received per hectare (and not the amount actually used) but it would not have accounted for possible resales, once a household receives subsidized fertilizer. This is why we decided to use the variable that is the closest to the actual amount of subsidized fertilizer used[14] (the sample means are 27 kg and 23 kg with the highest value for the amount received). To control for the potential endogeneity of the continuous variable, we followed Ricker-Gilbert et al. (2011), Holden and Lunduka (2012), Jayne et al. (2013), Mason and Jayne (2013), and Sibande et al. (2015) that used the control function (CF) approach.[15] As in the case of the ESR method, it requires an identification strategy based on an instrument. We used the instrument capturing whether a member of the household holds a political role at the district level or below or is a member of the local committee.[16] In a 1st-stage, we estimate a reduced form Tobit model of the continuous endogenous variable on the exogeneous covariates plus the instrument. In a 2nd-stage, the residuals from the reduced form equation plus the exogeneous covariates are included to assess the influence of the amount of subsidized fertilizer on the outcome variable. Functional forms used in the 2nd-stage differ according to the nature of the outcome variables. A Probit model is used for the binary outcome manure use, a linear regression is used for the continuous outcome gross margin, and corner solution (Tobit) models are used for the total amount of nitrogen used and total amount of commercial nitrogen used (about 20 % of the sample do not use any fertilizer which motivate the use of a corner solution model rather than a linear model).

Table E1 displays the results of the two stages although we will only discuss the 2nd stage. Results show that a 1 % increase in the use of subsidized nitrogen is associated with a 0.37 % increase in total nitrogen use, a reduction by −0.95 % of commercial nitrogen use, and a 0.11 % increase in gross margin. Yet, the estimated association with manure use is insignificant. Except for the use of manure where we found a negative association under the ESR framework, the signs and significance of the parameters are consistent with those displayed in the core of the article.

Table E2 shows the results at the disaggregated level, by agroecological zone and main crop. The signs found are the same as those displayed in the core of the text under the ESR framework with a very few discrepancies in terms of statistical significance. We observe a positive association between the intervention and the total use of nitrogen, but this association is only significant in the GB. The non-significant association in the SRV could be explained by the large crowding-out effect observed in the SRV while this association is insignificant in the GB (just as under the ESR framework). The association between the amount of subsidized fertilizer and the gross margin is positive, significant, and in the magnitude in both zones, showing about a 0.15 % increase of gross margins. Eventually, the impact on yield is positive and significant in both zones. Like under the ESR framework, the association is larger in the GB.

Table E3 compares qualitatively the regression results obtained with the ESR approach using a binary endogenous variable (*D* in the text) and the CF approach using the continuous endogenous variable *Sub ferti use*. There are no contradictory results. At the disaggregated level, the results are very much the same. At the aggregated level, the main difference is on the association between subsidized fertilizer and manure use (negative in the ESR framework and positive but non-significant with the CF approach).

Table E1
Regression results for the outcome variables using a control function approach.

	1st-stage	2nd-stage			
	Log(Sub ferti use)	Log(Ferti tot)	Log(Ferti com)	Manure use	Log(Gross margin)
Log(Sub ferti use)		0.378**(0.047)	−0.953***(0.000)	0.120(0.557)	0.112*(0.089)
Residual from reduced form equation		−0.074(0.694)	0.300(0.266)	−0.116(0.572)	−0.069(0.275)
PolRol (instrument)	0.547**(0.019)				
Age	0.015*(0.081)	−0.010**(0.045)	−0.011(0.120)	0.006(0.285)	0.002(0.176)
Male	0.914(0.236)	0.122(0.720)	0.653(0.154)	0.102(0.763)	−0.015(0.880)
Literacy	0.212(0.365)	0.150(0.215)	0.081(0.639)	0.054(0.650)	−0.021(0.567)
Wolof	−0.019(0.949)	0.229(0.130)	0.214(0.323)	0.268(0.185)	−0.012(0.786)
AME	0.047*(0.062)	0.035**(0.014)	0.056***(0.002)	0.022(0.377)	0.001(0.839)
Land	−0.018(0.921)	−0.284***(0.008)	−0.140(0.379)	0.109(0.314)	−0.012(0.758)
CowFat	0.421**(0.026)	−0.007(0.931)	0.035(0.795)	0.154(0.186)	−0.012(0.735)
Credit	−0.109(0.703)	0.078(0.604)	0.032(0.900)	−0.059(0.766)	0.065(0.285)
PO	1.229***(0.002)	−0.115(0.632)	0.380(0.304)	−0.408(0.152)	−0.133(0.136)
DistRoad	0.032(0.797)	−0.083(0.183)	−0.099(0.267)	0.034(0.671)	0.008(0.686)
DistSuppl	0.182(0.201)	−0.034(0.656)	−0.038(0.706)	−0.028(0.766)	−0.003(0.914)
NumQualPlot	0.198(0.112)	0.172**(0.017)	0.338***(0.001)	−0.025(0.756)	0.068***(0.001)

(*continued on next page*)

[14] Yet, we run regressions using the amount of subsidized fertilizer received and did not find any qualitative changes. As expected, the estimates are weaker but have the same sign.
[15] Yet, we use cross-sectional data while the mentioned studies used panel data allowing to better control for time-invariant unobserved heterogeneity.
[16] We did not use the second instrument as it is not enough associated with the intensity of access to subsidy (p-value = 0.115).

Table E1 (*continued*)

	1st-stage	2nd-stage			
	Log(Sub ferti use)	Log(Ferti tot)	Log(Ferti com)	Manure use	Log(Gross margin)
SubsSeed	−0.579(0.660)	0.029(0.948)	1.181*(0.075)	−0.143(0.758)	−0.145(0.316)
Instrument for SubsSeed	1.686**(0.021)				
Intercept	−0.682(0.589)	3.214***(0.000)	3.501***(0.000)	−2.266***(0.002)	5.972***(0.000)
Observations	983	983	983	983	983
Pseudo R2	0.16	0.23	0.15	0.32	0.23

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. standard errors clustered at village level. Bootstrapped standard errors in the 2nd-stage models (column 3 to 6) with 400 repetitions to account for 1-stage estimation. p-values in parenthesis. All specifications include district and seasonal dummies.

Table E2
Regression results across crops/zones for the outcome variables using a control function approach.

	Log(Ferti tot)		Log(Ferti com)		Log(Gross margin)		Log(Yield)	
	Groundnut (GB)	Rice (SRV)	Groundnut (GB)	Rice (SRV)	Groundnut (GB)	Rice (SRV)	Groundnut (GB)	Rice (SRV)
Log(Sub ferti use)	0.640*** (0.007)	0.073 (0.410)	−0.035(0.922)	−0.800*** (0.000)	0.160*(0.091)	0.136** (0.024)	0.202**(0.033)	0.117** (0.027)
Residual (reduced form equation)	0.237(0.259)	0.042 (0.681)	0.218(0.498)	−0.168(0.513)	−0.156(0.103)	−0.086 (0.181)	−0.199** (0.042)	−0.072 (0.169)

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. standard errors clustered at village level. Bootstrapped standard errors with 400 repetitions to account for 1-stage estimation. p-values in parenthesis. All specifications include district dummies. SRV zone include a seasonal dummy.

Table E3
Comparison of the regression results between the Endogenous Switching Regression (ESR) and Control Function (CF) frameworks both for the pooled and crop/zone specific samples.

	Aggregate level		Groundnut Basin		Senegal River Valley	
	ESR	CF	ESR	CF	ESR	CF
Log(Ferti tot)	Pos	Pos	Pos	Pos	Pos	NS
Log(Ferti com)	Neg	Neg	NS	NS	Neg	Neg
Log(Gross margin)	Pos	Pos	Pos	Pos	Pos	Pos
Manure use	Neg	NS[1]				
Log(Yield)			Pos	Pos	Pos	Pos

[1] NS: non-significant.

References

Baird, S., McIntosh, C., Özler, B., 2011. Cash or condition? Evidence from a cash transfer experiment. Q. J. Econ. 126 (4), 1709–1753.

Bardhan, P., Mookherjee, D., 2005. Decentralizing antipoverty program delivery in developing countries. J. Public Econ. 89 (4), 675–704.

Burke, W.J., Snapp, S.S., Jayne, T.S., 2020. An in-depth examination of maize yield response to fertilizer in Central Malawi reveals low profits and too many weeds. Agric. Econ. 51 (6), 923–940.

Caliendo, M., Kopeinig, S., 2009. Some practical guidance for the implementation of propensity score matching. J. Econ. Surv. 22 (1), 31–72.

Chibwana, C., Fisher, M., Jumbe, C., Masters, W.A., Shively, G., 2014. Measuring the impacts of Malawi's farm input subsidy program. Afr. J. Agricult. Resour. Econ. 9 (2), 132–147.

Clougherty, J.A., Duso, T., Muck, J., 2016. Correcting for self-selection based endogeneity in management research: review, recommendations and simulations. Organ. Res. Methods 19 (2), 286–347.

Di Falco, S., Veronesi, M., Yesuf, M., 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. Am. J. Agric. Econ. 93 (3), 829–846.

Druilhe, Z., Barreiro-Hurlé, J., 2012. Fertilizer subsidies in sub-Saharan Africa. (2521-1838). Rome, Italy: Food and Agriculture Organization.

Falconnier, G.N., Cardinael, R., Corbeels, M., Baudron, F., Chivenge, P., Couëdel, A., Giller, K.E., 2023. The input reduction principle of agroecology is wrong when it comes to mineral fertilizer use in sub-Saharan Africa. Outlook on Agriculture 52 (3), 311–326. https://doi.org/10.1177/00307270231199795.

FAO, 2022. FAOSTAT 2022.

Holden, S., Lunduka, R., 2012. Do fertilizer subsidies crowd out organic manures? The Case of Malawi. Agric. Econ. 43 (3), 303–314.

Holden, S. T. (2019). Economics of Farm Input Subsidies in Africa. *Annual Review of Resource Economics*, *11*(1), 501-522. https://doi.org/10.1146/annurev-resource-100518-094002.

IPAR (2015). Subventions des intrants agricoles au Sénégal: Controverses et réalités.

Jayne, T.S., Mason, N.M., Burke, W.J., Ariga, J., 2018. Taking stock of Africa's second-generation agricultural input subsidy programs. Food Pol. 75, 1–14.

Jayne, T., Rashid, S., 2013. Input subsidy programs in sub-Saharan Africa. Agric. Econ. 44 (6), 545–734.

Jayne, T., Mather, D., Mason, N., Ricker-Gilbert, J., 2013. How do fertilizer subsidy programs affect total fertilizer use in sub-Saharan Africa? Crowding out, diversion, and benefit/cost assessments. Agric. Econ. 44 (6), 687–703.

Kelly, V. A., Crawford, E. W., & Ricker-Gilbert, J., 2011. The New Generation of African Fertilizer Subsidies: Panacea or Pandora's Box? (Policy Synthesis for cooperating USAID offices and country missions number 87 , May, USAID and MSU, Issue.

Khandker, S.R., Koolwal, G.B., Samad, H.A., 2009. Handbook on impact evaluation: quantitative methods and practices. World Bank publications.

Lewbel, A., 2012. Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. J. Bus. Econ. Stat. 30 (1), 67–80.

Lin, B., Wang, X., Jin, S., Yang, W., Li, H., 2022. Impacts of cooperative membership on rice productivity: evidence from China. World Dev. 150, 105669.

Liverpool-Tasie, L.S.O., 2014. Fertilizer subsidies and private market participation: the case of Kano state, Nigeria. Agricult. Econ. 45 (6), 663–678.

Liverpool-Tasie, L.S.O., Takeshima, H., 2013. Input promotion within a complex subsector: fertilizer in Nigeria. Agric. Econ. 44 (6), 581–594.

Lokshin, M., Sajaia, Z., 2004. Maximum likelihood estimation of endogenous switching regression models. Stata J. 4 (3), 282–289.

Mason, N.M., Tembo, S.T., 2015. Do input subsidy programs raise incomes and reduce poverty among smallholder farm households? Evidence from Zambia.

Mason, N.M., Jayne, T.S., 2013. Fertiliser subsidies and smallholder commercial fertiliser purchases: crowding out, leakage and policy implications for Zambia. J. Agric. Econ. 64 (3), 558–582.

Mason, N.M., Jayne, T., Mofya-Mukuka, R., 2013. Zambia's input subsidy programs. Agric. Econ. 44 (6), 613–628.

Mason, N.M., Wineman, A., Kirimi, L., Mather, D., 2017. The effects of Kenya's 'Smarter'Input subsidy programme on smallholder behaviour and incomes: do different quasi-experimental approaches lead to the same conclusions? J. Agric. Econ. 68 (1), 45–69.

Mather, D.L., Jayne, T.S., 2018. Fertilizer subsidies and the role of targeting in crowding out: evidence from Kenya. Food Security 10, 397–417.

Ministère de l'Agriculture et de l'Equipement Rural. (2014). *Programme d'Accélération de la Cadence de l'Agriculture Sénégalaise (PRACAS) - Volet agricole du Plan Sénégal Emergent*.

Morris, M.L., Kelly, V.A., Kopicky, R.J., Byerlee, D., 2007. Fertilizer use in African agriculture: Lessons learned and good practice guidelines. World Bank Publications.

Pan, L., Christiaensen, L., 2012. Who is vouching for the input voucher? decentralized targeting and elite capture in Tanzania. World Dev. 40 (8), 1619–1633.

Ricker-Gilbert, J., Jayne, T.S., 2012. Do fertilizer subsidies boost staple crop production and reduce poverty across the distribution of smallholders in Africa? Quantile Regression Results from Malawi International Association of Agricultural Economists Triennial Conference - 18-24 August, Foz do Iguaçu, Brazil.

Ricker-Gilbert, J., Jayne, T.S., Chirwa, E., 2011. Subsidies and crowding out: a double-hurdle model of fertilizer demand in Malawi. Am. J. Agric. Econ. 93 (1), 26–42. https://doi.org/10.1093/ajae/aaq122.

Ricker-Gilbert, J., Jayne, T.S., 2017. Estimating the enduring effects of fertiliser subsidies on commercial fertiliser demand and maize production: panel data evidence from Malawi. J. Agric. Econ. 68 (1), 70–97.

Rosenbaum, P.R., Rubin, D.B., 1983. The central role of the propensity score in observational studies for causal effects. Biometrika 70 (1), 41–55.

Sall, M., 2015. Les exploitations agricoles familiales face aux risques agricoles et climatiques: stratégies développées et assurances agricoles Université de Toulouse]. Toulouse, France.

Seck, A., 2017. Fertiliser subsidy and agricultural productivity in Senegal. World Econ. 40 (9), 1989–2006. https://doi.org/10.1111/twec.12487.

Sibande, L., Bailey, A., Davidova, S., 2015. The impact of farm input subsidies on household welfare in Malawi. 2015 Conference of the International Association of Agricultural Economists, August 9-14, 2015, Milan, Italy.

Takeshima, H., Nkonya, E., 2014. Government fertilizer subsidy and commercial sector fertilizer demand: evidence from the Federal Market Stabilization Program (FMSP) in Nigeria. Food Pol. 47, 1–12.

Van Dijk, M., Morley, T., Jongeneel, R., van Ittersum, M., Reidsma, P., Ruben, R., 2017. Disentangling agronomic and economic yield gaps: an integrated framework and application. Agr. Syst. 154, 90–99.

Wooldridge, J.M., 2015. Control function methods in applied econometrics. J. Hum. Resour. 50 (2), 420–445.

Wossen, T., Abdoulaye, T., Alene, A., Feleke, S., Ricker-Gilbert, J., Manyong, V., Awotide, B.A., 2017. Productivity and welfare effects of Nigeria's e-voucher-based input subsidy program. World Dev. 97, 251–265.

Xu, Z., Burke, W.J., Jayne, T.S., Govereh, J., 2009. Do input subsidy programs "crowd in" or "crowd out" commercial market development? Modeling fertilizer demand in a two-channel marketing system. Agric. Econ. 40 (1), 79–94.