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EFFECTS OF FERTILIZER SUBSIDIES ON WOMENS DIET: QUALITY BY FOOD SUPPLY SOURCE IN MALI

By

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Abstract

The Malian Government has introduced the Fertilizer Subsidy Program as a policy strategy to increase agricultural productivity and food production with the aim of improving the food security and well-being of smallholder farm households. However, there is a lack of reliable evidence regarding the effects of the subsidy program. We tested the effects of fertilizer subsidies on diet quality of women of reproductive age by applying propensity score matching methods to farm household survey data collected in 2018. We found that subsidized fertilizer has a positive effect on overall women's dietary diversity in the Niger Delta but is negatively associated with the overall dietary diversity in the Koutiala Plateau. One of the innovations of this study is that the dietary diversity score is broken down according to food supply sources. Analysis by component allows a thorough understanding of the channel through which the subsidized fertilizer program affects women's nutrition outcomes. A close look at the different components of women's dietary diversity reveals no effects on dietary diversity from the consumption of own production in either of the two zones. Analysis showed a negative impact of subsidized fertilizer on dietary diversity sourced from gift food in Niger Delta. Finally, we found that the effect of subsidized fertilizer on the dietary diversity sourced from purchased food was strong and positive in the Niger Delta, but negative in the Koutiala Plateau. The negative results for the Koutiala Plateau are not entirely surprising given the history of the "Sikasso Paradox." Decomposing diet diversity by food source suggests that income is the main pathway linking subsidized fertilizers program to women's nutrition outcomes.

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Introduction

Mali is a low-income country with a population of 19 million people, the majority of whom live in rural areas. Mali is also a food deficiency country according to the Food and Agriculture Organization of the United Nations (FAO 2015). Around 40% of Mali's population live in food insecurity. The 2018 World Food Program food security analysis in Mali indicates that slightly more than twenty-five percent of households suffer from moderate to severe food insecurity with an acute malnutrition rate of nearly eleven percent. Inadequate intake and micronutrient deficiencies are commonplace in Mali. For example, a study conducted among a population aged between 15 and 49 years in the Kayes region by Torheim et al. in 2004 showed that the calcium intake of 80% of respondents was lower than the recommended daily intake, 70 % of respondents for vitamin A and 49% of respondents for iron. The 2018 World Food Programme (WFP) food security analysis estimated that vitamin and mineral deficiencies affect 81.7 percent of children under five, and iron deficiency affects 51.4 percent of women of reproductive age.

Inadequate dietary intake is the most important cause of malnutrition in low-income countries, such as sub-Saharan African countries where diets are poorly diversified and staple-based. In addition, inadequate intake and the risk of micronutrient deficiency are strongly and positively correlated with low dietary diversity, mainly based on staple foods (Arimond et al., 2010). Mali is one of the countries most affected by malnutrition and food insecurity with 25.6% of households suffering from moderate to severe food insecurity and an acute malnutrition rate of 10.7% (WFP 2018). Women of reproductive age are potentially at high risk of micronutrient deficiencies such as vitamin A deficiency, iron deficiency anemia due to their high nutritional requirements during pregnancy and breastfeeding (WHO FAO, 2004).

The challenge of malnutrition with its potential impacts on health and well-being, in recent years, has focused global attention on the issue of food security and nutrition and highlighted the role of agriculture in reducing hunger and malnutrition. A potential pathway to reducing hunger and malnutrition consists of improving the nutrition sensitivity of agricultural investments (Fan and Pandya Lorch, 2012).

The fertilizer subsidy is a policy strategy to increase access to and use of fertilizers. It has been reintroduced in many African countries, including Mali, as a key strategy for improving food production and food security in the aftermath of the food and financial crises of the 2000s. The Malian new subsidy program started in its initial phase with rice as the target cereal crop. Today, in addition to the main cereal crops, including rice, maize, sorghum, and millet, it covers cowpea and cotton.

Despite the widespread use of fertilizer subsidies as a key agricultural policy to reduce food insecurity in sub-Saharan African countries, little is known about their actual effects on nutritional outcomes. The role of agricultural input subsidies in terms of productivity, food security, and nutrition is still unclear. The lack of evidence, due to the scarcity of impact evaluation studies of agricultural input subsidies on food security and nutrition, aggravates the status quo. The few studies on nutritional outcomes related to the agricultural input subsidy have often focused on the consumption of the target staple, measured in terms of calorie intake. Broader consideration of the impacts on nutrition and dietary diversity is important, given the impact of food quality on human health and welfare (Walls et al. 2018). Much of the existing literature on fertilizer subsidies has focused on program efficiency, crop productivity, and intensity of fertilizer use. In the context of the Malian program, few empirical studies examined the impacts of fertilizer subsidies. From a policy perspective, understanding the impact of fertilizer subsidies on food production and its link with nutrition would be of great worth to Malian policy makers and their partners for improving the nutrition sensitivity of agricultural investments.

Hence, in this paper, we attempt to assess the effects of these fertilizer subsidies on the nutritional outcomes of farm households using a dataset collected in two agro-ecological zones in Mali, the Niger Delta and the Koutiala Plateau. The purpose of the study is to provide a rigorous measure of the impact of fertilizer subsidies on women's diets quality. More specifically, we evaluate the effects on dietary diversity score and food accessibility measured as consumption of purchased and gift food.

The paper first provides a review of the literature on the major pathways linking agriculture to nutrition and the conceptual framework. The next section presents the method employed, including data description, econometrics approach, and sensitivity analysis. The results section consists of data analysis through descriptive statistics of key outcome variables, including measures of quality of women's diets followed by econometric results of average treatment effects of subsidized fertilizers on women's diets quality. Finally, the paper discusses the main results and draws conclusions.

Linking agriculture to nutrition

Various papers on the interactions between farm input policies and nutritional outcomes have identified several pathways through which agricultural interventions may affect the nutritional outcomes (Harris and Herforth 2013; World Bank 2007). In essence, agricultural interventions can affect the nutrition outcomes of farm households through four main pathways. In fact, such pathways work through synergistic interactions and interact with a number of contextual factors, which may include other interventions. Therefore, it is useful to recognize the different pathways through which agricultural interventions can affect nutrition outcomes in relation to contextual factors for effective program impacts assessment. There is no universal pathway through which agricultural interventions can affect nutrition outcomes. Depending on the context and the nature of policy intervention, a combination of these linkages is often useful for impact analysis. Below, we highlight the main pathways through which agriculture can affect nutrition outcomes, namely production for own consumption, income pathways, market prices channel, and women's empowerment pathways.

Production for own consumption is the primary direct pathway through which agriculture interventions affect nutrition outcomes. A policy such as fertilizer subsidies may increase staple food production, thereby improving food availability and increased energy intake. It can also encourage diversity of food production, including vegetables, fruits, and animal source foods through improved productivity. In this case, it directly affects smallholder nutrition and diet quality (World Bank. 2007). This is especially true in low-income countries where most of smallholder households consume a substantial part of their own production (World Bank. 2007). A case study examined dietary diversity in relation to crop diversity among 169 households in Kiambu, Kenya, and 207 households in Arusha, Tanzania (Herforth, 2010). Using mixed models with cross-sectional household data, the study demonstrated that crop diversity positively affects household dietary diversity. Furthermore, the study showed that crop diversity was positively associated with child dietary diversity in Arusha, Tanzania. Similarly, using multiple regression analyses and national representative farm household survey data from Malawi, Jones et al., 2014 showed that the diversity of agricultural production has a positive impact on the dietary diversity of farm households. Other studies demonstrate the link between agriculture and households' diets quality. For example, enhancing homestead production has improved household micronutrient intake in Cambodia (Olney et al., 2009). One of the most recent systematic reviews of agricultural inputs and nutrition in South Asia by Shankar et al. (2019) has shown that raising land productivity through policies promoting the use of irrigation, fertilizer and improved seed varieties has positive impacts on nutrition outcomes of farm households.

Another potential pathway is by increasing the income of farm households through related activities and the sale of surplus crops. Fertilizer subsidies can generate higher revenues through market participation and improve the diversity of diets accordingly (World Bank. 2007). As production increases, economic activities are created at different levels of the chain, from harvesting, transportation, and distribution. These chains generate employment and income opportunities for households. Although increasing agricultural production is positively associated with dietary diversity in some cases, market-based production appears to be more effective in improving nutrition outcomes (Sibhatu et al., 2015). Ricker-Gilbert (2014) estimated the effects of the Malawi Fertilizer Subsidy Program on wages and employment. The results of his estimates indicate a decrease in supply and a slight increase in the labor demand of the beneficiaries as well as a slight increase in agricultural wage rates. The author also found that the subsidy program has a positive impact on household income. Examining the share of households' own production in their diets and the seasonal sensitivity of this share among smallholder farmers in rural areas in Ethiopia, Sibhatu and Qaim (2017) found that markets play a vital role in diet quality. Their estimates show that 80% of dietary diversity comes from purchased foods regardless of the season and household type, suggesting the importance of income as a key mediator linking agriculture to nutrition.

A number of indirect links between agriculture and nutrition have been discussed in the literature through theoretical and conceptual frameworks, which show the pathways in which agriculture may affecting food and diet quality. These pathways include food prices as an important link between agriculture and nutrition outcomes. In examining the relationship between agriculture and nutrition, Johnson-Welch et al. (2005) proposed a framework in light of food price trajectories, which shows the role of smallholder farmers as food suppliers in developing countries. The basic idea of the framework suggests that the promotion of smallholder agricultural production will lead to more food products entering the market, leading to lower food prices. This is especially true for poor people who spend a large part of their income on food expenses. Lowering the prices of food items is the third pathway through which agriculture may affect household dietary quality and nutrition. By increasing food availability, agriculture can contribute with other policy measures to reducing food prices in the market, enabling greater access to food and micronutrients. By lowering commodity prices, subsidies help to increase the purchasing power of large numbers of small farmers, which should lead to increased demand for non-staples food and off-farm goods and services, boosting local labor demand and wages and improve people's nutrition (Chirwa and Dorward, 2013).

The empowerment of women is the fourth channel identified by previous research. The empowerment of women in agriculture has positive effects on dietary quality for both children and adults in the household. More interesting, the effects of women's empowerment on dietary diversity and dietary intakes of adults are becoming increasingly significant (Sraboni and Quisumbing, 2018). A paper by Ruel and al. (2013), suggests that women's participation in agriculture improves their empowerment, thereby affecting their control over household assets, their decision-making power regarding household resource allocation, and their social status in the community, which ultimately leads to improved nutritional outcomes. Another paper by Jones et al. (2012) shows that changes in household income can affect women's workload, nutrition, and the time they allocate to childcare, which, in turn, can affect children's nutrition through child-care practices. An impact assessment in Nepal by Malapit et al. (2013) indicates that improving the decision-making power of women in production significantly improves the nutritional status of mothers and children.

It should be noted that not all research has resulted in a positive relationship between agriculture and nutrition, and some research has found a little or adverse linkage between nutritional outcomes and agriculture (Headey, Chiu and Kadiyala, 2011). Masset et al. (2012), Ruel and Alderman, 2013). Headey, Chiu, and Kadiyala (2011) in India examined the link between agricultural growth and nutrition during the period 1992-2005. They found that despite the positive correlation in some states between agriculture and nutrition, overall nutritional improvements could not be explained by agricultural growth. Masset et al. (2012) reviewed 23 studies from developing countries and found positive effects on agricultural production, unclear effects on overall dietary intake, and little evidence of improved nutritional outcomes for children under five years old. However, the authors argue that the poor approaches of many studies limit the conclusiveness of these findings. Although Ruel and Alderman (2013) emphasize the importance of promoting agricultural production, keeping prices low and increasing incomes, they recognize the weak evidence supporting the link between nutritional outcomes and agricultural programs. They attribute this weakness to the quality of the evaluations. Some authors have noted the perverse effects of women's empowerment in agriculture. The workload is associated with low birth weight and size in children born to mothers engaged in agricultural work during pregnancy (Herforth 2012).

The main pathway from fertilizer subsidy to nutrition is probably its effects on productivity and income. The promotion of fertilizer to increase productivity and income is the direct pathway between fertilizer subsidies and nutrition. Changes in farm assets and fertilizer use can also affect the quality of women's diets, with implications for child nutrition through women's empowerment. As noted by Ruel et al. (2013), the links between changes in agricultural productivity and nutritional outcomes are often influenced by women's decision-making power within the household. A study by Snapp and Fisher in Malawi (2014) shows that fertilizer subsidies have a positive effect on the household dietary quality through two main channels, crop diversification associated with input subsidies, and income from the commercialization of maize. Unlike Snapp and Fisher, Gine et al. (2015) in Tanzania did not detect the effects of fertilizer subsidy on household nutritional outcomes. The authors explain this failure to detect the effects of subsidies in this case by the short term of the assessment. A study conducted in Ghana by Wiredu et al. (2015) revealed a positive impact of fertilizer subsidies on food security. In addition, the authors found that, combined with other factors such as nutritional education, adequate crop mix farming, and income-generating activities, fertilizer subsidies can improve and ensure food stability.

This paper addresses several gaps in the understanding of this topic by testing the effects of fertilizer subsidies on the household women's diet quality through production and income pathways. Most of the studies that examined the impacts of agricultural interventions on nutritional outcomes, focused on the effects on anthropometric indicators, dietary diversity scores, and nutrient and calories intake. Nevertheless, the sources of food consumed by the household can be very useful indicators for analyzing the situation of vulnerability to food insecurity. For example, a household can meet their food needs, but if the food consumed by this household comes mainly from gifts, then that household is vulnerable to food insecurity. To our knowledge, very little or no empirical research has explored the relationship between input subsidies and food sources. We attempt to reduce this gap by measuring, in addition to the dietary diversity score, access to food in terms of purchased and gift foods relative to own production. We believe that this approach is an original one that will provide a more in-depth insight into food security issues and its link to agriculture in the context of Mali.

Conceptual framework

We hypothesize that the main linkages between fertilizer subsidy and diet quality are described in Figure 1 (a more detailed exposition is found in Assima 2019). Based on Figure 1, a fertilizer subsidy may directly increase access to and fertilizer use. This may lead to increasing agricultural productivity and food production. If the increased production or productivity is oriented toward staple food crops, it may lead to greater availability of food for the household and household, meaning that it may improve energy intake but not diet diversity, production for own consumption do not improve diet quality. In contrast, fertilizer subsidies may provide incentives to farmers to produce a diversity of food crops, including vegetables, fruits, and livestock that household can consume. In this case, production for own consumption plays an important role between agriculture and diet quality. Increasing agricultural productivity and food production may lead to increased income through sales of a surplus of production or agricultural related activities. Increasing income would lead to raising expenditures on highly nutritious foods, thereby improving household diet quality.

Method

Data

In 2008/09, Mali initiated a fertilizer subsidy program with the Rice Initiative. The subsidy now covers cotton, maize, wheat, millet, and sorghum. All Malian producers are eligible for the subsidy program provided that they cultivate at least one of the target crops and have the means to afford the unsubsidized part (70-80%). In 2018, a team of researchers from the Institute d'Economie Rurale and Michigan State University conducted a farm household survey to assess the impacts of the fertilizer subsidy program. We use data from this survey.

The sample was drawn from a baseline census of households in 120 villages located in two agro-ecological zones: i) Koutiala Plateau mainly based on cotton, maize, and sorghum production system; and ii) Niger Delta mostly oriented toward irrigated rice production system (Figure 2). Twenty farm families were randomly selected for interview in each sampled village. The total sample included 2400 households. The data were weighted by the inverse of the probability of selection to ensure the statistical representativeness of the sample. Village level surveys were also undertaken in all the communities. Data details are provided in Haggblade et al. (2019).

The household surveys included demographic characteristics, household and farm assets, economic activities, farming, and non-farming income. In addition, the survey questionnaires covered several other modules including a section on dietary diversity, a section on the use of fertilizer (subsidized or not subsidized), and a section on production as well as plots size measurement with GPS. All women of reproductive age in each household responded to the questionnaire on dietary diversity, constituting a total sample of 5,930 women. The team used a multi-visit survey to collect data in four field visits using computer-assisted personal interview (CAPI) methods. The survey questionnaires were programed on tablets using CSPro software. Data were converted into STATA format for cleaning and analysis. Visits took place from September 2017 through August 2018.

Outcome variables of interest

The outcome of interest in this study is the Women's Dietary Diversity Score (WDDS). The WDDS assesses the variety of foods consumed by women within households. The WDDS allows us to focus on the individual level of access to food, especially women, whose nutrient needs are greater, and whose role in the preparation of meals and feeding children is crucial, indicating that their nutritional status is important for the well-being of the whole household. WDDS is a quantitative variable that counts the number of food groups out of a total of nine that each woman of reproductive age reported consuming in the last seven days prior to the survey (Martin-Prével et al. 2015). Food items consumed over the seven day recall period are grouped into the following nine food groups: 1) starchy staples; 2) dark green leafy vegetables; 3) other vitamin A-rich fruits and vegetables; 4) meat, poultry, and fish; 5) other fruits and vegetables; 6) dairy; 7) eggs; 8) organ and 9) pulses, nuts and seeds.

Using the source of each food, we calculated the WDDS for each source, namely *ownWDDS* for own production, *purchaseWDDS* for purchases and *giftWDDS* for gifts or food aid. This decomposition of *WDDS* by food source enable us not only to assess the pathway through which fertilizer subsidies affect the quality of women's diets but also to assess the impact of fertilizer subsidies on the vulnerability of households to food insecurity. It also provides insight into food access as measured by purchased food relative to the consumption of food gifts. Given that the statistical unit in this study is household, we have transformed the original dietary diversity scores of women at the individual level into household levels by computing the average across women's scores within each household.

Independent variables

There is no rule in the selection of independent variables to include in propensity score matching. However, we can find some recommendations in the literature. The recommendations suggest that the variables that simultaneously influence the treatment and the outcome variable should be included in the model in order to satisfy the conditional independence assumption. In addition, the model should always include variables that are not correlated to treatment but correlated with the outcome. The addition of these variables in the model allows a gain of precision of the estimated treatment effects (Caliendo and Kopenig 2008).

The independent variables that were selected based on these recommendations are summarized in table 2. Table 2 shows independent variables, along with their summary statistics. Drawing from previous literature, control variables included three levels of analysis. At the individual level, we included women's age, education and membership in a cooperative. These variables play an important role in access to information, meaning that they strongly affect participation in the subsidized fertilizer program and dietary diversity of food consumption. At the household level, variables include the status of plot manager, family size, number of children, dependency ratio, non-farm income, transfer income, farm income from sales of targeted crops, quantity of sales of all crops, total farm size, plot age and transport equipment owned (bicycle and motorbike). These factors have direct effects on households' decisions to participate in the subsidized fertilizer program, treatment, and households' food consumption patterns. Based on the conditional independence assumption, we included these variables in the model as they simultaneously affect participation decision and the outcomes. Community level variables include distance to the nearest market, distance to paved road, distance to health center, and whether or not a weekly market is available within the community. These variables capture the role of the village level infrastructure in enhancing households' diets quality.

Econometric strategies

The most accurate method for measuring the effects of subsidized fertilizer should be to perform randomized controlled trials (RCTs) in which participant in the subsidies program are randomized into two groups, one receiving subsidized fertilizers, treatment group, and the other receiving no subsidized fertilizers, control group (Imbens and Wooldridge, 2008). Although RCTs are the most robust impact assessment method, as these eliminate selection bias, their application was impossible in the subsidized fertilizer program for ethical and logistical reasons.

In the absence of such an approach, we know that the decision to participate in the program may depend on participants' intrinsic characteristics, such as motivations, which are unobserved. Participants' self-selection may lead to endogeneity reflecting these differences in characteristics. Because of this endogeneity, simple comparisons across program beneficiaries and non-beneficiaries are not able to distinguish effects produced by subsidies program and changes due to initial differences between participants.

Various methods have been used to address the question of endogeneity with cross-sectional data (Imbens and Wooldridge, 2009). These include the class of treatment effect models such as propensity matching score (PSM). Propensity score matching is one of the most commonly used econometric methods for constructing an appropriate counterfactual group to assess program impacts with non-experimental data. This technique has been used in different contexts, including agriculture, to determine the effects of agricultural interventions. We use matching models were used to test the empirical link between the subsidy and nutrition outcome variables. Rosenbaum sensitivity analysis was applied to test the robustness of results.

Average treatment effects

The main objective of the analysis is to estimate the average treatment effects of fertilizer subsidies on women's dietary diversity scores.

Let *Yi (1)* represents the potential outcome of individual i with participation in the fertilizer subsidy program and *Yi (0)* without participation. The dummy variable, *Di* $\in\{0,1\}$ equal to 1 if individual i is treated, that is to say, one with participation in fertilizer subsidy program and 0 otherwise, and *Xi* denotes a vector of covariates that denotes household, individual and farm characteristics. Assuming that women's diets quality is a linear function of the vector of covariates *Xi*, and the treatment dummy variable Di, the impact model, can be specified as:

$$Y_i = \alpha D_i + \beta X_i + \varepsilon \quad (1)$$

A represents a change in outcome Y_i due to participation in the subsidy program and ε is the error term.

Estimating the effect (α), in equation (1) using ordinary least squares assumes that participation in the subsidy program is random while it is not. Hence, we are confronted with the problems of counterfactual or potential selection bias. As a solution, we will employ a propensity score model developed by Rosenbaum and Rubin, (1983) to find comparable participating and nonparticipating farmers based on the set of covariates such as women, and household characteristics.

For each individual *i*, we observe {*Xi, Di, Yi*}, where *Yi = Yi (0) if Di=0* and *Yi = Yi (1) if Di=1*. We observe the outcome from participating *Yi (1)* or not participating *Yi (0)*, but cannot observe the outcome from both participation regimes. What we can actually observe is given by the following equation:

$$Y_i = D_i Y_i(1) + (1 - D_i) Y_i(0) \quad (2)$$

One of the key assumptions of the propensity score method is the conditional independence assumption (Rosenbaum and Rubin, 1983). This assumption implies that selection bias can be controlled if there is a set of observable variables conditionally to which treatment assignment independence can be verified. The common support or overlap assumption is the second key assumption. This assumption ensures that individuals in the treatment and control groups are sufficiently similar to allow meaningful comparisons. Assuming that the conditional-independence assumption holds, and the overlap condition satisfied, the average treatment effect (ATE) is identified as:

$$ATE = E[Y_i(1) - Y_i(0)]. \quad (3)$$

Different matching approaches can be used to match the units of the control group with the units of the treatment group. These approaches include nearest-neighbour matching, radius matching, and kernel-based matching. Nearest-neighbour matching is a matching procedure in which units of the control group are matched to units in the treatment group based on the nearest propensity score distance. The nearest-neighbour matching has the advantage of producing more accurate estimates; however, it has the challenge of good matching. Radius matching provides a tolerance level by specifying a maximum propensity score distance or caliper for matching. In kernel-based matching, matching is achieved with an inversely proportional weighting of the propensity scores that gives the highest weightings to the control group units with a lower propensity score distance (Heckman et al., 1998). The Gaussian kernel matching uses all the available information of the control group units, which reduces the variability of the estimators. When the common support condition is satisfied, the kernel match provides more robust estimates because of the lower variance resulting from the use of more information. Given the problem of poor matching with the nearest-neighbour matching and the difficulty in determining a proper radius for radius matching, this study adopts the Gaussian kernel matching approach.

Sensitivity analysis

Since the matching methods are based on observable characteristics, the analysis of the sensitivity of the matching estimates to determine how robust they are to the unobserved factors has become important in the literature (Becker and Caliendo, 2007). I performed the sensitivity analysis using the Rosenbaum Boundary Method (Rosenbaum 2002). Following Rosenbaum (2002), the ratio of the odds that a treated case i has the unobserved factors to the odd that the control case j has same factors is defined by

$$\frac{P_i}{P_j} * \frac{1-P_j}{1-P_i} = exp[(\gamma(u_i - u_j)] \quad , (4)$$

where P_i and P_j are treatment probabilities, and u_i and u_j are an unobserved covariate for the two individuals. γ is the effect of unobserved covariate on the treatment selection.

If u_i-u_j=0, or γ=0, the unobserved variable is the same for the treatment and the control. That is to say, the unobserved variable has no influence on the probability of treatment then $exp[\gamma(u_i - u_j) = 1$, suggesting that there is no the hidden bias due to unobservable variables.

Let us set $\Gamma = exp(\gamma)$. The Rosenbaum (2002) bounds on the odds ratio are then defined as:

$$\frac{1}{\Gamma} < \frac{P_i}{P_j} * \frac{1-P_j}{1-P_i} < \Gamma$$

The Rosenbaum bounds method computes the confidence intervals of the outcome variable for different values of Γ using the matching estimates. If the smallest value of Γ for which the confidence interval contains zero is less than two, the effect of the estimated treatment is sensitive to unobservable (Becker and Caliendo 2007).

Results

Descriptive statistics

Table 3 summarizes the results from bivariate analysis for key variables during lean and post-harvest seasons. In Mali, in a typical year, the lean season runs from June to August and the post-harvest period extends from September to May. The mean of *MDD_W* was just over 0.4 during the lean season while the mean of *MDD_W* was more than 0.7 during harvest season.

Similarly, the mean of *WDDS* was slightly more than four while during the lean season while it was more than five during the post-harvest season. The average of *ownWDDS* is 2.99 during the lean season and 2.70 during the harvest period, which means that during the lean period, households consume more food from their own production. The same goes for gifts with average values of 0.32 during the lean season and 0.27 during the post-harvest season. In contrast, consumption of purchased food increases during the post-harvest season, rising from 1.99 during the lean period to 2.73 on average after harvest.

With regard to *WDDS* components, purchase food constitutes the most important source of women's diets in the harvest season while own production is the most important source during the lean season. We observe significant differences between the two seasons, with the average scores for *MDD_W* and *WDDS* being lower during the lean season. By breaking down the dietary diversity score of women according to the food source, we note that, unlike the own production that is important in women's diets during the lean season, women get most of their diets from purchase food during the harvest season. This was expected as farm incomes are more likely to increase during harvests allowing farmers to have more money to spend on non-staple foods.

Econometrics results: Average treatment effects

Table 3 presents the results of the average treatment effects of the fertilizer subsidy on the *WDDS, ownWDDS, purchaseWDDS, and giftWDDS*.

Effects of subsidized fertilizer on Woman's Dietary Diversity Score (*WDDS*) varied across the two agro-ecological zones. In the Niger Delta, the average treatment effect of subsidized fertilizer on WDDS is positive and statistically significant at 5% level, meaning that participating in the subsidized fertilizer program improves overall dietary diversity score. At the same time, subsidized fertilizer is negatively associated with WDDS in the agro-ecological zone of Koutiala Plateau, suggesting that subsidized fertilizer may negatively affect women's diet quality outcomes in this zone. The model did not detect subsidized fertilizer effects on WDDS in the entire sample combining both Niger Delta and Koutiala Plateau agro-ecological zones—perhaps because of counteracting effects.

On average, women's dietary diversity scores from gift food are negatively associated with participation in the subsidy program in Niger Delta. Thus, participants in the program rely less on gift food for a diverse diet. This result suggests that the subsidy program improves household resilience to food insecurity in that zone, as indicated by the diet of women of reproductive age in the household. Conversely, we fail to detect no linkage between subsidized fertilizer effect and women's dietary diversity from gift food in the Koutiala Plateau or in the combined sample from the two zones.

The ATE of women's dietary diversity from food sources on the farm is negative but not statistically significant in either of the two agro-ecological zones, leading to some uncertainty about the own production pathway from subsidized fertilizer to diet quality. However, in the entire sample, the ATE on own production is negative and significant, suggesting that women's diet diversity from food sourced on the farm tends to decrease with participation in the subsidized fertilizer program.

In the agro-ecological zone of Niger Delta, the ATE of subsidized fertilizer on Women's dietary diversity score from purchased food is positive; on the Koutiala Plateau, it is negative. Both effects are statistically significant. Furthermore, the ATE of subsidized fertilizer on Women's dietary diversity score from purchased food is positive in the entire sample.

Robustness checks and sensitivity analysis

Balancing quality

The key concept of the matching methods is that of conditional independence assumption, which states that there are no differences between the treatment and control groups, conditional on the observed covariates. Therefore, the first step in using matching methods is to diagnose the quality of matching through the covariate balance in the matched groups. The graphical results of the balance test are reported in Figures 2 & 3 (performed with pstest in STATA). Figures 2 & 3 suggest that we achieve good balance after matching by reducing the percentage of balance bias up to more than 90% overall. After matching, we found no statistically significant difference between the means of all model covariates; this is to say, propensity score matching balanced covariate variables.

Overlap condition

To investigate the validity of the estimated effects, we verified the common support or overlap condition. As shown in Figure 4 & 5 (generated with psgraph in STATA), the probability of participating in subsidized fertilizer program knowing the observed covariates lies between 0 and 1. This means that participants with the same covariate values have a positive probability of being both participants and non-participants, suggesting that the common support condition is fulfilled. To ensure this, we trimmed the data by removing the observations that fell outside the common support region.

Propensity score

Table 5 in the appendix shows the logistic regression estimates used to compute propensity scores for matching. Overall, the model fits the data well. The McFadden pseudo R^2 of 27% indicates that we can reject the hypothesis that all coefficients are equal to zero at the 5% percent level of significance. Distance to infrastructure (market, paved road), number of children in the household, and value of non-farm income are negative and significant, which indicates that these decrease the likelihood of treatment (use of subsidized fertilizer). The probability of treatment augments with the education of plot manager, dependency ratio, and farm income.

Sensitivity analysis

Tables 5 and 6 indicate the critical values for which the gamma is the lowest with a confidence interval containing zero for each outcome. The tables show that the gamma for which the overall women's dietary diversity score is the lowest with zero in the 95% confidence interval is 1.4 in Niger Delta and 1.2 in Koutiala Plateau. For the dietary diversity score related to purchased food, the lowest gamma with zero in the 95% confidence interval is 1.6 in Niger Delta and 1.4 in Koutiala Plateau. For the dietary diversity score based on purchased food, we will begin questioning the estimated impact when the difference in odds of individuals with the same observed characteristics differ by 60% in Niger Delta and by 40% in Koutiala Plateau. The lowest value of gamma producing a 95% confidence interval containing zero for the dietary diversity score based on gift food is much higher, reaching 3.2 in the Niger Delta. These values suggest that the unobserved characteristic would have to increase the odds ratio by around 40% and 20% before we being to question the estimated impact on the overall dietary diversity in Niger Delta and Koutiala Plateau (respectively). The critical value of gamma for the dietary diversity score based on food received as gifts implies that the treatment effects are more robust to hidden bias from unobserved characteristics relative to the overall dietary diversity score and the dietary diversity score based on purchased food. However, the degree of sensitivity for these two outcomes fall within the range of acceptable degree of sensitivity reported in the literature (e.g., Becerril & Abdulai, 2010; Aakvik 2001).

Discussion

Descriptive statistics indicate significant differences in the dietary quality of women in farm households of Mali between seasons, with lesser extent of consumption during the lean season. Regarding the components of the dietary diversity score, while the dietary diversity resulting from own production is greater during the lean season, that resulting from the purchase is greater during the post-harvest season. One reason may be that the lack of financial means during the lean season prevents women from consuming certain purchased food items. These results are consistent with previous studies in the Sahel region. For example, in Burkina Faso, Savy et al. (2006) found that the lack of financial means during the lean season resulted in a decrease in the consumption of purchased food.

The regression from propensity score matching reveals a positive effect of subsidized fertilizer on the nutritional outcomes of farm households in the Niger Delta, in line with other studies in sub-Saharan Africa (Snapp and Fisher 2014, Wiredu et al. 2015). Wiredu et al. (2015) found a positive impact of subsidized fertilizer on the food security of rice smallholders in northern Ghana and suggested additional policy actions to stabilize food security. Snapp and Fisher (2014) found a positive impact from greater commercialization of maize on household dietary diversity scores in Malawi.

In contrast to the findings for the Niger Delta, we found a negative association between subsidized fertilizer and women's dietary diversity scores in the Koutiala Plateau. This seemingly surprising result appears to be consistent with findings from previous studies in this region of Mali regarding the "Sikasso Paradox." The paradox is that despite all of the investments in rural development related to the cotton value chain in this region, poverty and malnutrition persist. Examining the impact of cotton cultivation on the living conditions of households in Mali and Burkina, Mesple-Somps et al. (2008) showed that households in Mali's cotton zone spent much less on food, with unfavorable nutritional outcomes, while at the same time, they seemed much better equipped in terms of durable goods. In their analysis of the linkages between child nutrition and agricultural growth, Teff and Kelly (2004) found that women in the irrigated rice zone had better access to income and control over their incomes than their counterparts in the cotton zone, where the income is concentrated in the hands of the household head. However, evidence concerning the pathways linking agriculture to nutrition demonstrate that access to and control over households' resources by women is a major factor in improving the nutritional outcomes of women and their children. Teff and Kelly (2004) also found that the nutritional status of children under four years of age was better in the irrigated rice zone than in the cotton zone. More recently, Cooper and West (2017) studied agricultural change and malnutrition in the cotton zone of Sikasso. Although they found little evidence of association between nutritional outcomes and cotton cultivation at the household level, they did find a negative association between cotton cultivation and nutritional outcomes at the village level.

The innovation of this study lies in the fact that the overall dietary diversity score is broken down according to the food supply source—an approach which we have not found in previously published literature. We have decomposed the overall score according to whether the food was obtained on the farm, from market purchase, or from gifts. This allowed us to better understand the effects of subsidized fertilizers as well as the influence of contextual factors such as the role of the market and social networks in the changes of dietary diversity score.

Women's dietary diversity score from own production is negative in sign in both zones but not statistically significant in either. This indicates that though fertilizer subsidies may increase staple crop production like rice, they do not provide enough incentive for farmers to produce a variety of nutritious food and improve the quality of their diet. In fact, it may reduce cultivation of crops not targeted by the subsidy—a point which merits further research attention. According to the conceptual framework of the Agriculture and Food Organization of the United Nations (FAO), when policy interventions aim to increase the production of staple foods, they may affect the amount of energy available but not dietary diversity.

At the same time, women's dietary diversity score sourced from purchased food is positive in the Niger Delta but negative in the Koutiala Plateau and statistically significant in both zones. These findings underscore the important role that the market plays in changes in women's dietary diversity score and are consistent with the literature on the linkages between agriculture and nutrition outcomes. These results show the importance of income and the involvement of the market as mediators between fertilizer subsidies, production and consumption, and the nutritional outcomes. Clearly, these mediators work differently within farm households located in the two agroecological zones.

Another key result of this study is the fact that women's dietary diversity scores from gift food negatively correlates with subsidized fertilizer in Niger Delta, suggesting that fertilizer subsidy may improve the farm household's resilience to food insecurity in that region. In the Koutiala Plateau, the sign is positive on food receives as a gift but the coefficient is not statistically significant.

Like all studies based on cross-sectional, observational data, this study has some limitations. The endogeneity issue or selection bias limits the causal effects inferences of the matching technique, which relies on observed covariates. To address this, a sensitivity analysis was conducted to test the stability of the results. Another limitation of this study is the fact that we constructed women's dietary diversity scores based on 7-day recall as compared to direct measurement—the main challenge being the measurement error since we do rely on the memory of respondents.

Conclusion

Food security is a major concern for developing countries. To address this issue, several sub-Saharan Africa countries, including Mali, have adopted fertilizer subsidies policy to boost agricultural production in order to improve food security. However, little evidence exists on their effects on the quality of diets in the households of smallholder farmers. This analysis contributes to the literature by providing relevant evidence on the effects and pathways that link subsidized fertilizers to diet quality of farm households. The analysis was conducted in the specific context of irrigated rice and cotton cultivation zones of Niger Delta and Koutiala Plateau in Mali.

Taking into account the nature of the data used in this study, which are non-experimental, we applied propensity score matching methods to account for the issue of endogeneity in investigating the effects of subsidized fertilizer on the quality of the diet of farm households. For robustness checks, we also performed a sensitivity analysis to test the stability of the results.

The outcome variables of interest include women's overall dietary diversity score as well as its components in terms of food sources, namely *ownWDDS* which represents the dietary diversity score of women from own production, *PurchaseWDDS* which denotes women's dietary diversity score from food purchases, and *giftWDDS*, which represents women's dietary diversity from gifts. This decomposition was made possible by data collected on sources of food consumed, including food from own production, market purchases, and food from gifts. Examining the effects of subsidized fertilizer on household dietary diversity using these food source categories enabled a better understanding of the relative importance of the pathways linking fertilizer subsidies and household dietary diversity.

Descriptive statistics showed that the diversity of diets from own production is greater during the lean season, while that of purchased food is greater during the post-harvest period. The study reveals some differences across the two study zones. We found that the average treatment effects on women's overall dietary diversity and women's dietary diversity from purchased food are significant and positive in Niger Delta, indicating that subsidized fertilizers have positive effects on the diversity of women's overall diets through income pathway. Conversely, we found a negative association between women's overall dietary diversity and women's dietary diversity from purchased food in Koutiala Plateau. This latter result is disconcerting but consistent with the "Sikasso Paradox" often explored in the literature on Mali.

Findings illuminate the relationships among production, consumption, and the market. Looking back to the conceptual framework, this means that an increase in production generates higher incomes through sales of agricultural products and related activities that households may (or may not) use to purchase other nutritious foods. From the policy point of view, results suggest that any policy to improve nutrition by stimulating agricultural production should take into account the specificities of each zone and include measures on nutrition practices and the functioning of the market to stabilize prices and make available diversity of nutritious food on local markets.

Another major finding of this study is the negative relationship between subsidized fertilizer and dietary diversity sourced from gift food in one of the two regions. The negative relationship indicates that participants in the subsidized fertilizer program are less dependent on gift foods. This result is particularly important since it indicates an improvement in the self-sufficiency of households receiving subsidized fertilizers. This finding demonstrates that subsidized fertilizers have the potential to improve household livelihoods by improving their resilience to food insecurity.

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Table 1: Independent variables (Mean for treated and control)

Variable	Description	Treated	Control	p-value
age	Woman age (years)	32.91	32.17	0.03
distbitumee	Distance to paved road (m)	15.43	18.28	0.00
distmarket	Distance to market (km)	8.39	10.60	0.00
areaEAF	Land owned (ha)	11.53	13.40	0.00
children	Number of children	8.54	9.07	0.00
localmarket	Weekly market (dummy)	0.30	0.27	0.00
plotage	Plot age (years)	19.57	17.81	0.00
familysize	Family size	18.39	19.22	0.00
edugerant	Education of plot manager	1.82	1.13	0.00
agegerant	Age of plot manager (years)	44.76	42.70	0.00
ltransfert	Transfer income (FCFA)	3.41	3.59	0.21
nonfarminc	Non-farm income (FCFA)	6.90	7.55	0.00
headeaf	Plot manager is head's household (dummy)	0.61	0.50	0.00
farminc	Farm income (targeted crops) (FCFA)	12.81	11.46	0.00
allcropsaleskg	Total crops soled (kg)	22.41	19.39	0.03
disthealthcter	Distance to health center (km)	2.03	2.36	0.02
memberOP	Cooperative membership (dummy)	0.88	0.82	0.00
bicycle	Number of bicycle	3.09	2.78	0.00
motobike	Number of motorbike	1.80	1.73	0.05
depratio	Dependency ration	0.50	0.51	0.02

Table 2: Summary statistics for woman's diets quality

Variable	Obs	Jul-18		Feb-19		p-value
		Mean	Std. Dev.	Mean	Std. Dev.	
MDD_W	1,087	0.45	0.50	0.80	0.40	0.00
WDDS	1,087	4.32	1.51	5.61	1.44	0.00
ownWDDS	1,087	2.99	1.41	2.70	1.66	0.00
purchaseWDDS	1,087	1.99	1.66	2.73	1.76	0.00
giftWDDS	1,087	0.32	0.68	0.27	0.70	0.10

Table 3: Average treatment effects

Outcomes	**Niger Delta**	**Koutiala Plateau**
WDDS	0.228**	-0.143**
ownWDDS	-0.044	-0.014
purchaseWDDS	0.410**	-0.145**
giftWDDS	-0.204**	0.036
N(Treated)	708	1122
N(Untreated)	346	504
N(total)	1054	1626

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$

Table 4: Logit regression for computing propensity scores results

Variables	Niger Delta	Koutiala Plateau
subvention1: dependent variable		
age	0.010	0.003
distbitumee	-0.038***	0.003*
distmarket	-0.038**	-0.01
areaEAF	-0.047***	-0.019*
children	-0.096*	0.017
localmarket	0.000	0.000
plotage	-0.007	0.012**
familysize	0.040	-0.028
edugerant	0.066**	0.073**
agegerant	0.001	0.004
ltransfert	-0.014	-0.006
nonfarminc	-0.043***	-0.008
headeaf	0.236	0.145
farminc	0.473***	0.093***
allcropsaleskg	-0.001	-0.001
disthealthcter	-0.011	-0.015
memberOP	-0.212	1.239***
bicycle	-0.012	0.050*
motobike	0.146	0.144**
depratio	1.630*	0.267
_cons	-5.074***	-1.895**
McFadden pseudo R^2	0.268	0.057
N	1333	1626

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$

Table 5:Rosenbaum bounds sensitivity analysis for the main outcomes, Niger Delta

Outcome variables	**Gamma**	**CI+**	**CI-**
WDDS	1	0.217	0.328
	1.2	0.156	0.633
	1.4	-0.112	0.692
	1.6	-0.210	0.728
ownWDDS	1	-0.141	0.015
	1.2	-0.275	0.088
	1.4	-0.398	0.194
purchaseWDDS	1	0.289	0.526
	1.2	0.093	0.662
	1.4	0.002	0.839
	1.6	-0.069	0.970
	1.8	-0.213	1.014
	2	-0.335	1.072
giftWDDS	1	-0.466	-0.422
	3	-0.573	-0.007
	3.2	-0.578	0.009
	3.4	-0.582	0.022

Table 6:Rosenbaum bounds sensitivity analysis for the main outcomes, Koutiala Plateau

Outcome variables	**Gamma**	**CI+**	**CI-**
WDDS	1	-0.10815	-0.01207
	1.2	-0.46485	0.013484
	1.4	-0.47451	0.027194
ownWDDS	1	-0.06283	-0.05218
	1.2	-0.06858	-0.04416
	1.4	-0.07762	0.05127
	1.6	-0.09938	0.417201
purchaseWDDS	1	-0.27474	-0.25001
	1.2	-0.29599	-0.23023
	1.4	-0.33232	0.142029
	1.6	-0.67277	0.19666
giftWDDS	1	-0.34553	0.1392
	1.2	-0.34865	0.143183
	1.4	-0.34973	0.145231

***Figure 1**. Conceptual framework: From fertilizer subsidy to diet quality*

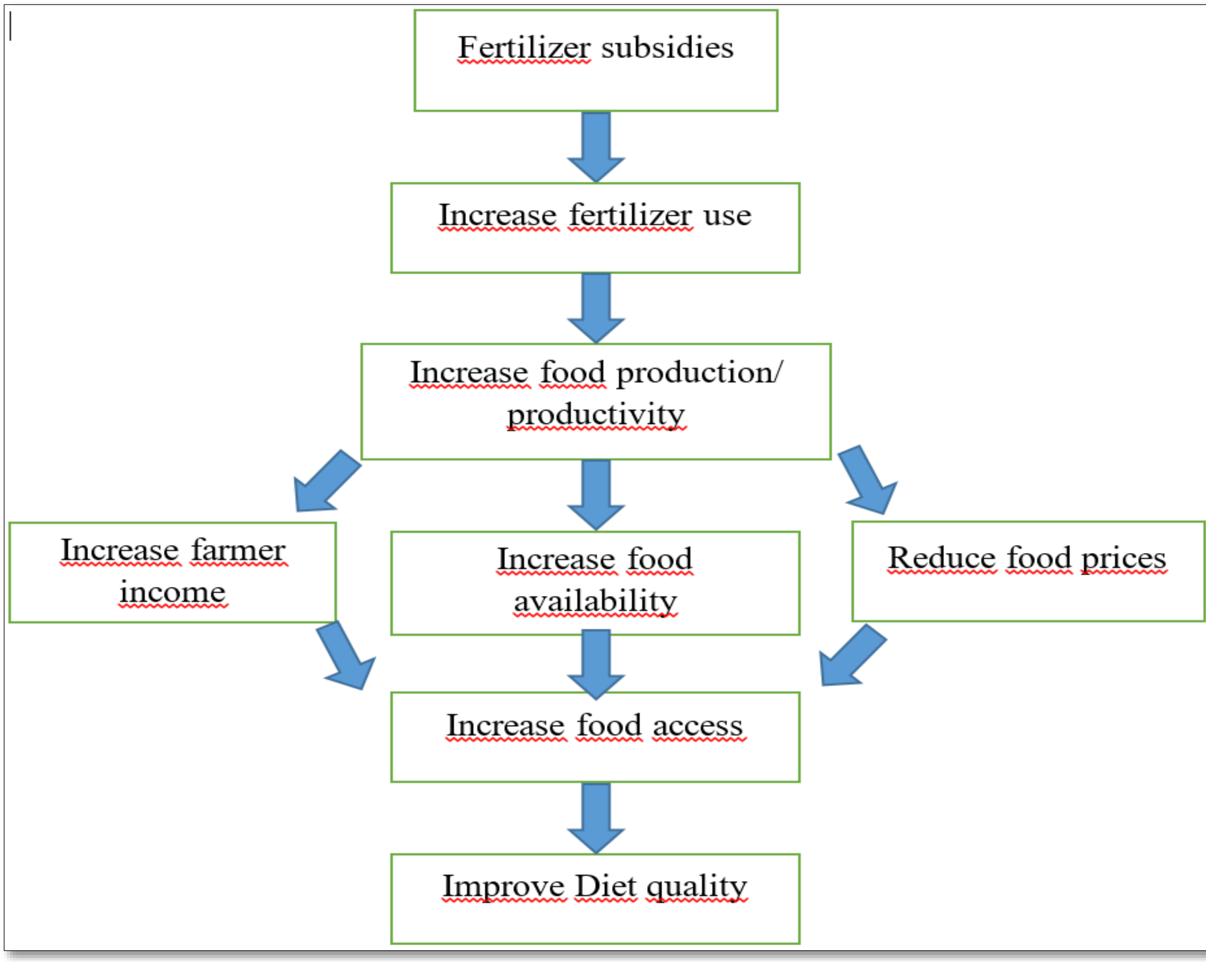


Figure 2. Covariate balance test: Niger Delta

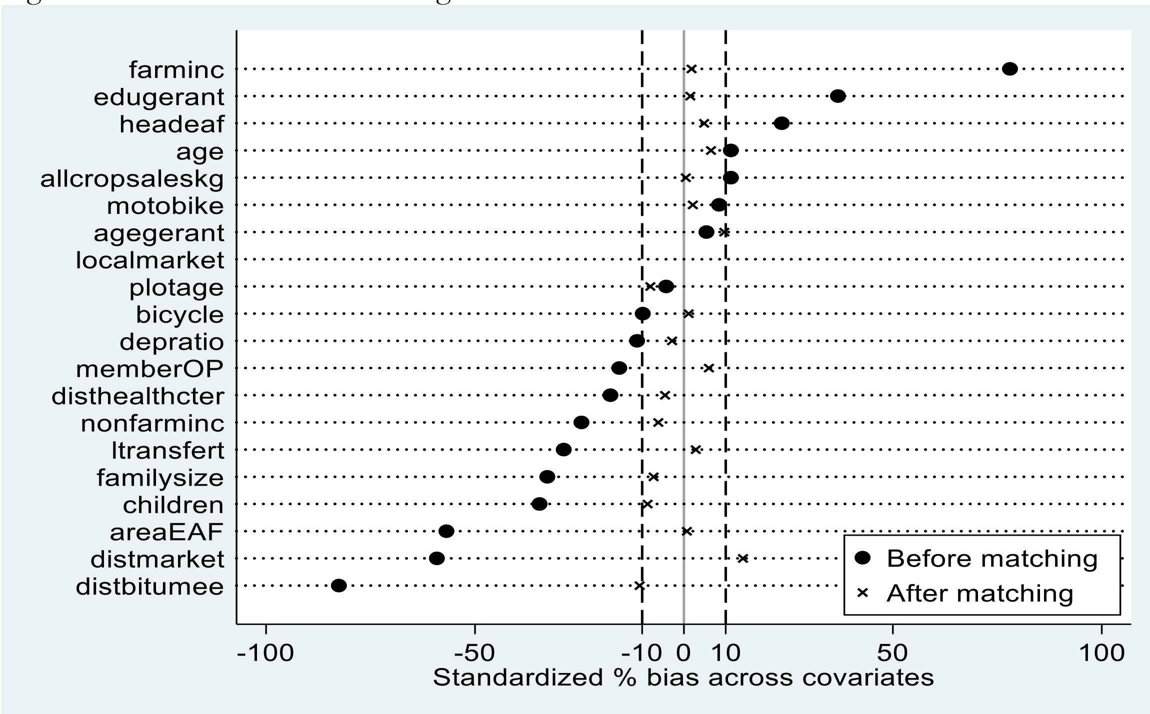


Figure 3. Covariate balance test: Koutiala Plateau

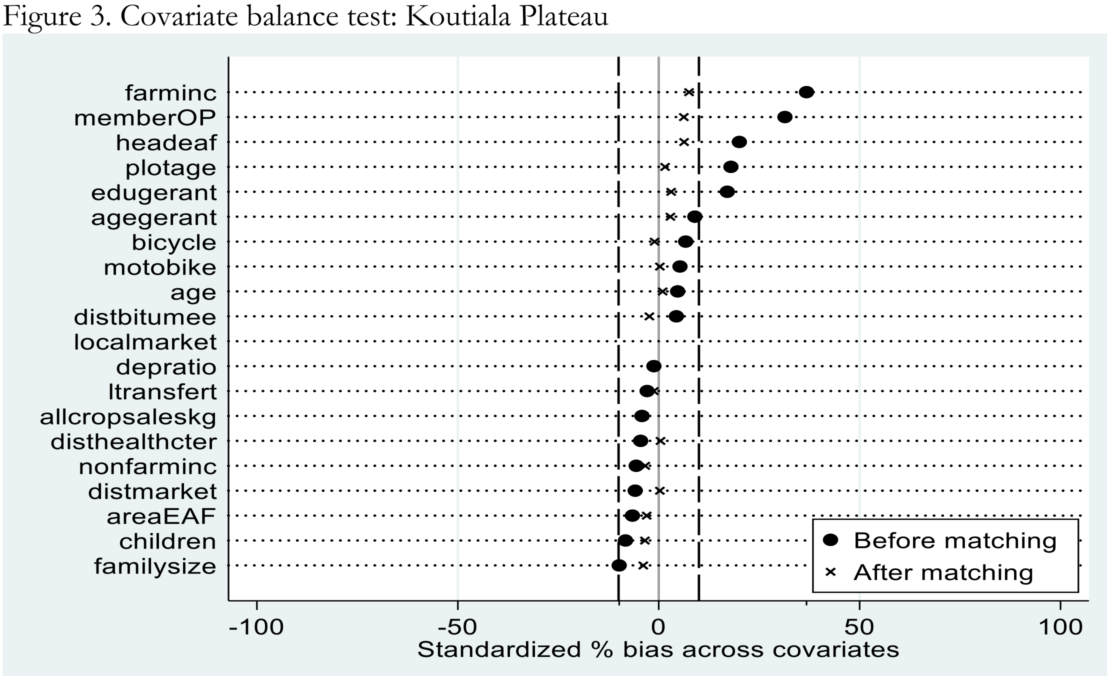


Figure 4. Propensity score before and after matching: Niger Delta

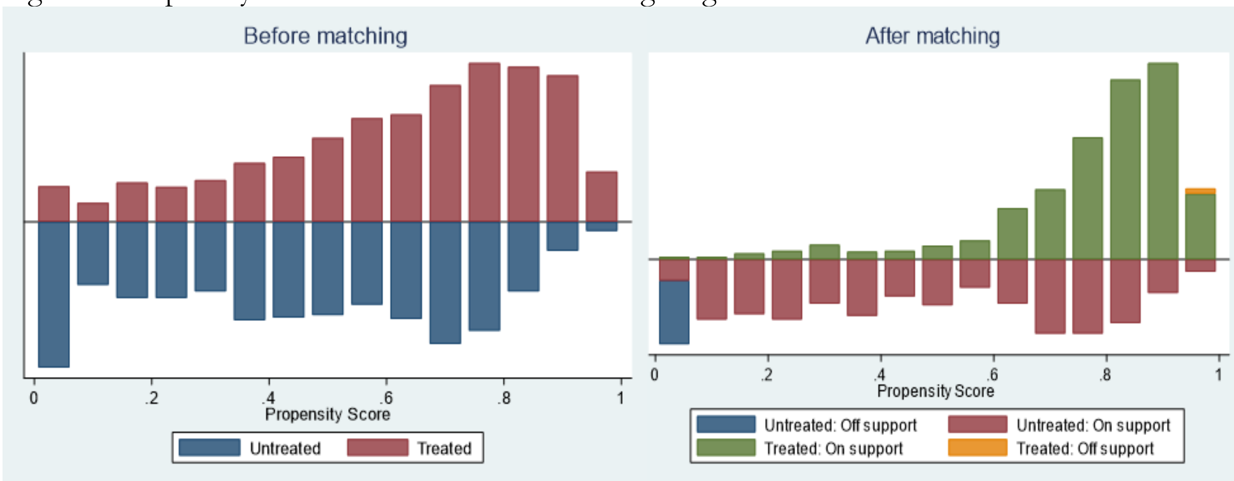


Figure 5. Propensity score before and after matching: Koutiala Plateau

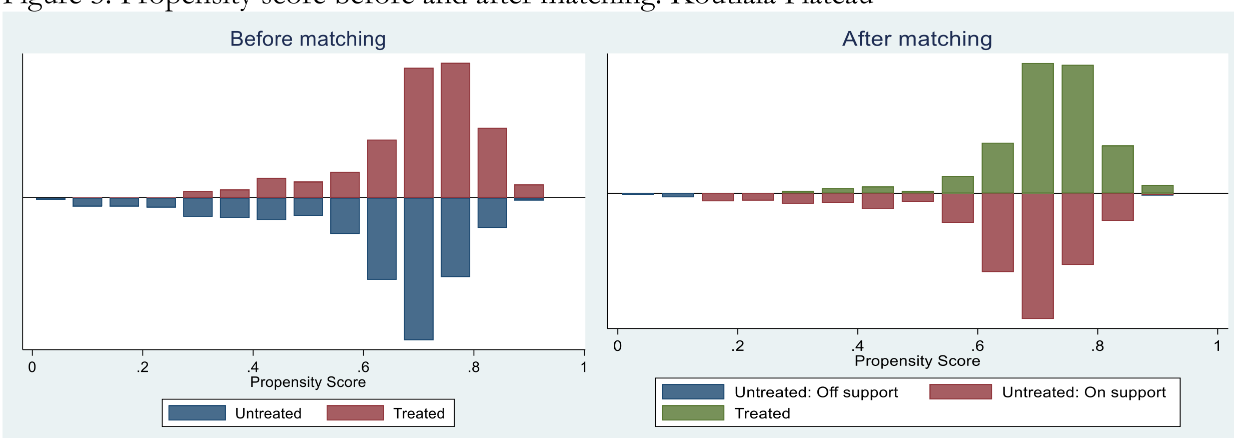
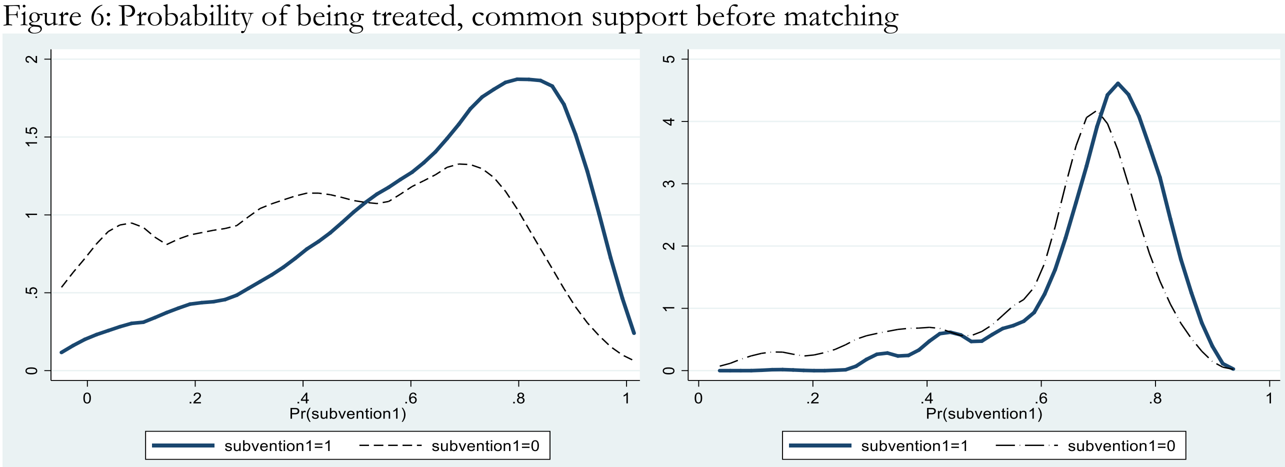


Figure 6: Probability of being treated, common support before matching



Niger Delta

Koutiala Plateau

Figure 7: Map of the study area