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Fertilizer Subsidy and Agricultural Productivity in Senegal

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Table of Contents

Abstract

In a consistent effort to raise productivity and unlock the economic and social potential of the agricultural sector, the Senegalese government has implemented heavy subsidy programs, some of which target the use of inputs. This paper assesses the potential impact of the fertilizer subsidy on farmers' productivity. We use data envelopment analysis to generate efficiency scores, which are then related to the subsidy program using an endogenous treatment-regression model that accounts for potential endogeneity and self-selectivity issues. The results indicate that the subsidy program appears to be associated with increased efficiency, hence providing empirical support to the political will to revamp the program. The results also suggest ways to improve the effectiveness of the subsidy program, as well as additional policy options to further unlock the agricultural potential.

Résumé

Dans le but d'améliorer la productivité agricole et libérer tout le potentiel économique et social du secteur, le Sénégal a mis en œuvre des programmes ambitieux de subventions qui pour la plupart ont cibles l'usage des intrants. Ce papier propose une analyse de l'impact potentiel des subventions de l'engrais sur la productivité des agriculteurs. Le papier utilise l'approche non-paramétrique de *data envelopment analysis* pour calculer les scores d'efficience, puis il développe un modèle de traitement endogène qui corrige le double biais d'endogènéité et d'auto-sélection. Les résultats obtenus à partir de données d'enquête auprès des agriculteurs de la Vallée du Fleuve Sénégal indiquent que les programmes de subvention de l'engrais ont significativement contribué à améliorer la productivité, offrant ainsi un argument empirique à la volonté politique d'étendre ces programmes. Les résultats suggèrent aussi différentes voies à envisager dans une perspective d'améliorer davantage l'efficacité de ces programmes et la productivité du secteur.

1. Introduction

In Senegal, more than half of the labor force contributes to a meager 14.8 percent of gross domestic product (GDP)[1], and the average farmer is more than six times less productive than her average counterpart in the rest of the economy. The low productivity of the agricultural sector greatly contrasts with its potential to improve economic and social conditions. More productive agricultural activity would help close the country's enormous food gaps, which mainly originate from low domestic production relative to ever-increasing domestic demand. In addition, by strengthening domestic food markets and reducing structural dependence on imports, greater agricultural productivity would help reduce vulnerability to foreign shocks, particularly those related to food prices; it would also help improve food security by increasing the availability and affordability of agricultural products. Finally, increased agricultural productivity would provide increased incomes and economic opportunities for a large majority of the population, particularly in the rural sector, thereby reducing overall poverty and inequality.

Policymakers in Senegal well understand these economic and social potentials of the agricultural sector and have enacted a consistent policy to provide generous subsidies to farmers. The support scheme was meant to ensure the availability of inputs, particularly fertilizers, on the one hand, and advantageous market conditions through guaranteed market prices, on the other. In 2004, renewed interest from the Senegalese government translated into significant financial investments in the agricultural sector. This would be echoed two years later by the "Abuja Declaration," in which many African governments committed to significantly reviving input subsidy programs with the aim of significantly increasing fertilizer use and agricultural productivity across the continent. Since the Abuja Declaration, the Senegalese government has increased the amount dedicated to subsidies to a record FCFA 36.3 billion in 2011 (US$ 72.6 million), up from only FCFA 75 million in 2001. This amounts to a 484-fold increase over a 10-year period.

Fertilizers have been the main target of the subsidy programs; some 30 percent of agricultural subsidies was intended to improve the availability and use of fertilizers through a reduced purchasing price. More recent data also indicate the government's clear emphasis on fertilizers. During 2011-2012, close to half of the FCFA 30.9 billion subsidy budget was directed to fertilizers. This follows a general trend across Africa south of the Sahara, where governments spend an estimated US$ 2 billion each year on fertilizer subsidy programs (Rickert-Gilbert et al., 2013).

There is a clear perception that fertilizer subsidies can improve the use of the input and overall agricultural productivity. The resulting change in the relative price of fertilizers would weaken the budget constraint faced

[1]Ministry of Agriculture and World Development Indicators Online.

by farmers, expand farmers' technical space, allow for additional investment, and lead to more efficient, accessible combinations of inputs. This efficiency-ladder effect, also referred to as a "crowd-in" effect, is synonymous with greater productivity (Mason and Jayne, 2012). Furthermore, even if farmers' production techniques do not change, there could be a productivity gain in an input-oriented sense, for the farmer can now reach the same level of output with reduced input costs. Additional arguments relate to the possibility of overcoming missing or imperfect markets for farmers, such as the credit market (IFDC, 2003) or the insurance market (Donavan, 2004), as well the possibility to correct negative externalities (Gladwin et al., 2002).

However, the still low productivity of farmers in Senegal could indicate that the fertilizer subsidy may not have yielded all of these benefits. Some arguments in the literature support such a theory. By lowering the price of fertilizers, subsidies can lead to inefficient use of the input. In effect, farmers' response to these incentives could be a substitution toward crops that respond best to fertilizers but that are not necessarily more productive. Farmers can also turn away from "more sustainable, profitable, and promising land-use practice such as organic matter, minimum tillage, and low-input agroforestry" (Donavan, 2004). Furthermore, in some cases, fertilizer demand can be inelastic to price change. In effect, there is often some specific technical guidance that constrains the use of fertilizers for the sake of preserving a given organic and chemical equilibrium of the soil and the cultivated crops. To the extent that the production process might already be operating at the frontier of these requirements, a price reduction may not lead to an increase in fertilizer usage.

An additional argument could be related to the extent to which the income generated by a price reduction are spent on agricultural activity. Farmers facing financial constraints in their daily subsistence are very likely to direct any monetary gains brought about by subsidies to their final consumption instead of to acquiring additional acres of land or new technology. This disincentive to invest in farming is known as the "crowding-out" effect and results in no direct impact on the efficiency of the production process (see for instance Nyirongo (2005) for a case study in Malawi and Xu et al. (2009) for Zambia). Furthermore, some authors point to the possibility of "leakages" (Mason and Jayne, 2012); farmers may be tempted to resell subsidized fertilizers at higher prices. In such a situation, subsidies could lead to a reduction in the amount of fertilizers and other inputs that farmers use, which could subsequently lead to a reduction in agricultural output.

Overall, the evidence seems to suggest that fertilizer subsidies have questionable benefits, both in terms of increased use and in terms of improved overall productivity. Any study addressing the effectiveness of the fertilizer subsidy needs to weight these arguments with respect to their relative ability to portray the productivity profile of Senegal's farming activity. In the specific context of the Senegalese agricultural sector, what are farmers' response mechanisms to the incentives brought about by the subsidy programs? Do these

mechanisms translate into greater efficiency? Is the government's main focus on subsidizing fertilizers the most cost-effective policy option when it comes to promoting agricultural productivity?

This paper aims to assess the impact of public support to agriculture on the productivity of farmers. More specifically, it analyzes farmers' responses to the incentives associated with the fertilizer subsidy and the extent to which these responses have translated into improvements in productivity. It also places the fertilizer subsidy into a broader scheme of agricultural support and compares its effectiveness with that of alternative approaches to boosting farmers' productivity.

The study is based on recent farm-level data collected in the agro-ecological region of the Senegal River Valley. The survey collected detailed information on more than 180 farmers and reveals that about half of these farmers benefit from the subsidy program, with a price coverage ratio ranging from 5 to 100 percent. The empirical approach is first based on a non-parametric approach known as the data envelopment analysis (DEA), which estimates the technical efficiency of the farming units. Then a variant of switching models known as an endogenous binary-variable model is developed to relate efficiency and various covariates, chief among them being whether the farmer has benefitted from the fertilizer subsidy program. This model addresses the potential endogeneity and self-selectivity issues associated with the use of subsidized fertilizers and views the latter as an endogenous binary-treatment variable.

The remainder of the paper is organized as follows. Section 2 offers a brief overview of the government support for agriculture in Senegal, as well as a description of the fertilizer subsidy program. Section 3 details the methodological approach. Section 4 describes the data. Section 5 presents the results and their interpretation. Finally, section 6 offers concluding remarks.

2. Agricultural Support in Senegal

The crucial role of agriculture in both overall economic activity and general well-being of the population has long been understood by Senegalese policymakers and foreign development partners. This recognition has translated into various public programs aimed at unlocking the potential of the agricultural sector for economic growth, poverty alleviation, and rural development. The many public support mechanisms with which the government has experimented can be grouped into three phases spanning the period from independence in 1960 to recent years.

The period from 1960-1980 was an era of very active government involvement in the agricultural sector. A variety of agricultural programs were designed to create a cooperative mechanism that would help farmers from both sides of agricultural production; that is, ensuring that various agricultural inputs were readily available, on one hand, and that crop markets offered sufficient opportunities for higher incomes, on the other

hand. The main policy instrument during this period focused on price, with the government setting prices for most agricultural inputs and crops. Those guaranteed prices, coupled with somewhat effective control mechanisms, were designed to provide sufficient incentives for farmers to increase their productivity, hence contributing to sustained economic growth and improved living conditions, especially in rural areas. However, the burden on the government's finances and a lack of significant improvement in food security, combined with an international context of a looming public debt crisis, made this heavy government involvement unsustainable.

Starting in 1980, there was a complete reversal of the government's approach to agriculture and rural development. With the advent of the structural adjustment programs, mostly imposed upon the country by international organizations like the International monetary Funds and the World Bank, the government ended up trimming its involvement in the agricultural sector. The new "liberal" approach, under the framework of the Agricultural Sector Adjustment Program (Politique d Ajustement Sectoriel Agricole, or PASA) and the Political Strategy for Agricultural Development (Lettre de Politique de Developpement Agricole, or LPDA), meant that economic and even social outcomes would be determined solely by market mechanisms, without any government interference in terms of price control. In addition, direct government support in the form of agricultural subsidies based on production would be eliminated. Among the rare inputs that still benefitted from some form of government subsidy were fertilizers; however, as a consequence of the new ideology, access to those subsidized inputs was very restricted. These subsidy programs would be gradually reduced until their elimination in 1989.

The relative failure of these various liberalization programs to significantly improve agricultural productivity, overall economic growth, and living standards of farmers prompted the government to bring back some public support to agriculture. From 1997 to 1999, the government launched a national program aimed at significantly improving access to fertilizers. The intervention scheme would take the form of a large distribution with heavily subsidized prices. However, the program encountered practical difficulties in its implementation and in the end, the expected goals would not be achieved. Nevertheless, sustained economic growth picked up for the first time since independence, and overall poverty started its long-term decline.

The final period started in 2000, a year in which the country experienced a political transition, and witnessed both a further weakening of pressure from international organizations' pressure and bolder steps toward more active intervention in agriculture. The first such step was the design of a general framework that laid out the institutional foundation of the new government's vision for agriculture. This vision was translated into the main policy framework known as the Agriculture, Forestry, and Livestock Act, or Lettre d' Orientation Agro-Sylvo-Pastorale (LOASP), adopted by the Senegalese government in June 2004 after a long and very inclusive

participatory process. This framework defined the general guidelines for the following 20 years; as such, any specific initiative geared toward agriculture needs to refer to this formal framework. The main objectives range from reducing the impact of external shocks to the agricultural sector to improving farmers' social and economic conditions and promoting private investment in rural and agricultural sector. More than 50 decrees were supposed to translate these commitments into actual policies, but less than 10 have been issued so far. This has been a recurrent problem in Senegal's policy process - a lack of consistent political will that would go beyond the designing step and into actual full implementation.

One important program to come out of this generalized framework was the Great Push Forward for Agriculture, Food and Abundance, or Grande Offensive pour l' Agriculture, la Nutrition et l' Abondance (GOANA). This was more of political response to the 2007 food crisis than a true medium- to long-term agricultural development strategy. The initiative aimed to significantly increase domestic production of Senegal's main food and export crops and achieve self- sufficiency and food security by 2015. Rice, which is the main staple food in Senegal, was targeted to increase production from 195,000 metric tons in 2007-2008 to 500,000 metric tons to 2008-2009, an increase of 156 percent. Other crops were also targeted, like millet (a yearly 3-fold increase), sorghum (5-fold increase), and maize (more than 12-fold increase). These targets were to be achieved mainly through providing more equipment and subsidized seeds to farmers, as well as making an additional 500 hectares of land available at no charge.

Another major initiative geared toward the agricultural sector, the Return to Agriculture or Retour vers l' Agriculture (REVA), was designed to tackle rural migration. The main support for this program came from Spain, which is one the main destinations of Senegalese migrants. REVA aims to improve rural agricultural infrastructure and encourage young farmers and female farmers through training and the provision of tools and equipment.

Unlike the LOASP, which had a very inclusive formulation process, GOANA and REVA did not fully involve all agricultural actors at all stages of the programs' development. This translated into less ownership by some relevant actors (such as farmers) and ultimately into low effectiveness in terms of producing sustainable results that would set the sector on the path of reduced vulnerability and greater food security.

Throughout these various programs, subsidies have remained one of the most favored tools. In 2004, fertilizer subsidies resumed for the first time since 1988 (with the exception of the brief 1997-1999 program). These subsidy programs encompassed a large spectrum of agricultural crops, such as groundnuts, millet, sorghum, and maize. They also mobilized greater public resources. In addition to fertilizers, other subsidized products included seeds, phytosanitary products, fuel, machinery and equipment, water, and producer prices. The support programs also took the form of the removal of import tariffs and value-added taxes on agricultural

inputs. After the world food crisis of 2007-2008 that hit the Senegalese economy relatively hard, this increase in various subsidies to farmers was part of the government's efforts to increase agricultural outputs as a way of reducing the country's vulnerability to external shocks.

These vast subsidy programs have come with significant financial costs. In effect, they went from a meager FCFA 75 million in 2001 to FCFA 36.3 billion in 2011, which amounts to a 484-fold increase in a 10-year period. These figures amount to a little over 0.1 percent of the total budget allocated to agriculture in 2001 and more than 31 percent in 2011 (CRES, 2012). Fertilizers were the main target of these subsidy programs, with more than 30 percent of the total subsidy amounts going to this input, followed by the commercialization of groundnuts (27.8 percent), groundnut seeds (13.7 percent), other seeds (8.3 percent), and machinery and equipment (6.7 percent).

A regional component has recently been introduced into the government's agricultural strategy in order to further align domestic actions with a broader regional framework. As a national translation of the African Union's Comprehensive Africa Agricultural Development Program (CAADP), the Senegalese National Agricultural Investment Program (NAIP) provides the main action plan to develop the agricultural sector in the medium and long run and to improve rural living conditions. This program is the main arm of the National Agricultural Development Program, or Programme National de Developpement Agricole (PNDA).

In practice, fertilizer markets are organized in a way that aims to guarantee greater access and usage by farmers. The government imposes a price at which it purchases various chemical fertilizers from private suppliers and, ultimately, a price paid by farmers, after the 50 percent subsidy. Until 2006, the dominant provider of fertilizers was the "Industries Chimiques du Senegal (ICS)" (Chemical Industries of Senegal). The financial difficulties the company faced in supplying the expanding market led to greater liberalization of the market, with an increasing number of domestic suppliers as well the entry of foreign suppliers. Quota systems are used among suppliers, who first sell fertilizers to farmers at the government's set price and then collect the subsidies from the government.

The system faces various shortcomings, however, chief among them being the opacity that surrounds the distribution of quotas among suppliers, as well as the lack of reliable control mechanisms over the actual quality and quantity of fertilizers sold to farmers (IRG, 2011). In practice, each farmer receives at most three bags of fertilizers, totaling 150 kg to be used on a plot size of one hectare. Farmers decide whether or not to purchase the subsidized fertilizer; given their long farming experience, the information about the program can be assumed to be readily available. However, there is a wide belief that not all farmers are treated equally: larger, market-oriented farms with greater political or economic bargaining power are believed to benefit the most from the program in terms of quantity, quality, and timing compared to smaller, subsistence family farms.

In addition, some farmers have revealed that they paid nothing to obtain their fertilizers. Informal relationships may then have the potential to bring significant amount of heterogeneity among farmers when it comes to the extent to which they benefit from the program, as well as the program's potential impact on farmers' efficiency.

3. Methodology

To assess the effectiveness of government support in raising farmers' productivity, a two-part empirical approach is considered. First, a non-parametric approach is used to compute efficiency scores of farming units. Second, these scores are related to a set of variables, chief among them being whether or not farmers have used subsidized fertilizers.

The concept of efficiency broadly relates to the extent to which the technological process transforms inputs (say, labor, capital, and land) into outputs (agricultural products). An efficiency measure can therefore be viewed as a ratio between outputs and inputs: the greater the ratio, the more efficient the decision-making unit. Consequently, two approaches to efficiency can be considered: maximum outputs for a given level of inputs (output orientation or the minimum use of inputs to reach a given level of outputs (input orientation). In the context of a production technology that exhibits constant returns to scale (i.e., productivity independent of output level), both approaches generate similar measures of efficiency scores. Under the assumption of variable returns to scale, the measures tend to be different, but the choice of orientation is shown to have a minor influence on the efficiency scores, in particular as far as the ordering of the units is concerned (Coelli and Perelman, 1996; 1999).

One of the non-parametric approaches to estimating productivity is known as the data envelopment analysis (DEA), which is very popular in evaluating firms' performance (Cooper et al., 2007). Unlike measurement strategies based on econometric regressions, such an approach makes no prior assumptions regarding the data generating process. Instead, it allows the data to reveal the most appropriate functional form of the technical process that transforms inputs into outputs.

The method starts with a production process that transforms a combination of various agricultural inputs into a given level of output. The procedure is based on linear programming techniques that derive an efficient frontier. Best performing units in the sample are used to draw the efficiency frontier and are assigned a score of unity. For the remaining decision-making units, the assigned scores tell how far from the frontier they are located. The scores therefore vary from zero (a zero output and non-zero inputs) to one (the most efficient farmers located at the frontier).

More formally, let us consider the DEA model of Charnes et al. (1978), which allows for variable returns to scale. The output-orientation efficiency score θ_k for a given decision-making unit (DMU) k in a multiple-output, multiple-input setting is obtained from the following optimization program solved through linear programming:

$$Max \quad \theta_k = \sum_{r=1}^{s} u_r y_{rk} + c_k \qquad (1)$$

subject to the following constraints

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rk} - c_k \geq 0, \qquad j = 1, \ldots, n$$

$$\sum_{i=1}^{m} v_i x_{ik} = 1$$

$u_r, v_i > 0$ *for any r = 1, ..., s; i = 1, ..., m*

where y_{rk} and x_{ik} are the quantity or value of production of good r and of input i for DMU k, u_r and v_i are the weights to be determined for each DMU, c_k is a measure of returns to scale for farming activity k. The first two constraints guarantee that the efficiency score B_k is bound between 0 and 1.

More specifically, we consider a production function in which the output is total production and the inputs are labor, capital, and land. Under various assumptions regarding the nature of returns to scale, a decomposition of "total" (in)efficiency can be made to reveal its various sources (Huguenin, 2013). Under the constant returns to scale assumption, the generated scores provide a measure of "total" efficiency. The assumption of variable returns to scale leads to a measure of "pure" efficiency. This "pure" efficiency is one component of "total" efficiency, and the ratio between these two measures yields the second component, also referred to as "scale" efficiency. This decomposition suggests the two main sources of (total) inefficiency: poor management or organization (pure inefficiency) and inappropriate scale (scale inefficiency). All three measures will be considered, with a particular focus on total efficiency.

Once we obtain the measure of efficiency for each farm, we then consider a parametric model which helps explain its main drivers. Efficiency scores are regressed on various farmers' characteristics, chief among them being a dummy for the use of subsidized fertilizers. A simple regression model is very likely to be plagued by endogeneity and selection bias. More specifically, it is reasonable to assume that the propensity to use subsidized fertilizers may in part respond to the need for efficiency: the prospects of gaining additional efficiency often associated with lower cost and greater use of fertilizers could well be a driver of the likelihood

of using the subsidized input. In addition, some unobservable characteristics may well affect both the probability that a farmer will use subsidized fertilizers and efficiency.

We then consider a variant of switching regression models known as the endogenous binary-variable model, brought into the modern literature by Heckman (1976, 1978). It is also described as a constrained endogenous switching model (Maddala, 1983), in which the self-selection bias of a simple OLS is non-zero (Barnow et al., 1981). The approach consists of viewing the use of subsidized fertilizer as a treatment variable, the outcome variable being efficiency. This endogenous treatment-regression model is therefore a potential-outcome model in which there is a specific correlation between the unobservable factors that affect the treatment and those that affect the potential outcomes. More specifically, a linear model is developed for the outcome variable and a constrained normal distribution is used to model the deviation from the conditional independence assumption imposed by the estimators (see Maddala, 1983 for a description of the version of the model used in this paper).

The structure of the model is made up of two parts. First is the selection process that sorts farmers into two regimes: those who benefit from the subsidy program and those who do not.

$$S_k = \begin{cases} 1 \; if \; S_k^* = Z_k\gamma + \mu_k > 0 \\ 0 \; if \; S_k^* = Z_k\gamma + \mu_k \leq 0 \end{cases} \qquad (2)$$

The observed regime choice S_k for farmer k (1 if users of subsidized fertilizers, 0 otherwise) is governed by a latent process S_k^* that depends on instrumental variables (Z_k)[2]. The quality of the latter relies on their effectiveness in explaining regime choice, while being no predictor of efficiency. Traditional instruments used in the literature include the distance between the farm and the fertilizer selling points, or social capital proxied by how long the farmer has lived in the community. Unfortunately, such statistical information was not collected during the survey. Instead, we consider two alternatives: farmers' political preferences and the share of subsidy beneficiaries in the community. We consider the first factor because it is very likely that farmers with greater connection with the incumbent political party are more likely to benefit from special treatment in the allocation of the program; thus, we also consider voting in the last presidential elections (2012). The second factor is a straightforward measure of the likelihood that any given farmer who resides in a specific location benefits from the subsidy. The higher the measure, the more likely a farmer in the location is found to be among the beneficiaries.

The second part of the model is an equation for the outcome variable (efficiency scores):[3]

[2] We opt for a very parsimonious model specification by considering only instrumental variables as explanatory variables. The main reason for this has to do with convergence, which becomes an issue in higher dimension.

[3] An alternative, augmented version of the switching regression model is also considered, which assumes that both unobservable and observable factors contribute to explaining heterogeneity across farmers. More specifically, the efficiency model is regressed

$$E_k = X_k\beta + \delta S_k + \varepsilon_k \quad (3)$$

where E_k is the efficiency score of farmer k, X_k are the covariates used to model efficiency of farmers, S_k is the dummy for subsidized fertilizer use, β and δ are parameters to be estimated, and ε_k, along with μk, are bivariate normal random errors with zero mean and a variance-covariance matrix as follows:

$$\Omega = \begin{bmatrix} \sigma & \rho\sigma \\ \rho\sigma & 1 \end{bmatrix}$$

The statistic ρ is the correlation coefficient between the outcome errors (ε_k) and the treatment errors (μ_k). It is an indication of the extent to which the unobservables that raise or lower farmers' efficiency tend to occur with the unobservables that drive the likelihood of benefitting from the subsidy. A formal test of the significance of the coefficient will tell about the extent of the endogeneity and selection bias and, subsequently, the appropriateness of the modelling strategy.

In addition to the subsidy dummy set of explanatory variables to be considered in the efficiency equation includes whether the farmer was affiliated with a farmers' organization (1 if yes, 0 otherwise), land size (in hectares), land tenure (1 if the farmer owns the land, 0 otherwise), a dummy for crops (1 for rice, 0 otherwise), number of cultivated crops, experience in farming activity (years), and a dummy for the Diama village, which turned out to be more populous and located relatively far from the other two villages included in the sample. Any significant spatial differences (access to the river for instance) would be captured by the coefficient of this dummy variable.

4. Data

The data used for these various analyses were collected in 2013 from 183 farmers in the agro- ecological region of the Senegal River valley. The information collected relates to the general characteristics of farmers and their activity, input usage, output, and investment and finance. The tables in the Annex provide detailed summary statistics.

4.1 General Characteristics

Farmers were scattered over three main rural communities: Diama (62.3 percent), Gandom (19.6 percent), and Ronkh (19.1 percent). In most cases (88.5 percent), the owner of the land was also the one who cultivated it. For the average farmer, the activity on the current land has been going on for nearly three decades; this was a decade shorter than the length of farming experience. Some 53.3 percent of farmers had some form of formal

separately for subsidy beneficiaries and non-beneficiaries, with the assumption that the technologies they use may be a key driver of their choice of fertilizer use. However, the results, shown in the Appendix, do not support such specification of the model.

education, but the vast majority of them did not go very far: some 48.9 percent of the total sample have reached primary or secondary levels.

A large majority of farmers (85.3 percent) were affiliated with farmers' organizations. They contributed annually an average of FCFA 104,138 and received in return a variety of benefits ranging from some form of help such as community assistance during harvests (22.4 percent), subsidies (27.9 percent), advantages in kind (9.3 percent), purchase and marketing support (7.7 percent), and insurance services (7.7 percent).

More than 62 percent of farmers cultivated at least two distinct pieces of land. The land size ranged from less than a hectare (ha) to 70 ha, with an average size of 2.5 ha, suggesting a relatively large number of smallholders. The most frequent forms of land acquisition were attribution by the rural community (40 percent) and heritage (30 percent). Most of the cultivated land (71.7 percent) was located on areas already designated for agricultural activity and with adequate public infrastructure such as roads. The farming activity was somewhat diversified, with only 31.7 percent of farmers cultivating just one crop. Rice was by far the most popular crop, occupying more than 58 percent of all land. Onions came next with 28 percent, followed by tomatoes with less than 10 percent. All farms used some form of irrigation, and about two-thirds were less than 80 km from the Senegal River.

As a further indication of the low-scale farming activity in the area, the labor force consisted of no more than five workers in more than 90 percent of the surveyed farms. The corresponding total salary averaged FCFA 210,253. The total cost of labor, however, went beyond salaries, for 88.8 percent of farmers were also paid in kind (namely, some part of the harvest). Because most of the farms used irrigation, total water usage for the average farm was 3886.8 cubic meters (or 19.4 per acre), which amounted to a total cost of FCFA 105,112.

Machinery and equipment used combined both traditional methods (use of animals, particularly horses) and modern equipment (such as irrigation equipment and tractors). The end-period market value of the total capital stock was estimated at FCFA 3.4 million on average. This relatively low capital accumulation might be due to the small scale of the activity, as well as to some difficulties in accessing credit markets. The range of borrowing opportunities was quite narrow. More than two- thirds (67.7 percent) of farmers self-financed their own investment through non-distributed profits. Access to banks and microfinance institutions was very limited: 7.7 percent for the former, 14.8 percent for the latter. Alternative sources of financing included commercial loans from input providers or clients (5.5 percent), as well as relatives and friends (2.7 percent).

Total production averaged 7.3 tons, and it concerned on average 78.0 percent of the actual land. With a corresponding 1.6 ha of land use, the yield amounted to 4.6 tons per ha. Most of the production was sold; only one-fifth of the total harvest did not go to market. Most likely, the unsold portion was either used for the subsistence of farmers and their workers or damaged due to a lack of appropriate storage facilities. About one-

third of farmers did not have access to a storage facility, either individually or collectively. For those who did, more than 55 percent owed storage facilities for themselves and 45 percent used collectively owned facilities. The main destination of harvested crops was the domestic market; only 7.1 percent was exported. A large majority of farmers (61.9 percent) who sold in the domestic markets did so indirectly, using a vast network of intermediaries; this indicates that they did not capture the full market value of their products. In addition, the vast majority of farmers sold product unprocessed. Only 20.6 percent of farmers possessed processing facilities, further suggesting that a significant portion of the value chain was still out of the farmers' hands.

4.2 Fertilizer Subsidy and Demand

Table 1 shows the extent of the government's effort to subsidize fertilizers. Of the 179 farmers surveyed who used fertilizers, more than half have benefitted from the subsidy programs. It is most likely that those who did not receive subsidies were using traditional fertilizers, like composting or manure. Furthermore, there is some heterogeneity in the extent of the subsidy benefits. As a share of fertilizer price, the coverage rate ranged from 5 to 100 percent. Officially, the subsidy rate is 50 percent. The fact that the actual rate may be different from the official rate could be indicative of a lack of government control over the allocation of the subsidized input and the prevalence of informal mechanisms. In addition, farmers who fully benefitted from the subsidy were using only the type of fertilizers that were subsidized. Those receiving a smaller benefit might be using either some types of fertilizers that were not supported by the public program or some combination of fertilizers that fell into these two categories.

Table 1: Extent of government subsidy on fertilizers

	Count	Mean	Min	Max
Subsidy beneficiaries	183	0.5	0	1
Subsidy on price (FCFA)	92	117.6	10	500
Price (FCFA)	179	245.4	26	500
Subsidy: share of price (%)	92	82.1	5	100

Source: Author's calculations, from farm-level survey data.

On average, farmers use 25.9 kg of fertilizer per hectare, and the data indicate a significant amount of heterogeneity in demand. The subsidy program seems to be associated positively with fertilizer use. In effect, farmers who benefit from the program use on average 28.4 kg/ha, compared to 23.3 kg/ha for non-beneficiaries, suggesting that the reduction in price as a result of the subsidy tends to encourage farmers to purchase more fertilizer. Second, land size seems to matter when it comes to fertilizer use: farmers with a plot size above the 2.5 hectare average use on average 16.6 kg/ha, compared to 28.3 kg/ha for their smaller counterparts. This negative correlation is consistent with the "peasant mode production" hypothesis which

indicates that small farmers tend to use more inputs per hectare that their large counterparts (Carter, 1984). Large farms are nevertheless more likely to use subsidized fertilizers (58.8 compared to 48.5 percent), which could indicate some underlying political and economic process in terms of bargaining power when it comes to accessing fertilizers (quantity, quality, and timing), or some efficiency in the use of the input.

5. Empirical Results

Table 2 provides the results for the non-parametric measurement of (in)efficiency, the sources of inefficiency, and the various sources of heterogeneity in the distribution across farmers. First, the relatively low average of "total" efficiency (27.1 percent) is suggestive of some concentration of farmers at the lower end of the distribution scale, or a relatively small share of "frontier" farmers, indicating a log-normal distribution of the scores (this is shown in Figure 3 in the Annex). One interpretation would be that farmers are generally very inefficient, with the assumption of some homogeneity. However, the statistical analysis points to various sources of heterogeneity, and this is consistent with what appears to be a "three-mode" shape of the distribution in Figure 3. Therefore, it is more likely that farmers may somehow be technically efficient, but the technologies they are using are just different, depending, for instance, on the crops cultivated or the specific constraints the farmer faces (for instance, in the credit market).[4]

The descriptive statistics also point to the main characteristics of the most efficient farms (the envelope) as opposed to their least efficient counterparts. First, the most efficient farmers are more likely to benefit from the subsidy program. Second, they are relatively large, with plot size above the 2.5 ha average. Third, they tend to be located in Gandon and Ronkh, as opposed to Diama. Fourth, they are more likely to be affiliated with unions. Finally, they appear to be less constrained when it comes to access to credit.

The results also indicate that inefficiencies have more to do with the management of the organization of the farming activity rather than the scale at which farmers are operating (relatively high "scale" efficiency and low "pure" efficiency). This indicates a channel that could be explored to reduce inefficiency. In addition, Figures 1 and 2 in the Annex provide a further decomposition that shows how each of the input factors contributes to efficiency.[5]

When labor is measured as the number of workers, capital appears to matter most, as most efficient farms tend to be relatively more capital intensive (as shown in Figure 1). For a level of capital accumulation greater than the minimum (around FCFA 6 million), additional workers would end up hurting efficiency, while additional

[4] An alternative approach that would account for the heterogeneity in the technology would consist of computing efficiency score within different sub-samples. But the small size of the latter does not allow any meaningful analysis, and structural inefficiencies that are sector-specific may not be accounted for.

5 Only labor and capital are considered, for the sake of graphical representation and because they constitute factors that can be easily adjusted.

capital would not. However, total salaries (which account for both the number of workers and the unit salaries), then the labor factor tends to play a greater role than physical capital (as depicted in Figure 2). To the extent that the salary reflects the marginal contribution of a worker, on one hand, and that more skilled workers have greater contribution, on the other, skilled labor matters more than the simple headcount. In addition to the organization of the farming activity, farmers' efficiency could be improved through an improvement in workers' skills, as well as through greater investment in physical capital: the winning combination is both higher skill and more capital.

Table 2: Efficiency score distribution (in percent)

		Total	**Pure**	**Scale**
All farmers		27.1	32.4	82.7
Fertilizer subsidy	Beneficiaries	29.0	33.1	84.9
	Non-beneficiaries	25.1	31.7	80.5
Farm size (land used)***	Above-average	36.0	45.9	76.9
	Below-average	24.3	28.2	84.5
Commodities	Rice	28.4	33.6	82.4
	Others	23.5	29.2	83.4
Villages	Diama	25.0	30.5	80.6
	Gandon**	17.0	22.6	79.0
	Ronkh***	43.6	48.1	93.2
Experience	Above-average	25.3	35.6	82.9
	Below-average	28.9	31.7	82.7
Ownership	Owners	28.9	32.3	82.8
	Non-owners	28.5	33.1	81.6
Union affiliation***	Members	29.3	34.3	84.0
	Non-members	12.9	20.4	74.3
Storage facilities	Owners	27.8	33.2	81.8
	Non-owners	24.3	29.2	86.4
Processing units	Owners	27.8	33.8	81.4
	Non-owners	26.8	31.9	83.2
Access to credit***	Yes	32.8	39.4	81.5
	No	20.0	23.8	84.2
Output marketing	Direct sales	26.6	30.7	84.4
	Indirect sales	27.4	33.8	81.4

Notes: "Total" refers to efficiency under the assumption of constant returns to scale, "pure" assumes variable returns to scale, while scale efficiency is a ratio between these two. The last two offer a decomposition into two main sources of (in)efficiency, namely management/organization and scale.

***, **, * are indications of significance (1, 5, and 10 percent) of a simple t-test of comparison between means.

Table 3 shows the estimation results of both a simple linear model and the endogenous treatment- variable model. The Wald test fails to reject the null hypothesis for independence between the error term in the outcome errors and treatment errors. The strong significance of the corresponding statistic is an indication of the appropriateness of the model that treats the subsidy program as an endogenous process in which farmers self-select. This result is further reinforced by the significance of the correlation coefficient ρ (as well as the

coefficients σ and λ). The negative coefficient estimate suggests that unobservables that raise efficiency tend to occur with unobservables that lower the likelihood of subsidized fertilizer use. In addition, voting preferences and the share of subsidy beneficiaries in farmers' location are good predictors of the likelihood that farmers will use subsidized fertilizers.

Table 3: Estimation results

Efficiency score equation	**(I)**	**(II)**
Land size	0.0305***	0.0173
	(0.01)	(0.01)
Length of exploitation	0.0001	0.0153***
	(0.01)	(0.01)
Owner exploitant	-0.0167	-0.4229**
	(0.23)	(0.20)
Farmers' organization	0.7864***	0.6665***
	(0.29)	(0.26)
Rice	0.0126	-0.0041
	(0.19)	(0.17)
Number of crops	-0.0642	-0.0416
	(0.06)	(0.05)
Diama village	-0.0299	-0.0676
	(0.15)	(0.13)
Subsidized fertilizer use	-0.1104	1.5451***
	(0.15)	(0.28)
Intercept	-2.0544***	-2.6970***
	(0.35)	(0.38)
Subsidy use equation		
Voting		0.3360**
		(0.15)
Share subsidy beneficiaries		5.8919***
		(1.65)
Intercept		-3.1903***
		(0.86)
N	179	162
F	3.27***	
R2	0.13	
Wald chi2 (joint significance)		73.5***
Log likelihood		-312.0
Rho (ρ)		-0.88***1.19***
Sigma (σ) Lambda ($\lambda = \rho\sigma$)		-1.05***
Wald chi2 (independence)		36.66***

Notes: The dependent variable is the logarithm of "pure" efficiency scores. Column (I) shows the results for a simple linear model, ignoring the potential selection and endogeneity biases associated with subsidized fertilizer use variable. Column (II) shows the results of the endogenous treatment-variable model.

Robust standard errors are in parentheses, and significance at 1, 5, and 10 percent is indicated by ***, **, and *.

The results suggest that the subsidy program has indeed contributed to an improvement in farmers' efficiency. The average treatment effect, which is also the average treatment on the treated, is positive, statistically significant, and quite substantial. This tends to validate the argument that lower input prices, as a result of the subsidy, provide incentives for farmers to use more of the inputs, which in turn translates into increased output. To the extent that output rises more than inputs, output-oriented efficiency would also rise.

The data indicate that the unit price of subsidized fertilizers was on average FCFA 195.6, compared to FCFA 296.9 for fertilizers with no subsidization. In addition, farmers who benefitted from the subsidy tended to use larger quantities of fertilizer; this increased fertilizer use is associated with increased efficiency, all else equal.

Results also suggest that subsidizing inputs reduces the extent of financial constraint on farmers, pushing the budget constraint outward. As a result of income and substitution effects, farmers tend to shift to technology that uses relatively more of the subsidized inputs. Such a reshuffling naturally responds to the need for greater efficiency. Therefore, the final outcome is an increase in overall productivity.

This result appears to be in line with most of the literature, although at the upper end of the various estimates of the magnitude. For instance, Ricker-Gilbert and Jayne (2010) find that in the case of maize production in Malawi, a fertilizer subsidy is positively associated with increased production, with an important dynamic effect: the gain is significant within the same year, and there are some indications of positive effects in subsequent seasons. World Bank (2010) also finds a positive effect of fertilizer subsidy on maize production in Zambia, which corresponds to 89 percent growth in output as a result of the program, mostly due to higher yield (a 50 percent increase). Even in the case of a general decline in agricultural output as a result of major shocks, fertilizer subsidies could maintain the level of input use and reduce the scope of the decline. Yawson et al. (2010) report that the fertilizer subsidy program implemented in Ghana 2008 may have reduced the decline in food output in 2008-2009 by as much as 20 percent.

The results in Table 3 also suggest additional explanations for farmers' efficiency. Farmers with greater experience exhibit greater efficiency than those with less time spent in farming. This points to greater returns to some learning by farming and is consistent with the contribution of skills as shown in Figures 2 and 3. In addition, ownership tends to matter: farmers cultivating land that does not belong to them are more likely to be more efficient than their counterparts who operate their own land. This is surprising, given the common assumption that property rights, with the added security that goes with them, offer stronger incentives in the form of more investment and longer-term vision, all of which being more prone to greater efficiency. The result could be an indication that even with no direct ownership of the cultivated land, existing contractual arrangements between the farmer and the actual owner provide equal security for the former to operate in a relatively risk-free environment.

Furthermore, farmers who are affiliated with organizations are more efficient than those who are not. This stems from the many benefits that organizations provide to their members, such as various forms of subsidies, group purchase and marketing support, and insurance services. All of these benefits are provide incentives for increased efficiency.

On the other hand, land size does not seem to matter in terms of efficiency. Although the sign indicates a positive association between size and efficiency, the result is not statistically significant. There is a large literature on a hypothesized inverse relationship between plot size and productivity, and the empirical results have been mixed and inconclusive. Recent evidence seems to indicate that the use of productivity-enhancing inputs such as inorganic fertilizers, pesticides, and insecticides, as well as the intensity of input use, tend to increase with landholding size (see, for instance, Nkonde et al., 2015). However, farmers surveyed in this study tend to be of small size and with relatively little variation. In effect, 80 percent of plots are less than 3 hectares, and only 4 percent are more than 10 hectares. In such a context, one may not expect the size returns to fully materialize, hence the result of non-significant association between size and productivity.

Furthermore, there seems to be no efficiency difference across the four villages that make up the survey. They are all located in a relatively homogenous agro-ecological area of the Senegal River Valley and hence tend to benefit equally from the same infrastructure and natural endowments.

6. Conclusion

In order to increase farmers' productivity and improve food sufficiency, the Senegalese government has been consistently using subsidy programs, with fertilizer being a prime target. This paper has been concerned with measuring the extent to which the fertilizer subsidy program has succeeded in raising farmers' efficiency. The results, based on survey data on farmers in the Senegal Valley River, provide some evidence that the subsidy program does in fact work and has contributed to an increase in farmers' efficiency. These results add to the existing empirical evidence across the continent that shows that fertilizer subsidies are a good approach to increasing agricultural productivity. Although the results should be interpreted with great care and precaution, mainly because of the complexity of agricultural production and its heterogeneous and random nature, it is reasonable to believe that these are meaningful results, with some degree of acceptable accuracy. In particular, the results could provide some empirical ground for the collective political will of African governments to unlock the agricultural economic and social potentials through subsidizing fertilizers.

Various analyses suggest that there is ample room to increase the effectiveness of the fertilizer subsidy program in Senegal. The opacity that surrounds the implementation of the program needs to be removed, especially when it comes to quota allocation and distribution to farmers. Quality control should be systematic, and an adequate timing of the delivery of fertilizers should be considered. Liberalization also needs to be

pushed further; the competition among a greater number of providers would lower the price at both ends of the subsidy, as well as reduce the financial burden on public finances.

Because of the complexity of farming decisions in developing countries, the success of such a policy approach could be optimized by putting equal focus on additional sources of efficiency increase. The paper has produced additional results that could offer potential policy directions, such as the correction of markets failures by reinforcing farmers' organizations or providing similar services, such as insurance, input and output marketing services, and loans. Additional policy options could focus on easing access to bank credit, which would help farmers invest in machinery and equipment and reach a minimum capital stock. A focus on farmers' skills, especially when it comes to the organization of the production process, would also help increase efficiency. All of these routes appear to be associated with significant efficiency gains and would greatly contribute to improved food security and sufficiency in Senegal.

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Annexes: Additional descriptive statistics of the survey data and figures, and an alternative specification of the regression model.

Table A1: General characteristics of farmers

Rural community (count)	Gandon	34
	Diama	114
	Ronkh	35
Land ownership (%)	Ownership document	8.2
	Lease	2.7
	Occupation permit	39.3
	Public allocation	14.8
	Other legal documents	9.3
	No legal document	22.9
Affiliation to farmers' organizations (yes: %)		85.3
Benefits from organizations (%)	Subsidy	27.9
	Aid/help	22.4
	Advantage in kind	9.3
	Marketing services	7.7
	Insurance	2.7

Source: Author's calculations, from survey data

Table A2: Farming activity

Cultivated crops (count)	One	33.3
	Two	23.0
	Three	43.7
Main cultivated crop (%)	Rice	65.9
	Onion	22.0
	Tomatoes	5.0
Land size (ha)		2.5
Labor force (count)		3.8
Irrigation (%)		100.0
Fertilizer subsidy beneficiaries (yes: %)		50.3
Market for crop (%)	Domestic: direct	39.4
	Domestic: indirect	55.6
	Foreign	5.0
Infrastructure/ownership (%)	Storage: private	42.9
	Storage: collective	40.0
	Processing units: private	3.0
	Processing units: collective	28.3

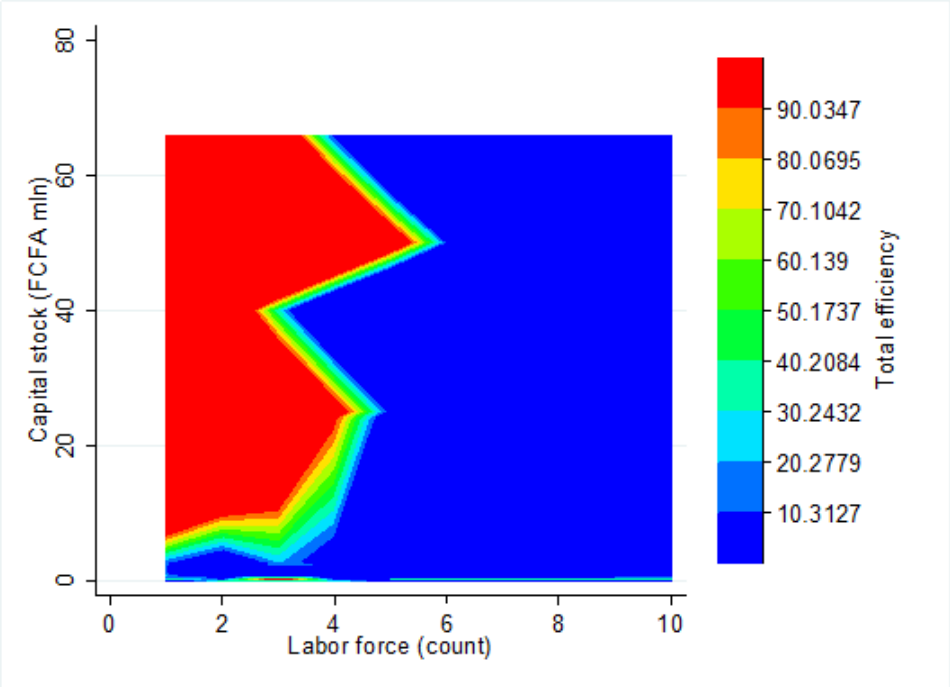
Source: Author's calculations, from survey data.

Table A3: Sources of financing

Investment financing (%)	Self/non distributed profit	67.8
	Banks	14.8
	Microfinance institutions	7.7
	Commercial credit	5.5
	Organizations/relatives	2.7
	Public institutions	1.6

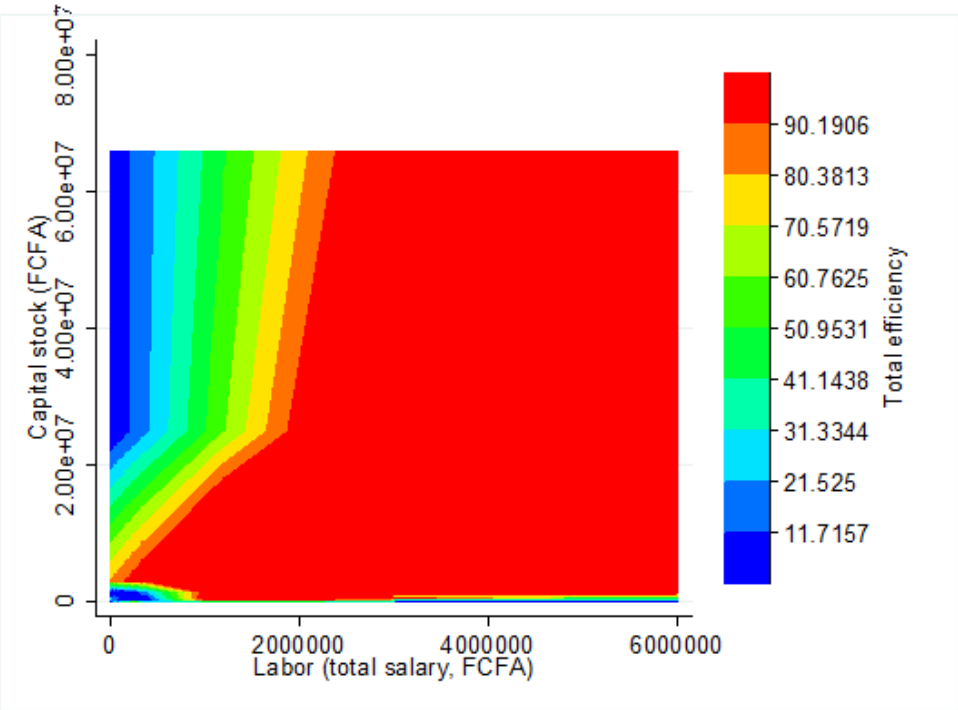
Source: Author's calculations, from survey data.

Figure 1: Relative contribution of physical capital and labor (headcount) to efficiency



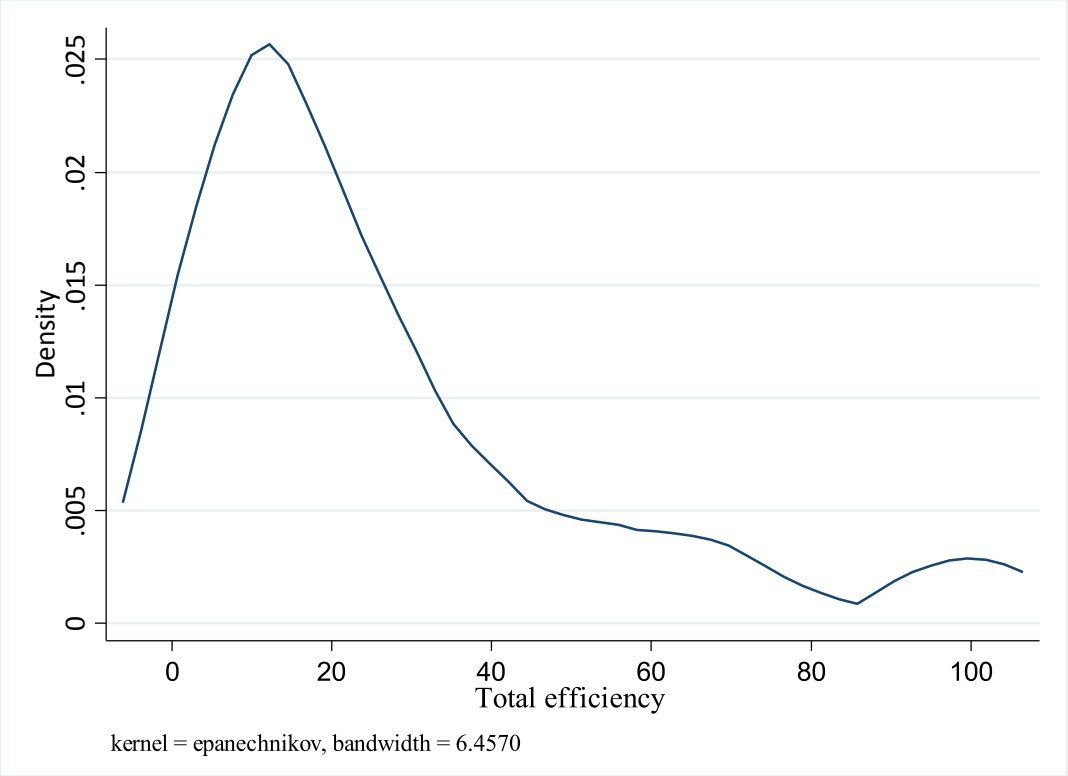
Source: Author, from survey data.

Figure 2: Relative contribution of physical capital and labor (total salary) to efficiency



Source: Author, from survey data.

Figure 3: Density estimate of (total) efficiency scores



Source: Author, from survey data.

Table A4 shows the results for a simple ESR model, which assumes that heterogeneity across farmers go beyond unobservable characteristics (correlation in the errors terms between the regime selection model and, separately, the efficiency model of beneficiaries and non-beneficiaries) to encompass observed factors, namely the explanatory variables in the model. The insignificance of both the Wald test of independence between the generating process of observed allocation outcome and efficiency and the correlation coefficients between the error terms of regime selection and efficiency equations (the rho's) suggests that this augmented version of switching model is not appropriate to capture the two main characteristics of the data generating processes (endogeneity and self-selectivity), and that accounting for unobservables seems to be sufficient to account for significant part of heterogeneity.

Table A4: Simple endogenous switching regression estimation results

	Regime selection	Efficiency scores	
	Subsidy	**Beneficiaries**	**Non-beneficiaries**
Farm size	-0.1197	0.4244	0.2198
	(0.30)	(0.31)	(0.29)
Diama	-0.0382	-0.9130***	-0.7419***
	(0.39)	(0.21)	(0.27)
Gandon	0.0163	-1.5642***	-0.7905**
	(0.47)	(0.41)	(0.38)
Experience	0.0028	0.0427	0.0031
	(0.06)	(0.21)	(0.30)
Rice	0.3560	-0.2641	-0.1091
	(0.30)	(0.55)	(0.30)
Ownership	0.3267	-0.2419	-0.3236
	(0.49)	(0.81)	(0.25)
Union affiliation	0.4116	1.4460	0.0654
	(0.38)	(0.90)	(0.33)
Storage facilities	-0.0523	-0.1614	-0.3874
	(0.28)	(0.28)	(0.25)
Processing units	0.9221***	-0.5225	0.0623
	(0.32)	(0.96)	(0.49)
Access to finance	0.2921	0.1591	0.3555
	(0.23)	(0.40)	(0.28)
Direct sale	0.3507	0.4510	-0.1171
	(0.23)	(0.36)	(0.20)
Vote	0.5345		
	(0.53)		
Intercept	-1.7552**	-1.4409	-1.1128**
	(0.78)	(3.97)	(0.46)
N		161	
Wald chi2		62.3***	
rho1		-0.54	
rho2		-0.68	
Wald chi2 (independence)		0.41	

Notes: The dependent variable is whether farmers are using subsidized fertilizers or not in the regime selection model, and the log of efficiency score in the regression model for each group. Robust standard errors are in parentheses, and significance levels at 1, 5, and 10 percent are indicated by ***, **, and *.

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