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Invited paper presented at the 5th International Conference of the African Association of Agricultural Economists, September 23-26, 2016, Addis Ababa, Ethiopia

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Fertilizer subsidy and agricultural productivity in Senegal

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Abstract

In a consistent effort to raise productivity and unlock the unrivaled economic and social potentials of the agricultural sector, the Senegalese government, as many of its African counterparts, has designed and implemented heavy subsidy programs, some of which targeting the use of inputs. This paper assesses the potential impact of fertilizer subsidy on farmers' productivity. Using a farm-level survey data from the Senegal River Valley, the paper develops a two-part methodology: first the data envelopment analysis is used to generate efficiency scores, and then the latter is 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 programs seem to be working, as they appear to be associated with increased efficiency. The results also suggest ways to improve the effectiveness of the subsidy program as well as additional policy options to further unlock the agricultural potentials.

JEL Classification Codes: Q12; Q18.
Keywords: Fertilizer subsidy, efficiency, Senegal.

Acknowledgement: This research work was carried out with financial and technical support from the African Growth and Development Policy Modeling Consortium (AGRODEP/IFPRI) under the Innovative Research Grants program. The support is gratefully acknowledged. Usual disclaimer applies.

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1. Introduction

In Senegal, more than half of the labor force contributes to a meager 14.8 percent of gross domestic product (GDP).[2] This is one the main features of the country's agricultural sector in which 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 sector greatly contrasts with its somewhat unrivaled potentials for improving economic and social conditions. In effect, a productive agricultural activity would contribute to resorb the enormous food gaps that mainly originate from low domestic production relative to the ever-increasing domestic demand. In addition, by increasing the domestic components of the food markets and reducing the structural dependence on imports, greater productivity in agriculture would help reduce the vulnerability to foreign shocks, particularly those related to prices. It would also help improve food security by increasing the availability of agricultural products, as well as their affordability, thanks in part to more favorable price dynamics. Furthermore, it would provide increased income and economic opportunities to a large majority of the population that depends directly or indirectly on the sector for their livelihood, particularly in rural areas, thereby reducing poverty and inequality.

Public authorities in Senegal, as well as in many African countries, have well understood these economic and social potentials of the agricultural sector. A consistent policy has been to provide generous subsidies to farmers that would help unlock their productive potentials. 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. Starting in 2004, a renewed interest from the Senegalese government has been translated into significant financial effort towards the sector. This would be echoed two years later by the "Abuja Declaration" by which many African governments committed to significantly reviving input subsidy programs with the aims to significantly increase fertilizer use and agricultural productivity across the continent.

Since then, the amount devoted by the Senegalese government to subsidies has increased to reach 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 that 10-year period. Fertilizers have consistently been the main target of the subsidy programs. In effect, some 30 percent of agricultural subsidy was intended to improve the availability and use of the input through a reduced purchasing price. This figure places fertilizers on top of the targets of the various subsidy programs, which include the sale of groundnuts which price support accounted for 27.8 percent of the overall subsidies, groundnuts seeds for 13.7 percent, and other seeds for 8.3 percent. More recent data also indicate the clear emphasis on fertilizers. During the 2011-2012 agricultural campaign, close to half of the FCFA 30.9 billion subsidy envelope has been directed to this particular input. This follows a general trend across Sub-Saharan Africa 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 subsidy on fertilizers, and on other inputs as well, can improve the use of input and overall agricultural productivity. The resulting change in the relative price of the input would weaken the budget constraint faced by rational farmers, expand the technical space, allow additional investment, and lead to more efficient, once-unreachable, 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 the production technique does not

[2] Ministry of Agriculture of Senegal and World Development Indicators Online.

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 to overcome 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).

But the still low productivity of farmers in Senegal could indicate that the fertilizer subsidy may not have yielded all of these benefits. Some theoretical arguments in the literature support such an outcome. 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 towards crops that respond best to fertilizers and that are not necessary 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 constraints the use of this chemical product 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, price reduction may not lead to increase in the usage, lest an improvement in overall productivity.

An additional argument could be related to the extent to which the economies allowed by price reduction are spent on the agricultural activity. Farmers facing financial constraints to their daily subsistence are very likely to direct any monetary gains brought about by the subsidies to their final consumption instead of acquiring additional acres of land or new technology. This disincentive to invest in the farming activity is known as the "crowding-out" effect, and results in no direct impact, at best, 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 at higher prices the fertilizers they obtain for next-to-zero price. This is particularly the case for farmers that heavily discount the uncertain future agricultural returns. In such a situation, subsidies could lead those farmers to actually reduce the amount of fertilizers and other inputs they use in their agricultural activity, which could possibly lead to a reduction in agricultural output.

Overall, the weight of evidence seems to point to questionable benefits of fertilizer subsidy, both in terms of an increased use and in terms of improved overall productivity. Any study addressing the effectiveness of fertilizer subsidy needs to weight these series of arguments with respect to their relative ability to portray the productivity profile of the farming activity in the country. In the specific context of the Senegalese agricultural sector, what are the farmers' response mechanisms to the incentives brought about by the subsidy programs? Do these mechanisms translate into greater efficiency? Is the main focus of the government on subsidizing fertilizers the most cost-effective policy option when it comes to promoting agricultural productivity?

Providing rigorous answers to these questions would in part reveal the extent to which the subsidy program on fertilizers is effective, if any. In the face of the many constraints faced by African governments, a wise choice of policy tools is warranted to ensure greater effectiveness. Furthermore, shedding light on the performance of the various support policies experimented so far by the agricultural sector would be an important step towards unlocking the great economic and

social potentials of the sector and lead to the structural transformation at the heart of which reside agricultural and rural sectors.

This paper aims at assessing the impact of public support to agriculture on the productivity of farmers. More specifically, it analyses farmers' responses to the incentives associated with the fertilizer subsidy and the extent to which these responses have been translated into any productivity improvement. It also places 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. The data reveal that about half of 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 technical efficiency of the farming units. Then a variant of switching regression models known as an endogenous binary-variable model is developed to relate efficiency scores 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 fertilizer, and views the latter as an endogenous binary-treatment process.

The remainder of the paper is organized as follows. Section 2 offers a brief overview of government support towards agriculture in Senegal as well as the 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. Fertilizer subsidies in Senegal

Subsidy has remained one of the most favored tools the government has used to support agriculture. In 2004, subsidy on fertilizers would resume, the first time since 1988 (except the 1997-1999 parenthesis). These programs encompassed a large spectrum of agricultural crops, such as groundnuts, millet, sorghum, maize. They also mobilized greater public resources. Apart from fertilizers, other targets of the subsidy include seeds, phytosanitary products, fuel, machinery and equipment, water, and producer prices. The support programs could also take the form of fiscal exoneration on import of agricultural inputs, be it on import tariffs or value added taxes. Furthermore, after the world food crisis of 2007-2008 that hit relatively hard the Senegalese economy, an increase in various subsidies to farmers was part of the government response with the general objective of increasing agricultural output as a way of reducing the country's vulnerability to external shocks.

These vast subsidy programs have come with significant financial efforts. In effect, they went from a meager FCFA 75 million in 2001 to FCFA 36.3 billion in 2011, which amount to a 484-fold increase in this 10-year period. These figures amount to a little over 0.1 percent in 2001 to more than 31 percent in 2011 (CRES, 2012).

The distribution of this subsidy effort reveals that fertilizers were the main target, with more than 30 percent of the total subsidy amounts. Next come the commercialization of groundnuts (27.8 percent), groundnut seeds (13.7 percent), other seeds (8.3 percent), and machinery and equipment (6.7 percent).

Lately, a regional component has been introduced at the core of the government strategies towards agricultural and rural development and food security, with the aim to further align domestic actions to a broader regional framework. In effect, as a national translation of the African Union's Comprehensive Africa Agricultural Development Program (CAADP), the Senegalese National Agricultural Investment Program (NAIP) appears to be the main action plan of the government in terms of how it envisions developing the sector in the medium and long run and improving living conditions of farmers. This program is the main arm of the National Agricultural Development Program or *Programme National de Developpement Agricole* (PNDA).

Throughout these various programs, subsidy continues to be the main component of the Senegalese government involvement into agriculture. In effect, for the 2011/2012 campaign, some FCFA 30.9 billion were necessary to subsidize various agricultural inputs. This financial effort went in part to the groundnuts sub-sector, with 69,000 tons of seeds that amounted to FCFA 10.6 billion. In addition, with the goal of promoting diversification in agricultural production, there was a subsidy of 66 to 87 percent of the price of seeds for crops targeted by the Special Programs (maize, millet, sorghum, rice, cassava, etc.) for some FCFA 3.4 billion. More importantly, subsidy on fertilizers was by far the main support tool. With more than FCFA 15 billion, the government was able to subsidize almost all varieties of fertilizers to the tune of more than 50 percent of their price. Since then, the level of effort has been constant, and it shows the crucial role of fertilizers in the various government subsidy schemes to improve agricultural productivity, thereby contributing to food security and rural development.

In practice, fertilizer markets are organized in a way 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, the 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 it has to supply the expanding market and the ever-increasing public ambitions with respect to fertilizer access and use have led to greater liberalization of the market, with increasing number of domestic suppliers as well an entry of foreign suppliers. Quota systems are used among suppliers, who first sell fertilizers to farmers at a government's set price and then collect the subsidies from the government.

The system appears to be rigged with various shortcomings, chief among them being the opacity that surrounds the distribution of quotas among suppliers as well as the lack of reliable control mechanisms over actual quality and quantity of fertilizers sold to farmers (IRG, 2011). In practice, each farmer receives at most 3 bags of fertilizers, totaling 150 kg of fertilizers to be used on a plot size of one hectare. Farmers decide whether to purchase the subsidized fertilizer or not, and given their long farming experience, the information about the program can be assumed to be readily available. But 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. A telling fact is that some farmers revealed having paid nothing to obtain their bags of fertilizers, or a subsidy price coverage of 100-percent. 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 and the potential impact on 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 farmers have used subsidized fertilizers or not.

The concept of efficiency broadly relates to the extent to which the technological process transforms inputs (say, labor, capital and land) into outputs (agricultural product). 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 exhibit 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) that 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:

$$\boldsymbol{Max\ \theta_k = \sum_{k=1}^{s} u_k y_{rk} + c_k,} \qquad \textbf{(1)}$$

subject to the following constraints:

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

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

$$\boldsymbol{u_r, v_i > 0,\ r = 1, \dots, s; i = 1, \dots, m}$$

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 θ_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 latter is one component of the first, 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 of these three measures will be considered, with a particular focus on total efficiency.

Once we obtain the measure of efficiency for each farm, we develop a parametric model that relates efficiency scores and 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. In effect, the prospects of gaining additional efficiency could well drive farmers to recourse to subsidized inputs. In addition, some unobservable characteristics may affect both the likelihood to use subsidized fertilizers and efficiency.

We 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, say, 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 outcome.

The structure of the model is made up of two parts: the selection equation and the outcome equation. The selection process sorts farmers into two regimes: subsidy benefiters and non-benefiters.

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

The observed regime choice S_k for farmer *k* (1 if he/she is a benefiter, 0 otherwise) is governed by a latent process S_k^* that depends on instrumental variables Z_k.[3] 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 by the survey. Instead, we consider two alternatives:

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

political preferences of farmers and the share of subsidy beneficiaries in the location. It is very likely that farmers with greater connection with the incumbent political party have greater chances to benefit from special treatment in the allocation of the program. We therefore consider voting preferences in the last presidential elections (2012). The second is a straightforward measure of the likelihood that any given farmer that resides in a specific location benefits from the subsidy. The higher the measure, the more likely a randomly selected farmer in the location is found to be among the beneficiaries.

The outcome equation (efficiency scores) is specified as follows:[4]

$$\boldsymbol{\theta_k = X_k\beta + \delta S_k + \varepsilon_k} \qquad \textbf{(3)}$$

where 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 μ_k, are bivariate normal random errors with zero mean and a variance-covariance matrix as follows:

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

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 simultaneously with those that drive the likelihood of benefitting for 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.

The set of explanatory variables to be considered in the efficiency equation includes, in addition to the subsidy dummy, whether the farmer was affiliated to a farmers' organization (1 if yes, 0 otherwise), land size (in hectares), land tenure (1 if the farmer own 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.

4. Data

The data used for these various analyses were collected in 2013. Some 183 farmers were surveyed in the agro-ecological region of the Senegal River valley. The rich set of information relates to the general characteristics of farmers' and their activity, input usage, output, and investment and finance.

4.1. General characteristics

The following statistical profile of farmers that made up the sample can be drawn. They were scattered over three main rural communities: Diama (62.3 percent), Gandom (19.6 percent), and

[4] An alternative, augmented version of the switching regression model is also considered, which assumes that both unobservable and observable factors contribute to explain heterogeneity across farmers. More specifically, the efficiency model is regressed 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. The results, shown in appendix, do not however support such specification of the model.

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, which was a decade short to match the length of his farming experience. Some 53.3 percent of farmers had some form of formal 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.

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 small farm holders. 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, like roads. The farming activity was somewhat diversified, with only 31.7 percent cultivating just one crop. Rice was by far the most popular speculation: it occupied more than 58 percent of all land. All farms used some form of irrigation, and about two-third were less than 80 km from the Senegal River.

As a further indication of the low-scale farming activity, the labor force was no more than 5 workers in more than 90 percent of farm plots. 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 usage of water for the average farm was 3,886.8 cubic meters (or 19.4 per acre), which amounted to a total cost of FCFA 105,112.

Machinery and equipment used in the farming combined both archaic or traditional methods (use of animals – horses) and modern equipment (such as irrigation equipment and tractors). The end-period market value of the total capital stock was estimated to FCFA 3.4 million on average. This relatively low capital accumulation might be associated with the small scale of the activity as well as some difficulties to accessing credit markets. The range of borrowing opportunities was in effect 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 later. Alternative sources of financing included commercial loans from input providers or clients (5.5 percent), and from relatives and friends (2.7 percent).

Total production averaged 7.3 tons, all crops included. 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 was not. The unsold part was most likely either used for subsistence or lost because of a lack of appropriate storage facilities, if any. In effect, about a third of farmers did not own one, individually or collectively.

The main destination of harvested crop was the domestic market, and only a tiny 7.1 percent was exported. A large majority of farmers (61.9 percent) who sold in the domestic markets did so indirectly. They used a vast network of intermediaries, indicating that they did not capture the full market value of their products. In addition, a great number of farmers did sell their product unprocessed, and 20.6 percent did possess 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

Government support in the form of subsidy programs encompasses large aspects of farming activities. Fertilizers represent the prime target. Table 1 shows the extent of the government effort to subsidize the input. Of the 179 farmers who used fertilizers, more than half have benefitted from the subsidy programs. It is most likely that those who did not were using traditional fertilizers, like composting or manure, with no mix with chemical fertilizers that are the focus of the subsidy programs. Furthermore, there is some heterogeneity in the extent of the subsidy benefits. As a share of fertilizers' price, the coverage rate ranged from five to 100 percent. Officially, the subsidy rate is 50 percent. The fact that the actual rate may be different from the official one 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 solely the type of fertilizers that were subsidized. Those receiving a smaller extent might be using either some types of fertilizers that were not supported by the public program or some combinations 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 per hectare, and the data indicate a significant amount of heterogeneity in the demand. First, the subsidy program seems to be associated positively with fertilizer use. In effect, farmers who do benefit from the program uses on average 28.4 kg/ha, against 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 fertilizers. Second, land size seems to matter when it comes to fertilizer use: farmers with a plot size above the 2.5-hectare-average uses on average 16.6 kg/ha, against 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 input per hectare that their large counterparts (Carter, 1984). Large farms are nevertheless more likely to recourse to subsidized fertilizers (58.8 against 48.5 percent), which could indicate some political and economic underlying 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. Estimation results

Table 2 provides the results for the non-parametric measurement of (in)efficiency, its sources, and its distribution across farmers. 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, indicating a log-normal distribution of the scores. This is more clearly shown in Figure 1 in the appendix. The "three-mode" shape of the distribution suggest some heterogeneity among farmers in the sense that many more firms may be technically efficient, but the technologies they are using are just

different, depending for instance on the cultivated crops or the specific constraints they face (for instance in the credit market).[5]

The descriptive statistics also point to the main characteristics of the most efficient farms (the envelope) as opposed to the least efficient counterparts. They are more likely to benefit from the subsidy program. They are relatively large, with plot size above the 2.5-ha-average. They tend to be located in villages such as Gandon and Ronkh, as opposed to Diama. They are more likely to be affiliated to unions. 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 organization of the farming activity than to the scale at which farmers are operating (relatively high "scale" efficiency and low "pure" efficiency). This indicates a direction that could be explored for policies aiming to reduce inefficiency.

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 offers a decomposition into two main sources of (in)efficiency: 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 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

[5] 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.

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 coefficient σ). 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 use subsidized fertilizers.

Table 3: Estimation results

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

Notes: The dependent variable is the logarithm of "pure" efficiency scores. 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 improve farmers' efficiency. In effect, the average treatment effect, which is also the average treatment on the treated, is positive and statistically significant and quite substantial. This tends to validate the argument that

suggests that lower input prices, as a result of subsidy, provide incentives for farmers to use more of the inputs, which in turn would translate into increased output. To the extent that output rises more than inputs, output-oriented efficiency would also rise.

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

An additional rationale of the positive effect of the subsidy program suggests that subsidizing inputs spells reducing the extent of financial constraint on farmers, pushing the budget constraint outward. As a result of income and substitution effects at play, farmers tend to shift to a 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 of growth in output as a result of the program, mostly due to higher yield (50-percent increase). Even in the case of general decline of agricultural output as a result of major shocks, fertilizer subsidy could have a positive effect of maintaining the level of input use and reducing the scope of the decline. Yawson et al. (2010) report that the fall in food output avoided in Ghana could be as much as 20 percent, thanks to the fertilizer subsidy program implemented in 2008, later extended in 2009. These results appear to be key ingredients in the renewed interest in subsidizing fertilizer across the continent.

The results in Table 3 also suggest additional explanations of farmers' efficiency. Farmers with greater experience in the activity exhibit greater efficiency than those with less time in the activity. This is due to the skills and know-how that come with the time spent farming. This points to greater returns to some learning by farming, and is consistent with the contribution of labor skills. In addition, ownership tends to matter: farmers cultivating land that do not belong to them are more likely to make the best out of it, compared to those that operate on land they do own. One might expect the opposite, that is, property rights, with the added security that goes with them, to 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 that are affiliated organizations are more efficient than those who are not. This stems from the many benefits organizations provide to members, such as various forms of subsidy, group purchase and marketing support, and insurance services. All of these benefits are sought to provide incentives to increased efficiency. For instance, insurance can help mitigate various risks associated with farming, such as crop failure. With the guarantee of coverage, insured farmers are more likely to extend the scope of their activity than their uninsured counterparts.

Among the factors that do not seem to matter as far as efficiency is concerned is land size. 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. But recent evidence seems to indicate that the use of productivity enhancing inputs such as inorganic fertilizers, pesticides and insecticides, as well as input intensity 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 endowment.

6. Conclusion

In order to increase farmers' productivity and improve food sufficiency, the Senegalese government has been consistently using subsidy programs, fertilizer being a prime target. The paper was 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. It has contributed to increase the efficiency of farmers. These results add to the existing empirical evidence across the continent that shows that fertilizer subsidy is 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 conditions and its heterogeneous and random nature, it is reasonable to believe that these are meaningful results, with some degree of acceptable accuracy, and they constitute an important step in a continuous research effort towards a better understanding of why farmers do what they do and suggest tools aimed at modifying their choices.

The results suggest 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 needs to be pushed further, and the competition among a greater number of providers would lower the price at both ends of the subsidy as well as reducing the financial burden on public finances.

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Appendix

Figure 1: Density estimate of (total) efficiency scores