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An Empirical Analysis of Expanding Rice Production in Sub-Sahara Africa

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No. 105

April 2015

JICA Research Institute

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On the Determinants of High Productivity Rice Farming in Irrigated Areas in Senegal: The Efficiency of Large Compared with Small-Scale Irrigation Schemes

Takeshi Sakurai*

Abstract

Irrigated rice farming in the Senegal River Valley is known to be highly productive, as indicated by the average yield of nearly 5 tons per hectare, and the extensive adoption of modern seed-fertilizer technology. This study seeks to understand why rice farming is so productive in this region; analyzing this situation from the viewpoint of the management efficiency of large versus small scale irrigation schemes. Contrary to popular belief, the study found that farmers in large-scale irrigation schemes achieve significantly higher yields and profits than those in small-scale irrigation schemes.

Keywords: large-scale irrigation schemes, small-scale irrigation schemes, productivity, rice farming, Senegal river valley

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1. Introduction

Since irrigated lowland farming is generally more productive than any other rice production ecology, the expansion of irrigated land for rice crops offers great potential for the enhancement of rural incomes and food security in Sub-Saharan Africa (SSA) (Balasubramanian *et al*. 2007; Larson *et al.* 2010). However, international agencies and national governments have become reluctant to develop irrigation schemes due to the high investment cost, declining world food prices, and the failure of many irrigation projects previously carried out in the 1970s and 1980s (Kay 2001; Inocencio *et al*. 2007). In this regard, Adams (1992) noted when reviewing the outcomes from large-scale irrigation projects in Sub-Saharan Africa, that: "The poor performance of large-scale irrigation in Africa is now widely acknowledged." Later, Inocentio *et al.* (2005) provided confirming evidence by showing that smaller irrigation schemes in SSA have performed better, as measured by the economic internal rate of return of projects that are controlled for project size. However, since the world food crisis in 2008, economic conditions have changed, and there is now an opportunity for public investment to raise agricultural productivity in SSA (Masters 2011). However, questions about the optimal size of irrigation schemes still remain unanswered.

With respect to rice production, there are several large-scale irrigation schemes in SSA that achieve relatively high yields. For example, Nakano *et al*. (2011) report that the average rice yield was 5.3 tons per hectare in the large-scale irrigation schemes of the Senegal River Valley, and Njeru, Mano, and Otsuka (2014) report that the average rice yield was 5.0 tons per hectare in the Mwea irrigation scheme in Kenya. In their concluding remarks, Nakano *et al*. (2011) wrote: "Although small-scale irrigation development seems to be a current trend in SSA among aid organizations, our analyses show that large-scale irrigation schemes also have high potential under proper management and are equally important." Nevertheless, the authors did not compare the two types of irrigation scheme directly. Such a comparison is difficult because the two types do not usually coexist, and differ not only in size but also in terms of irrigation technologies. But in the case of the Senegal River Valley, both types are located close to each other, and use similar irrigation technologies involving pumping water from the Senegal River.

This paper takes advantage of this rare setting to compare the performances of large and small-scale irrigation schemes, using household data collected in the Senegal River Valley. To the best of our knowledge, this is the first study that investigates the impact of irrigation scheme size on rice production efficiency in the smallholder agricultural sectors of SSA or Asia.[1]

Organization of this paper is as follows. Section 2 explains the basic characteristics of the study sites and the nature of the data collected by this study. Section 3 postulates the testable hypotheses, and is followed by the descriptive analyses found in Section 4, and the regression analyses outlined in Section 5. Finally, conclusions and policy implications are provided in Section 6.

2. Study Site and Data

2.1 Background of the Study Site

The study site is located in the Senegal River Valley. The Senegal River, originating in the highlands of Guinea, forms a 800 km long boundary between Mauritania to the north and Senegal to the south. Irrigated rice schemes in the Senegal River Valley exist on both sides of the river.[2] This study focuses however on the Senegalese side only, where the total area of

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[1] In the case of the Senegal River Valley, the study by Diagne *et al.* (2013), who analyze the determinants of rice production efficiency based on 5 year panel data obtained from about 100 households, may be exceptional. A dummy for large-scale irrigation schemes was used in this study as one of the variables to explain the residual from the translog production function, but had insignificant impact on this residual. But since their focus is not on scheme size, they do not discuss this result at all in their paper.

[2] An example of a Mauritania side study is Comas *et al*. (2012).

irrigated rice is about 103,000 hectares (SAED 2011). SAED[3] divides the Senegalese side of the Valley into 4 delegations: Dagana, Podor, Matam, and Bakel in the order from the mouth of the river. Dagana and Podor were selected for this study since most of the large-scale irrigation schemes are located in these two delegations.

The construction of large-scale irrigation schemes started in 1960 after independence, except for one constructed in 1938 by France, which was later updated to its current full-water control technology during the 1970s (Diallo 1980). SAED constructed all the irrigation schemes presently equipped with irrigation pumps, drainage pumps, and canal networks. SAED was not only in charge of their construction, but also their operation and maintenance. The latter responsibility included farm machinery services for land preparation, harvesting, and threshing, and input supplies in the form of in-kind credit, rice marketing, and extension services. Large-scale irrigation schemes were divided into blocks with feeder canals, and a group of 15 - 20 farmers made responsible for water distribution and feeder canal maintenance within each block.

In response to a series of severe droughts and famines from 1968 to 1974, villagers requested the government to construct irrigation facilities. As a result, the construction of small-scale irrigation schemes was added to the mission of SAED in 1975 (Wester, During, and Oorthuizen 1995). The small-scale irrigation schemes were village-based: a village-level committee for management and operation was established before construction, and the construction was carried out collectively by villagers (Diallo 1980). From 1975, SAED has not only constructed small-scale schemes (including the installation of one irrigation pump at times), but has also provided several services as for large-scale schemes. These have included pump maintenance, and input supplies in the form of in-kind credit, rice marketing, and extension services (Wester, During, and Oorthuizen 1995). Around this core, local farmers

[3] SAED (Société Nationale d'Exploitation des Terres du Delta du Fleuve Sénégal et des Vallées Sénégal et de la Falémé) is a parastatal agency specializing in the development of irrigation schemes in the Senegal River Valley.

formed a group, and were engaged in water distribution and canal maintenance. Since farm machines were not available outside the large-irrigation schemes, land preparation, seeding, harvesting, and threshing were done manually at least in the early period. Therefore, the differences between large-scale and small-scale irrigation schemes in the Senegal Ricer Valley were not only in their average size,[4] but also their technologies and governance structure at the time when they were constructed.

This costly government intervention into both large and small scale irrigation schemes through SAED could not be sustained. During the structural adjustment program requested by donors, a disengagement policy began, starting with the liberalization of input and output prices in 1984, and the withdrawal of SAED in 1987 (Wester, During, and Oorthuizen 1995). As a result, the maintenance of irrigation facilities such as pumps and main canals has become farmers' own responsibility. In the case of large-scale schemes, farmer groups that managed irrigation blocks formed a union to take the maintenance responsibility from SAED, while in the case of small-scale schemes, the responsibility was turned over to existing farmer groups. As for the provision of credit, this was transferred from SAED to the Caisse Nationale de Crédit Agricole du Sénégal (CNCAS), established in 1987 as part of the reforms of public irrigation schemes (Dia 2001).

In response to the liberalization of the agricultural market, private investment in irrigation has increased since the late 1980s in the Senegal River Valley.[5] The total area of such schemes reached 42,600 hectares in 1993, but then declined due to the impact on profitability of increases in input costs caused by the devaluation of the CFA Franc in 1994 (Dia 2001). Stimulated by the food crisis in 2008, and resulting high international prices, private

[4] The average size of large-scale irrigation schemes is 761 hectares, and that of small-scale irrigation schemes is 27 hectares, according to the authors' calculation based on SAED (2011). In the Senegal River Valley, the large-scale irrigation schemes are called GA (Grand Aménagement) or AI (Aménagement Intermédiaire), depending on scheme size. The total area of GAs is above 1000 hectares and that of AIs is less than 1000 hectares. Thus, large-scale irrigation schemes in this paper include both large and medium scales according to SAED's classification. On the other hand, the small-scale irrigation schemes are called PIV (Périmètre Irrigué Villageois), since they are managed by villagers.

[5] Private irrigation schemes are called PIP (Périmètre Irrigué Privé) in the Senegal River Valley.

investment in irrigation schemes has been growing again. In 2008/09, the total area of private irrigation schemes in the Senegal River Valley increased to 51,600 hectares, and the average size per scheme was 22 hectares, according to the authors' calculation based on SAED (2011). Thus, in terms of scheme size, the private irrigation schemes are also categorized as small-scale irrigation schemes. Not only their size but also their use of particular irrigation technologies is similar to that of village-based schemes: both use an irrigation pump to get water from streams (directly from the main stream or from its branches). However, an important difference is that one is owned and managed privately, and the other is owned and managed collectively by villagers. Thus, in the Senegal River Valley, large-scale and small-scale irrigation schemes coexist, and the small-scale irrigation schemes can be further classified into village-based and private ownership.

2.2 Data

Sampling was conducted based on the list of farmers' groups provided by SAED. In the case of small-scale irrigation schemes and private irrigation schemes, each farmer group listed corresponds to an irrigation scheme, since each scheme has only one farmers' group that manages the scheme. As for the large-scale irrigation schemes, the groups listed are not unions of farmer groups responsible for the management of the whole scheme, but those who manage blocks within a large-scale irrigation scheme. The total number of the farmer groups on the SAED list was 3304, and 120 were randomly selected for study. Then, five households were randomly selected from the member lists of each group. Thus, the total number of households surveyed was 600. The farmer group surveys were carried out via a group interview, and the household survey via an interview with the household head. These surveys were conducted during 2012, covering the rainy season of 2011, in collaboration with the Institut Sénégalais de Recherches Agricoles (ISRA).

As shown in Table 1, among the 120 farmers' groups, there are 42 groups belonging to large-scale irrigation schemes and 78 belonging to small-scale irrigation schemes. Of the small-scale ones, 40 groups represent village-based irrigation schemes, and 38 groups represent private irrigation schemes. Most of these groups were established in the early 1990s, and the total area under their individual management averages about 40 hectares. There are no significant differences in area controlled among the three types; however, the number of members and therefore the area per member are significantly different. Private schemes have the smallest number of members and hence the largest land area per member. On the other hand, village-based small-scale schemes have the largest number of members on average and the smallest area per member. As for scheme size, the farmer groups in the large-scale category belong to a large-scale irrigation scheme whose size is about 1200 hectares on average, while small-scale ones by definition do not belong to any large-scale schemes; and the size of the scheme is the same as the total area managed by the group.

3. Assumptions and Hypotheses

3.1 Assumptions

The study adopted two assumptions; one about the type of irrigation scheme, and the other about the use of formal credit:

Assumption 1: While each farmer can make a decision to be engaged in rice production, individual farmers cannot control the construction of an irrigation scheme, and hence a farmer has little choice but to use a rice plot in the irrigation scheme that is the most accessible one. Therefore, a farmer's selection of scheme type among the three - large scale, village-based small scale, and private small scale - is assumed to be exogenous. Please note that the types themselves have been fixed since the time of construction. Even in the case of large-scale irrigation schemes, although the management responsibility has been transferred from public to farmers' groups, their category is always large-scale.[6]

Assumption 2: We expected that credit will play an important role in irrigated rice production in the Senegal River Valley. As mentioned above, CNCAS was established in 1987 as part of a reform of public irrigation schemes, and even now CNCAS is the dominant formal credit institution in the study site although credits from input dealers and rice millers have also become available. One important feature of CNCAS credit is that it adopts a group lending and group liability policy; although each farmer decides the amount to be borrowed and bears the responsibility to pay this back, the contract is made between CNCAS and the farmer group. Thus, if a farmer in the group goes into default, all the farmers in the group become ineligible for further credit until the debt is cleared. This means that eligibility for CNCAS credit is beyond the control of an individual farmer. Thus, this paper assumes that CNCAS eligibility at the group level is exogenous when individual farmers make decisions.

3.2 Hypotheses

Our main hypothesis in this paper is that large-scale irrigation schemes are as equally well managed as small-scale irrigation schemes. This main hypothesis is divided into three testable hypotheses; postulated in accordance with the following considerations.

Regardless of the type of irrigation scheme, water sources and irrigation methods are the same: water is pumped from the Senegal River or its branches. Since there is always enough water, there is no problem of water supply, as long as the pumps work well and canals are well maintained. Water users must pay the maintenance costs as well as the running costs at the beginning of the cropping season, but since operating credit is not available to cover such costs,

[6] In management terms, this is a case of irrigation management transfer (IMT), as documented by Garces-Restrepo, Vermillion, and Muñoz (2007). Our study, however, is not concerned with such transfers since they had been completed by the time of survey, and all the irrigation schemes are managed by farmers regardless of scheme size.

it is difficult for a farmers' group to collect sufficient funds for ongoing maintenance. In contrast, CNCAS credit does cover the payment of irrigation fees, so that farmer groups eligible for CNCAS credit can maintain irrigation facilities more easily than non-eligible groups. As will be shown, the probability of being eligible for CNCAS is higher amongst farmer groups in large-scale irrigation schemes than in small-scale irrigation schemes. Thus, Hypothesis 1 may be stated as:

Hypothesis 1: Irrigation performance is better in large-scale irrigation schemes than in small-scale irrigation schemes.

The use of chemical fertilizers is quite high in both large-scale and small-scale irrigation schemes (Nakano *et al*. 2011; Diagne *et al*. 2013). This was confirmed even for private irrigation schemes during the preliminary interviews at our study site. Farmers told us that rice cannot be harvested without using a sufficient amount of chemical fertilizer, and that even though credit is not available (i.e. ineligibility for CNCAS), much fertilizer will be used. In addition, since credit for chemical fertilizer is available from other sources outside CNCAS, differences in the application rates of chemical fertilizer will be small. Hence, our second hypothesis is:

Hypothesis 2: The application rate of chemical fertilizer in small-scale irrigation schemes is no different to that in large-scale irrigation schemes.

If Hypotheses 1 and 2 are supported, rice yield and rice profit is higher in large-scale irrigation schemes than in small-scale irrigation schemes, because irrigation facilities are better maintained in the former even if the use of inputs is not much different between them. In other words, if we control for irrigation performance, rice yield and rice profit do not differ significantly between large-scale irrigation schemes and small-scale irrigation schemes. Therefore, Hypothesis 3 can be derived as follows:

Hypothesis 3: Rice yield and rice profit do not differ significantly between large-scale irrigation schemes and small-scale irrigation schemes.

4. Data Description

4.1 Irrigation Performance

At the study site, rice can be grown three times a year, but is usually grown twice a year (once in the rainy season and once in the dry season), or only once in a year (mainly in the rainy season, but sometimes in the dry season). Since this study uses data on household rice production obtained during the rainy season of 2011, we will focus only on rainy season rice production. Table 2 relates production to the proportion of land actually irrigated, and to irrigation pump and canal management, in 2009, 2010, and 2011. Every rainy season, regardless of scheme type, a significant number of farmer groups (from 20 to 30% of the total) did not grow rice, or grew nothing at all. This may be due to the break-down of pumps or a lack of funds for land preparation. The frequency of "no rice" did not however significantly differ between the three types of scheme. On the other hand, the proportion of irrigated area was significantly higher in large-scale schemes than in small-scale schemes. Since the area irrigated is an indicator of irrigation performance, this result means that large-scale schemes perform better than small-scale ones.

Irrigation performance should be largely determined by the maintenance of pumps and canals. As shown in Table 2, total expenditure for pump repair during the past three years was significantly lower in large-scale schemes than in small-scale schemes. High repair costs can be taken to imply that pump condition is not so good. As for canal maintenance, because canal length per group is very similar, and both large and small schemes depend on members' participation in canal cleaning (there is a penalty for non-performance), the maintenance levels of each scheme will not be very different. However, overall irrigation performance is better in large-scale schemes than in small-scale schemes, thus Hypothesis 1 is supported.

4.2 Eligibility for CNCAS Credit

Table 3 shows that the number of farmer groups that are eligible for CNCAS credit is much higher in large-scale schemes than in small-scale schemes. In addition, the ineligible period is significantly longer in the case of small-scale schemes than for large-scale schemes, implying that the latter tend to clear debts more quickly. In other words, farmers in small-scale irrigation schemes do not depend on CNCAS but must use other sources of credit, as will be shown in the next section.

4.3 Rice Production Technologies in the Rainy Season of 2011

Rice production technologies at the farmer group level are summarized in Tables 4 to 7. Of the 120 sample farmer groups, 87 grew rice in the rainy season of 2011. As shown in Table 4, average rice planted area per group does not significantly differ between large-scale and small-scale schemes, although it is relatively smaller in private schemes. However, large-scale schemes are more likely to adopt labor-saving technologies: using tractors for land preparation, conducting direct seeding, and spraying chemicals for weed control after seeding. On the other hand, the study found no difference in the adoption rate of manual leveling and modern varieties. It thus seems clear that credit from CNCAS makes it easy to pay cash for hiring tractors. As for the adoption of modern varieties of rice, since almost all farmers use them, there is no difference between the schemes. Both the varieties shown in Table 4 (i.e. Sahel108 and Sahel134) were originally selected by IRRI and developed for the irrigation conditions in the Sahel by the Africa Rice Center, according to their variety description notes.

Table 5 shows the use of chemical fertilizer and the methods of weeding after emergence. In spite of the significant difference in eligibility for CNCAS credit, the use of fertilizer and herbicide does not differ significantly. This implies that farmers have other sources of credit to purchase fertilizer, which supports Hypothesis 2. Table 6 concerns harvesting and threshing methods, and shows that combine harvesters are becoming popular in the study site. But in 2011 when the production survey was conducted, their adoption rate was low, and not significantly different between large and small schemes. As for threshing, although mechanical threshers are widely used, small-scale schemes tend to do it manually more often than large-scale schemes.

According to farmers, costs for harvesting and threshing do not differ between machine and hand, as common piece rates are applied: 10% of the harvest for harvesting, and 10% of the harvest for threshing (in the case of combine harvesters, 20% of the harvest). Since payment for crops is made after harvesting/threshing regardless of the method used, this choice does not seem to be related to the use of credit. But machines save time, and their use is important for farmers who have to pay back credit and borrow again to grow rice in the coming dry season. In sum, farmers in large-scale irrigation schemes tend to use more labor-saving technologies for land preparation and harvesting/threshing, but the use of chemical fertilizer and herbicide does not differ between the two scales. CNCAS credit seems to be related to machine use, either directly in the case of land preparation or indirectly in the case of harvesting/threshing.

Table 7 gives the data on irrigation facility maintenance for the rainy season of 2011. Canal maintenance is done by village participation and hired labor, and the cost of labor and machine rental is not significantly different, so neither is total cost. Pump repair expenditure, on the other hand, is much lower in the case of large-scale schemes than for small-scale schemes, indicating that pump condition is better in the former and repairs are needed less frequently. Another possible explanation is that there are economies of scale in pump repair, since large-scale schemes share one or several pumps among many farmer groups.

5. Regression Analysis

5.1 Sample Household Characteristics

While evidence at the farmers' group level supports Hypothesis 1; Hypotheses 2 and 3 were tested using household data. For the hypothesis testing we use sample households belonging to the farmers' groups that grew rice in the rainy season of 2011; as shown in Tables 4-7 there were only 87 out of 120 groups that grew rice in 2011. Some farmers have several rice plots in different schemes. In such cases, it is difficult to control for farmers' decisions about resource allocation among plots in different schemes. Therefore, in order to examine the impact of scheme size, farmers that had only one rice plot were selected. This meant that, finally, 228 farmers were included in the analysis.

The characteristics of the sample households are shown in Table 8. Farmers belonging to large-scale irrigation schemes and those belonging to small-scale irrigation schemes are very similar, except for the education level and marital status of the household head, and household size. In spite of these differences, there is no indication that there are systematic differences in household characteristics between the two groups. However, the inputs and outputs relating to rice production are significantly different, as shown in Table 9. Farmers in large-scale irrigation schemes use less fertilizer, less labor, and more machinery than those in small-scale schemes. Moreover, farmers in large-scale irrigation schemes enjoy significantly higher yields, profit, and income per hectare.

Since harvesting and threshing are not directly correlated with production efficiency, we consider two types of profit here: one is profit before harvesting, and the other is profit after harvesting and threshing (standard profit). In terms of credit use, as shown in Table 9, 6% of farmers belonging to large-scale irrigation schemes are members of farmer groups eligible for CNCAS credit. This share is significantly larger statistically than that of farmers belonging to small-scale irrigation schemes. But only a few farmers actually used CNCAS credit to purchase fertilizer in the rainy season 2011, even in the case of large-scale irrigation schemes. Also, many farmers use credit to buy fertilizer regardless of the type of irrigation scheme, but this is not necessarily CNCAS credit. And the share of credit users is not significantly different between large and the small schemes. Thus, from this simple comparison, it is not clear if credit has any impact on fertilizer use and rice yields.

5.2 Regression Results

In order to test Hypotheses 2 and 3, input use function and profit function are estimated by a two stage regression model, where the dummy variable of credit use is treated as an endogenous variable. There are two types of credit, CNCAS credit and the non-CNCAS credit provided by input dealers and rice millers, but as shown in Table 9, the number of users of CNCAS credit is very small, and so the two types are combined as one credit use variable. The finding that input dealers and rice millers provide credit is interesting, as it is common in Asia but seldom reported in SSA except for the Mwea irrigation scheme in Kenya (Njeru *et al*. 2014). Since the credit use variable is an endogenous binary dummy variable, selection bias is controlled for by the predicted probability of credit use obtained by a first-stage probit regression.

There are two explanatory variables concerning scheme size: one is a dummy variable for large-scale schemes, and the other is for scheme size. The former is expected to capture the unspecified institutional differences between large and small schemes, such as governance structure, and the latter is expected to capture the effect of the physical size of the schemes. However, since the two variables are highly correlated, we cannot use both at the same time due to multicollinearity. We present regression results using the dummy variable for large-scale schemes only because scheme size provides similar results. In order to control for the quality of irrigation facilities, the average percentage of irrigated area in the past three years, and total expenditure for pump repairs in the past three years were added as explanatory variables.

Table 10 shows the regression results of the input use functions. The dummy variable for large-scale schemes has a significant impact only on machine rental cost. Our main concern is the use of fertilizer. As is postulated in Hypothesis 2, scheme size does not influence fertilizer use. Rather, being consistent with Table 9, the private scheme dummy has a positive, significant effect on the use of fertilizer, which suggests superior management in the private system as opposed to the collective system.

Table 11 gives the regression results of yield and profit functions. As hypothesized, when controlled for irrigation performance and credit use, scheme size does not affect rice income or rice profit. However, rice yield is still significantly but only statistically at the 10% level, higher in large-scale irrigation schemes than in small-scale irrigation schemes, even after controlling for irrigation performance and credit use. Although Table 9 shows that profit is highest in large-scale irrigation schemes, this may be due to the irrigation performance captured by percentage area planted and pump repair cost in the past three years. As for yield, there may be other factors that affect the difference in yields between large-scale and small scale irrigation schemes. Thus, Hypothesis 3 is supported for rice income and profits, but not so strongly for rice yield.

So far, the comparison is being made between large-scale schemes and small-scale schemes, but as indicated in the tables, small-scale schemes include both village-based irrigation schemes and private irrigation schemes. Since these are quite different in all respects other than scheme size, dummy variables for private schemes are included in the regression analyses. However, in order to check the robustness of the results, regression analyses without private schemes were also conducted. Table 12 gives the regression results about the input functions, and Table 13 is for the regression results about the yield/profit functions. Scheme size has a significant and positive impact on machine use (Table 12) and rice yield (Table 13), and this is the same as those in the full sample regression shown in Tables 10 and 11 respectively. In addition, rice income per hectare is higher in large-scale irrigation schemes than in the small-scale irrigation schemes as shown in Table 13. The results are consistent with Table 9, implying that large-scale irrigation schemes have certain advantages over village-based small-scale irrigation schemes, even after controlling for irrigation performance.

6. Conclusions

In the Senegal River Valley, the average yield of irrigated rice production is much higher than the average throughout the rest of sub-Saharan Africa. Our data show that the overall average in this area is 4.5 tons per hectare, and that of the large-scale irrigation schemes is more than 5 tons per hectare. In addition to well irrigated conditions, the high yields seem to be due to the high doses of chemical fertilizer applied, i.e., 400 kilograms per hectare on average. It is therefore no exaggeration to argue that as in the Asian Green Revolution, the core of high productivity in rice farming in the Senegal River Valley lies in the adoption of improved "seed-fertilizer" technology under irrigated conditions.

Our main aim was to determine if large-scale irrigation schemes are more efficient than small scale irrigation schemes, or at least that they are as efficient as small ones; because it is widely believed that large-scale irrigation schemes are less efficient due to difficulties in irrigation management. Thus, this study compared the efficiency of rice production between large-scale irrigation schemes and small-scale irrigation schemes using household data collected in the Senegal Ricer Valley. The regression analyses demonstrate that large-scale irrigation schemes are as efficient as small-scale irrigation schemes when we control for the quality of irrigation facilities. That is, the seemingly better performance of large-scale irrigation schemes in the Senegal River Valley mainly comes from better management of irrigation facilities at the scheme level. However, the small-scale irrigation schemes are heterogeneous since they include village-based collective irrigation schemes and private irrigation schemes. If we compare large-scale schemes with village-based small-scale ones only, the former perform better even after controlling for observed advantage. The results imply that village-based small-scale collective irrigation schemes have inherent problems in irrigation management. Thus, we conclude that a part of the reason for the high productivity in rice farming in the Senegal River Valley can be attributed to the advantage of large-scale irrigation schemes over small-scale schemes.

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Table 1. Basic characteristics of sample farmer groups in Senegal

	Large-scale	Small-Scale		Total
		Village-Based	Private	
Number of Sample FGs	42	40	38	120
In Dagana Department	35	20	22	77
In Podor Department	7	20	16	43
Year when the FG was Established*	1994 (8.8)	1990 (9.3)	1992 (9.7)	1992 (9.4)
Total Area Managed by the FG (ha)	40.2 (31.5)	41.9 (46.3)	33.1 (33.6)	38.6 (37.5)
Total Number of FG Members	47.5 (55.2)	100.0 (147.0)	21.2 (24.0)	56.7 (96.8)
Managed Area per Member (ha/capita)**	1.16 (0.87)	0.88 (1.27)	5.07 (10.9)	2.31 (6.41)
Size of the Scheme (ha)[a,***]	1167 (829)	41.9 (46.3)	33.1 (33.6)	433 (728)

Standard deviations are in parentheses. *** and ** indicate that the mean results for farmer groups in the large-scale irrigation schemes and those in small-scale irrigation schemes are statistically different at the significance level of 1% and 5% respectively.

[a] In the case of small-scale schemes, size of the scheme is the same as the total area managed by the group.

Table 2. Irrigation performance of sample farmer groups in Senegal

		Large-scale	Small-scale		Total
			Village-Based	Private	
2009	Number of FGs that did not grow rice	9	7	8	24
	% of irrigated area in total area of FG[a],***	0.79 (0.27)	0.57 (0.32)	0.54 (0.29)	0.64 (0.31)
2010	Number of FGs that did not grow rice	13	10	9	32
	% of irrigated area in total area of FG[a],***	0.74 (0.29)	0.61 (0.31)	0.50 (0.30)	0.62 (0.31)
2011	Number of FGs that did not grow rice	15	8	10	33
	% of irrigated area in total area of FG[a],**	0.75 (0.29)	0.60 (0.32)	0.55 (0.28)	0.63 (0.30)
Number of Pumps Owned by FG[b], ***		0	1.40 (1.13)	1.32 (1.40)	0.88 (1.20)
Use of Rental Pumps (dummy) ***		0	0.13	0.21	0.11
Total Expenditure for Pump Repair in 2009, 2010, and 2011 (10^3 FCFA)*		91.7 (33.5)	186 (256)	231 (375)	167 (327)
Length of Canal Managed by FG (m)		1533 (1787)	1447 (1313)	1311 (1170)	1434 (1449)
Canal Management by Participation (dummy)		0.76	0.85	0.84	0.82
Penalty for Absence from Participation (dummy)		0.57	0.55	0.29	0.48
Number of Sample FGs		42	40	38	120

Standard deviations are in parentheses. ***, **, and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1%, 5%, and 10% respectively.
[a] The percentages are calculated among those farmer groups that grew rice during the rainy season in question (that is, farmer groups that did not grow rice were excluded from the average).
[b] In the case of large-scale irrigation schemes, each member FG does not own pumps. In the case of small-scale irrigation schemes, FGs usually use only one irrigation pump. Some FGs have two or more pumps, but the second ones are old and need to be repaired. There are several FGs, particularly in the case of private schemes, that do not own pumps and have to rent one.

Table 3. Credit eligibility of sample farmer groups in Senegal

	Large-scale	Small-scale		Total
		Village-Based	Private	
Number of FGs eligible for CNCAS[a, ***]	21	10	3	34
Number of FGs ineligible for CNCAS due to default in the past[a, *]	18	9	12	39
Year since when the FG has been ineligible for CNCAS[**]	2005 (4.0)	2003 (5.6)	1999 (6.2)	2003 (5.6)
Number of FGs that cannot tell since when it has been ineligible	5	4	4	13
Number of Sample FGs	42	40	38	120

Standard deviations are in parentheses. [***], [**], and [*] indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1%, 5%, and 10% respectively.

[a] The sum of the two numbers is not equal to the total number because ineligibility for CNCAS can be due to other reasons than default. In addition, several FGs do not depend on CNCAS from the beginning. In this case, eligibility for CNCAS is not known.

Table 4. Production technologies by farmer groups in Senegal in the rainy season of 2011

		Large-scale	Small-scale		Total
			Village-Based	Private	
Area Planted to Rice (ha)		33.3 (33.8)	39.6 (52.5)	21.4 (19.1)	31.8 (38.9)
Eligibility for CNCAS (dummy)***		0.63	0.22	0.11	0.31
Land Preparation[a]	by Hand (% of farmers)*	0	12.5 (33.6)	7.14 (26.2)	6.90 (25.5)
	by Tractor (% of farmers)***	94.4 (19.7)	66.8 (47.0)	82.1 (39.0)	80.3 (39.0)
Leveling	by Hand (% of farmers)	70.0 (42.6)	82.0 (35.9)	69.0 (45.9)	74.1 (41.4)
	by Tractor (% of farmers)	5.19 (20.5)	1.88 (10.6)	0	2.30 (13.1)
Seeding	Transplanting (% of farmers)*	10.2 (29.6)	25.6 (39.9)	21.4 (39.5)	19.5 (37.0)
	Direct Seeding (% of farmers)	82.4 (37.9)	74.4 (39.9)	78.6 (39.5)	78.2 (38.8)
Chemical Weeding after Seeding (% of farmers)*		68.1 (45.4)	42.2 (47.7)	51.8 (50.0)	53.3 (48.4)
Modern Varieties[b] (% of farmers)		88.7 (28.6)	99.7 (1.77)	93.8 (20.7)	94.4 (20.1)
	Use of Sahel108 (% of farmers)	47.0 (43.3)	58.7 (43.8)	63.8 (41.7)	56.7 (43.1)
	Use of Sahel134 (% of farmers)	8.93 (20.3)	4.94 (18.5)	1.25 (5.02)	4.99 (16.3)
Number of Sample Groups that Grew Rice in the Rainy Season 2011		27	32	28	87

Standard deviations are in parentheses. *** and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1% and 10% respectively.

[a] Land preparation is not deep ploughing, but harrowing with disc plough. In the study area this is called offsetting.

[b] In the study site, rice is not a traditional crop but is a new crop introduced by SAED. Therefore, all the farmers grew modern varieties from the beginning. In this table, relatively recent varieties developed by Africa Rice Center are counted as "modern varieties" namely Sahel 108, Sahel 201, and Sahel 202 (released in the early 1990s), and Sahel 134 (released in 2005). According to the Africa Rice Center, other new varieties (Sahel 159, Sahel 208, Sahel 209, and Sahel 210) were also released in 2005. Some farmers have adopted them, but they are not included in the figure.

Table 5. Production technologies by farmer groups in Senegal in the rainy season of 2011

		Large-scale	Small-scale		Total
			Village-Based	Private	
Area Planted to Rice (ha)*		33.3 (33.8)	39.6 (52.5)	21.4 (19.1)	31.8 (38.9)
Eligibility for CNCAS (dummy) ***		0.63	0.22	0.11	0.31
Use of Basal Fertilizer (% of farmers)		61.9 (48.7)	58.6 (45.4)	62.9 (46.5)	61.0 (46.3)
Use of Top Dressing (% of farmers)		66.7 (47.9)	55.6 (48.3)	81.3 (38.9)	67.3 (46.1)
Weeding during growth	Manual (% of farmers)	51.7 (46.1)	53.1 (46.0)	49.5 (45.4)	51.5 (45.3)
	Herbicide (% of farmers)	40.4 (45.3)	42.2 (46.3)	40.3 (45.8)	41.0 (45.3)
Number of Sample Groups that Grew Rice in the Rainy Season 2011		27	32	28	87

Standard deviations are in parentheses. *** and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1% and 10% respectively.

Table 6. Production technologies by farmer groups in Senegal in the rainy season of 2011

		Large-scale	Small-scale		Total
			Village-Based	Private	
Area Planted to Rice (ha)*		33.3	39.6	21.4	31.8
		(33.8)	(52.5)	(19.1)	(38.9)
Eligibility for CNCAS (dummy) ***		0.63	0.22	0.11	0.31
Harvesting	by Hand	88.2	84.0	98.2	90.0
	(% of farmers)	(25.3)	(32.3)	(7.72)	(25.0)
	by Harvester	0.74	0.63	0.36	0.57
	(% of farmers)	(3.85)	(3.54)	(1.89)	(3.18)
	by Combine Harvester	11.2	5.97	1.43	6.14
	(% of farmers)	(25.3)	(17.1)	(7.56)	(18.2)
Threshing	by Hand**	10.0	31.9	23.6	22.4
	(% of farmers)	(28.4)	(46.1)	(41.1)	(40.3)
	by Thresher*	78.8	52.7	75.0	68.0
	(% of farmers)	(37.5)	(47.6)	(41.0)	(43.7)
	by Combine Harvester	11.2	5.97	1.43	6.14
	(% of farmers)	(25.3)	(17.1)	(7.56)	(18.2)
Number of Sample Groups that Grew Rice in the Rainy Season 2011		27	32	28	87

Standard deviations are in parentheses. ***, **, and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1%, 5%, and 10% respectively.

Table 7. Facility maintenance by farmer groups in Senegal in the rainy season of 2011

	Large-scale	Small-scale		Total
		Village-Based	Private	
Canal Management by Participation (dummy)	0.63	0.72	0.75	0.70
Participation Rate of Canal Management	0.49 (0.43)	0.50 (0.48)	0.76 (0.97)	0.58 (0.67)
Cost of Participation Labor per Canal Length (FCFA/m)[a]	146 (259)	265 (347)	85.3 (104)	170 (270)
Cost of Hired Labor per Canal Length (FCFA/m)	9.20 (20.4)	11.0 (34.0)	8.69 (29.1)	9.71 (28.5)
Cost of Machinery Rental per Canal Length (FCFA/m)	34.4 (93.7)	30.6 (61.9)	41.2 (91.0)	35.2 (81.6)
Total Cost for Canal Maintenance per Canal Length (FCFA/m)	190 (266)	306 (337)	135 (160)	215 (275)
Total Cost for Pump Repairing (10^3 FCFA)***	23.7 (68.0)	99.3 (139)	91.5 (153)	73.3 (130)
Number of Sample Groups that Grew Rice in the Rainy Season 2011	27	32	28	87

Standard deviations are in parentheses. *** indicates that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1%.

[a] Members' participatory labor is evaluated at the standard daily wage rate of 2,000 FCFA.

Table 8. Household characteristics in Senegal in the rainy season of 2011

	Large-scale	Small-scale		Total
		Village-Based	Private	
Age of household Head	47.7 (12.4)	49.9 (14.5)	44.3 (14.6)	47.3 (14.2)
Number of Female Household Heads	0	1	2	3
Number of Years in Education, Household Head[**]	2.76 (2.07)	3.70 (2.34)	3.22 (2.21)	3.29 (2.26)
Number of Household Members[**]	12.5 (6.71)	10.7 (5.24)	9.62 (6.45)	10.8 (6.16)
Single Household Head (dummy)[***]	0.26	0.08	0.05	0.11
Monogamous Household Head (dummy)[**]	0.52	0.63	0.73	0.64
Polygamous Household Head (dummy)	0.19	0.27	0.19	0.22
Having Self-employment Jobs (dummy)	0.16	0.12	0.19	0.15
Having Employment Jobs (dummy)	0.12	0.08	0.04	0.07
Number of Months of Head's Absence in the Past Year	0.93 (2.97)	0.47 (1.93)	0.11 (0.81)	0.46 (2.00)
Rice Plot Size (ha)	1.29 (2.36)	1.38 (4.29)	1.63 (5.02)	1.45 84.17)
Households whose FG is located in Podor Department (dummy)[***]	0.17	0.54	0.40	0.39
Number of Sample Households Having Only One Rice Plot and Grew Rice in 2011	58	81	89	228

Standard deviations are in parentheses. [***] and [**] indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1% and 5% respectively.

Table 9. Rice production in Senegal in the rainy season of 2011

	Large-scale	Small-scale		Total
		Village-Based	Private	
Seed Cost per Ha (10^3 FCFA/ha)	40.0 (16.9)	35.7 (17.2)	44.7 (25.2)	47.0 (20.6)
Fertilizer Cost per Ha (10^3 FCFA/ha)**	68.5 (32.3)	70.8 (43.1)	99.2 (67.9)	80.3 (53.0)
Fertilizer Application Rate (kg/ha)***	315 (131)	350 (214)	496 (318)	393 (253)
CNCAS Credit Eligible (dummy)	0.60	0.29	0.13	0.31
Use CNCAS Credit for Fertilizer (dummy)	0.07	0.04	0	0.04
Use of Other Credit for Fertilizer (dummy)	0.26	0.17	0.38	0.27
Other Chemical Input per Ha (10^3 FCFA/ha)	25.4 (28.2)	20.8 (27.6)	17.9 (19.4)	21.0 (25.2)
Machinery Cost per Ha (10^3 FCFA/ha)***	163 (57.1)	128 (67.9)	144 (79.8)	143 (71.0)
Hired Labor Cost per Ha (10^3 FCFA/ha)**	58.6 (54.4)	79.0 (147)	154 (388)	100 (252)
Household Labor Cost per Ha (10^3 FCFA/ha)[a], ***	534 (611)	1187 (1573)	640 (921)	827 (120)
Rice Output per Ha (kg/ha)***	5220 (2164)	3916 (2574)	4512 (3024)	4460 (2689)
Rice Profit before Harvesting per Ha (10^3 FCFA/ha)***	147 (360)	-517 (1075)	-104 (801)	-201 (883)
Rice Profit after Threshing per Ha (10^3 FCFA/ha)***	-201 (596)	-1005 (1562)	-505 (1119)	-622 (1260)
Rice Income per Ha (10^3 FCFA/ha)***	334 (213)	182 (280)	136 (518)	204 (378)
Rice Income per Household (10^3 FCFA/household)	239 (382)	210 (414)	320 (1134)	256 (748)
Number of Sample Households having only one Rice Plot and Growing Rice in 2011	58	81	89	228

Standard deviations are in parentheses. *** and ** indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1% and 5% respectively. [a] Household labor is evaluated at the standard daily wage rate of 2,000 FCFA.

Table 10. Determinants of input use for rice production in Senegal in the rainy season of 2011[a]

	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6
Dependent Variable / Explanatory Variables	Seed Cost (10^3 FCFA/ha)	Fertilizer Cost (10^3 FCFA/ha)	Other Chemicals (10^3 FCFA/ha)	Machine Rental Cost (10^3 FCFA/ha)	Hired Labor Cost (10^3 FCFA/ha)	Household Labor Cost (10^3 FCFA/ha)
Scheme/FG Level Variables						
Large-scale scheme (dummy)	2.712	0.516	0.800	23.789	-2.411	-127.329
	[5.737]	[14.326]	[5.630]	[14.089] *	[44.154]	[246.443]
Area Managed by the FG (ha)	-0.115	-0.521	-0.236	-0.351	-0.051	-9.189
	[0.059] *	[0.236] **	[0.066] ***	[0.162] **	[0.455]	[4.123] **
Private scheme (dummy)	10.712	27.309	0.580	20.927	70.445	-255.042
	[5.845] *	[16.645]	[5.578]	[13.053]	[52.204]	[351.253]
% Irrigated Area (Mean of 3 years)	-6.917	-12.911	5.648	29.966	-76.217	218.26
	[7.757]	[22.346]	[7.937]	[19.904]	[114.691]	[314.959]
Total Canal Length (km)	3.705	11.108	1.638	8.829	3.202	95.171
	[1.792] **	[4.639] **	[2.210]	[3.626] **	[9.653]	[81.479]
Pump Repair in 3 years (10^5 FCFA)	-0.759	-1.733	-1.032	-1.536	5.92	25.056
	[0.595]	[2.522]	[0.498] **	[1.757]	[3.986]	[51.154]
Total Number of FG Members	0.027	0.114	0.034	0.141	0.058	2.462
	[0.025]	[0.059] *	[0.023]	[0.040] ***	[0.098]	[1.369] *
Year of Group Formation	-0.052	-0.16	-0.428	-0.529	3.841	-14.232
	[0.231]	[0.580]	[0.235] *	[0.600]	[2.977]	[11.725]
Located in Podor (dummy)	-12.274	12.633	-23.855	-28.67	5.737	1303.222
	[6.162] **	[18.352]	[5.507] ***	[14.730] *	[90.772]	[335.628] ***
Household (HH) Level Variables						
Credit for Fertilizer Purchase (dummy)	-11.655	76.715	-20.679	26.329	-39.739	1232.114
Endogenous	[8.854]	[16.029] ***	[8.651] **	[27.717]	[33.417]	[537.851] **
Age of HH Head	-0.113	-0.054	-0.199	-0.452	-1.426	6.814
	[0.113]	[0.332]	[0.139]	[0.349]	[1.336]	[6.109]
Years in Education of HH Head	-0.457	-0.646	0.936	-1.633	1.864	-51.346
	[0.651]	[1.999]	[0.586]	[1.978]	[3.910]	[35.430]
Number of HH Members	-0.035	0.025	0.691	-1.276	-2.324	9.110
	[0.265]	[0.789]	[0.391] *	[0.829]	[2.251]	[15.024]
Monogamy HH Head (dummy)	4.493	9.976	3.197	-6.289	53.18	-4.147
	[4.381]	[14.150]	[3.839]	[15.899]	[31.684] *	[203.373]
Polygamy HH Head (dummy)	3.895	24.299	0.699	3.293	61.006	443.252
	[4.822]	[13.635] *	[5.902]	[18.303]	[39.548]	[273.806]
Self-employment (dummy)	-8.893	2.76	0.487	-8.292	-65.889	389.349
	[3.072] ***	[9.738]	[5.486]	[12.860]	[44.517]	[207.237] *
Number of Months Being Away Home	-0.204	1.889	0.549	4.023	-2.85	30.778
	[0.452]	[2.032]	[0.611]	[4.126]	[3.931]	[32.852]
Size of Rice Plot in Question (ha)	-0.065	-1.122	-0.435	-1.663	-2.202	-27.429
	[0.227]	[1.004]	[0.317]	[1.037]	[1.433]	[21.534]

Constant	155.376	360.926	888.617	1207.494	-7482.079	27926.025
	[462.326]	[1161.216]	[468.737] *	[1193.184]	[5865.710]	[23327.871]
Number of Obs.	228	228	228	228	228	228

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1%, 5%, and 10% respectively.

[a] Each equation (Eq1 – Eq6) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of Table 6.11.

Table 11. Determinants of the yield and profit of rice production in Senegal in the rainy season of 2011[a]

	Eq. 7	Eq. 8	Eq. 9	Eq. 10	Eq. 11	First Stage
Dependent Variable / Explanatory Variables	Rice Yield (kg/ha)	Rice Income per Area (10^3 FCFA/ha)	Rice Income per HH (10^3 FCFA/HH)	Profit before Harvesting (10^3 FCFA/ha)	Profit after Threshing (10^3 FCFA/ha)	Credit for Fertilizer Purchase (dummy)
Scheme/FG Level Variables						
Large-scale scheme (dummy)	901.101 [533.658] *	92.536 [71.407]	-166.755 [127.666]	220.311 [171.856]	222.171 [257.606]	-0.166 [0.323]
Area Managed by the FG (ha)	-13.286 [6.138] **	-0.570 [0.772]	-0.250 [2.389]	6.046 [3.079] **	8.827 [3.965] **	0.005 [0.005]
Private scheme (dummy)	792.702 [494.434]	-33.403 [75.677]	66.765 [126.161]	224.973 [216.259]	240.18 [349.406]	0.219 [0.376]
% Irrigated Area (Mean of 3 years)	1135.062 [753.944]	216.659 [148.644]	135.981 [133.484]	214.131 [256.756]	-16.314 [350.571]	-0.170 [0.421]
Total Canal Length (km)	334.437 [137.365] **	17.147 [17.422]	8.121 [35.798]	-44.380 [65.720]	-81.431 [84.406]	-0.047 [0.114]
Pump Repair in 3 years (10^5 FCFA)	-58.193 [66.552]	-8.840 [8.633]	-13.842 [11.223]	-21.570 [33.092]	-33.211 [50.437]	0.032 [0.045]
Total Number of FG Members	5.325 [1.504] ***	0.344 [0.167] **	0.297 [0.443]	-1.705 [1.334]	-2.151 [1.396]	-0.002 [0.001]
Year of Group Formation	-20.05 [22.722]	-5.391 [4.083]	1.375 [4.132]	6.089 [7.744]	9.007 [12.003]	0.010 [0.013]
Located in Podor (dummy)	-1085.994 [557.965] *	-72.815 [109.025]	-158.055 [109.971]	-979.608 [194.995] ***	-1431.452 [309.800] ***	-0.896 [0.349] **
CNCAS Eligibility (dummy)	NA	NA	NA	NA	NA	0.500 [0.223] **
Household (HH) Level Variables						
Credit for Fertilizer Purchase (dummy) Endogenous	997.304 [1049.881]	177.381 [76.379] **	243.173 [112.082] **	-789.158 [191.061] ***	-1231.059 [254.071] ***	NA
Age of HH Head	-17.133 [13.234]	0.146 [1.934]	-3.373 [2.582]	-2.468 [4.268]	-7.042 [6.273]	-0.009 [0.007]
Years in Education of HH Head	-61.869 [74.939]	-8.869 [8.158]	-23.836 [17.784]	15.855 [25.991]	43.944 [35.701]	0.034 [0.043]
Number of HH Members	-48.329 [31.396]	-3.606 [3.960]	20.153 [16.877]	-14.511 [10.754]	-12.382 [15.904]	0.012 [0.015]
Monogamy HH Head (dummy)	-238.219 [602.246]	-96.348 [72.406]	-221.671 [109.256] **	-123.627 [170.775]	-91.405 [233.369]	0.140 [0.302]
Polygamy HH Head (dummy)	124.72 [693.295]	-77.88 [87.372]	-96.419 [134.996]	-319.181 [185.269] *	-518.483 [292.089] *	0.015 [0.307]
Self-employment (dummy)	-314.104 [487.127]	54.378 [63.532]	-90.913 [102.073]	-261.877 [126.739] **	-371.776 [174.399] **	-0.510 [0.242] **
Number of Months Being Away Home	152.401 [156.270]	18.338 [17.401]	7.592 [15.871]	-3.764 [15.268]	-16.182 [22.352]	-0.094 [0.045] **

Size of Rice Plot in Question (ha)	-62.983	-3.164	81.354	13.891	25.037	0.015
	[39.272]	[4.482]	[41.532] *	[13.669]	[20.680]	[0.020]
Constant	44791.445	10887.076	-2482.117	-11610.394	-17280.162	-19.642
	[45196.366]	[8070.768]	[8301.359]	[15485.051]	[23976.406]	[26.942]
Number of Obs.	228	228	228	228	228	228

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1%, 5%, and 10% respectively.

[a] Each equation (Eq7 – Eq11) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of the table.

Table 12. Effect of scheme size on input use in Senegal in the rainy season of 2011[a]

Explanatory Variables \ Dependent Variable	Eq. 12 Seed Cost (10^3 FCFA/ha)	Eq. 13 Fertilizer Cost (10^3 FCFA/ha)	Eq. 14 Other Chemicals (10^3 FCFA/ha)	Eq. 15 Machine Rental Cost (10^3 FCFA/ha)	Eq. 16 Hired Labor Cost (10^3 FCFA/ha)	Eq. 17 Household Labor Cost (10^3 FCFA/ha)
Scheme/FG Level Variables						
Large-scale scheme (dummy)	-0.563	3.449	-3.625	29.158	-29.871	-101.889
	[4.092]	[10.026]	[6.429]	[12.799] **	[28.940]	[170.949]
Area Managed by the FG (ha)	-0.009	-0.21	-0.269	-0.065	-0.572	-18.574
	[0.082]	[0.188]	[0.094] ***	[0.272]	[0.421]	[6.518] ***
% Irrigated Area (Mean of 3 years)	8.073	-15.625	18.892	15.47	57.741	379.105
	[5.347]	[15.631]	[10.000] *	[25.305]	[67.078]	[312.733]
Total Canal Length (km)	-0.080	3.340	-0.372	1.259	7.450	195.099
	[1.793]	[3.183]	[2.672]	[5.965]	[10.189]	[124.552]
Pump Repair in 3 years (10^5 FCFA)	-0.402	-0.973	-1.489	-2.626	3.186	21.920
	[0.521]	[1.688]	[0.862] *	[2.635]	[3.926]	[81.996]
Total Number of FG Members	0.004	0.046	0.055	0.136	0.146	3.275
	[0.023]	[0.036]	[0.022] **	[0.063] **	[0.062] **	[1.351] **
Year of Group Formation	0.464	0.284	-0.333	-0.422	-0.252	-29.833
	[0.224] **	[0.417]	[0.235]	[0.813]	[0.934]	[14.661] **
Located in Podor (dummy)	-5.365	10.076	-26.407	-16.948	-85.341	1136.599
	[4.839]	[11.356]	[6.136] ***	[16.389]	[55.209]	[301.909] ***
Household (HH) Level Variables						
Credit for Fertilizer Purchase (dummy) Endogenous	-2.078	11.875	0.515	31.261	-0.559	1412.378
	[8.383]	[21.360]	[17.649]	[33.476]	[72.387]	[584.762] **
Age of HH Head	-0.113	-0.054	-0.199	-0.452	-1.426	6.814
	[0.113]	[0.332]	[0.139]	[0.349]	[1.336]	[6.109]
Years in Education of HH Head	-0.056	-0.369	-0.253	-0.598	0.453	3.622
	[0.150]	[0.282]	[0.251]	[0.523]	[0.677]	[7.684]
Number of HH Members	-0.305	-0.515	0.060	-1.715	4.099	-94.979
	[0.981]	[2.090]	[1.103]	[2.845]	[4.946]	[55.004] *
Monogamy HH Head (dummy)	-0.013	0.200	0.634	-1.488	-2.786	17.054
	[0.247]	[0.583]	[0.534]	[0.925]	[2.204]	[17.647]
Polygamy HH Head (dummy)	3.322	17.155	1.768	-1.603	19.291	213.726
	[2.373]	[10.582]	[6.807]	[12.888]	[20.896]	[201.292]
Self-employment (dummy)	-1.663	21.757	5.969	15.621	38.927	823.913
	[5.550]	[12.426] *	[8.390]	[17.268]	[42.804]	[309.801] ***
Number of Months Being Away Home	-7.125	-3.533	12.784	-7.741	-2.315	38.38
	[3.129] **	[10.273]	[7.892]	[18.943]	[28.118]	[185.972]
Size of Rice Plot in Question (ha)	-0.285	0.424	0.284	4.197	1.911	72.853
	[0.603]	[1.705]	[0.971]	[3.724]	[4.064]	[33.880] **
Constant	-885.62	-491.754	697.853	1001.059	555.799	59168.719
	[443.684] **	[831.057]	[464.852]	[1613.738]	[1843.163]	[29108.605]
Number of Obs.	147	147	147	147	147	147

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1%, 5%, and 10% respectively.

[a] Each equation (Eq12 – Eq17) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of Table 6.13.

Table 13. Determinants of yield and profit of rice production in Senegal in the rainy season of 2011[a]

	Eq. 18	Eq. 19	Eq. 20	Eq. 21	Eq. 22	First Stage
Dependent Variable / Explanatory Variables	Rice Yield (kg/ha)	Rice Income per Area (10^3 FCFA/ha)	Rice Income per HH (10^3 FCFA/HH)	Profit before Harvesting (10^3 FCFA/ha)	Profit after Threshing (10^3 FCFA/ha)	Credit for Fertilizer Purchase (dummy)
Scheme/FG Level Variables						
Large-scale scheme (dummy)	1104.471	147.241	-110.023	215.464	249.13	-0.279
	[478.874] **	[65.829] **	[102.104]	[175.022]	[179.373]	[0.409]
Area Managed by the FG (ha)	-2.445	0.802	4.699	14.168	19.376	0.008
	[8.642]	[0.919]	[2.450] *	[4.446] ***	[6.528] ***	[0.008]
% Irrigated Area (Mean of 3 years)	585.995	-7.2	-41.758	-23.64	-386.305	-0.456
	[962.440]	[130.786]	[127.854]	[270.594]	[327.166]	[0.841]
Total Canal Length (km)	47.687	-5.302	-20.147	-126.517	-200.401	-0.346
	[187.676]	[26.043]	[41.196]	[88.430]	[116.042] *	[0.263]
Pump Repair in 3 years (10^5 FCFA)	-99.465	-10.826	-18.085	-16.805	-32.746	0.049
	[96.577]	[11.332]	[20.323]	[43.476]	[78.623]	[0.114]
Total Number of FG Members	5.142	0.292	-0.469	-2.434	-2.983	-0.003
	[2.350] **	[0.229]	[0.381]	[1.124] **	[1.258] **	[0.008]
Year of Group Formation	-15.966	-1.85	-0.819	19.776	27.983	0.005
	[31.138]	[3.643]	[3.298]	[10.437] *	[15.133] *	[0.031]
Located in Podor (dummy)	-641.974	39.244	-91.68	-787.197	-1097.355	-0.921
	[542.837]	[84.936]	[96.461]	[175.694] ***	[305.721] ***	[0.727]
CNCAS Eligibility (dummy)	NA	NA	NA	NA	NA	1.279
						[0.552] **
Household (HH) Level Variables						
Credit for Fertilizer Purchase (dummy) Endogenous	997.304	177.381	243.173	-789.158	-1231.059	NA
	[1049.881]	[76.379] **	[112.082] **	[191.061] ***	[254.071] ***	
Age of HH Head	-22.639	-2.165	-3.146	-3.482	-5.788	-0.008
	[23.614]	[2.205]	[2.648]	[5.796]	[6.998]	[0.013]
Years in Education of HH Head	-64.968	-10.199	1.44	43.394	84.781	0.154
	[92.617]	[12.154]	[13.173]	[31.097]	[51.528] *	[0.093] *
Number of HH Members	-56.377	-3.989	4.779	-19.923	-21.043	-0.005
	[39.456]	[4.037]	[6.490]	[11.920] *	[19.017]	[0.044]
Monogamy HH Head (dummy)	-60.706	-47.946	-119.016	-210.798	-261.672	-0.267
	[601.615]	[58.201]	[92.189]	[156.852]	[251.291]	[0.447]
Polygamy HH Head (dummy)	591.705	-2.506	-56.458	-423.441	-826.419	-0.568
	[891.227]	[73.356]	[123.488]	[240.307] *	[300.161] ***	[0.659]
Self-employment (dummy)	-293.212	-30.774	-92.96	-54.112	-69.154	-0.855
	[815.301]	[76.642]	[99.368]	[153.242]	[246.018]	[1.279]
Number of Months Being Away Home	158.98	14.455	9.784	-32.96	-58.398	-0.168
	[112.527]	[17.111]	[13.190]	[23.453]	[39.938]	[0.571]
Size of Rice Plot in Question (ha)	-112.512	-7.919	5.368	30.665	60.316	0.079
	[189.753]	[17.459]	[88.280]	[50.671]	[106.183]	[0.189]

Constant	36971.93	4002.959	1975.773	-38899.8	-55165.8	-8.897
	[61491.132]	[7219.971]	[6550.391]	[20779.864]	[29939.373]	[62.111]
Number of Obs.	147	147	147	147	147	147

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1%, 5%, and 10% respectively.

[a] Each equation (Eq18 – Eq22) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of the table.

Abstract (in Japanese)

要約

セネガル川流域の灌漑稲作は、平均単収がヘクタール当たり5トン近くになること、近代的な種子–肥料技術が広範囲に採用されていることから、生産性が非常に高いことが知られている。本研究は、当該地域の稲作の生産性が高い理由を、大規模灌漑と小規模灌漑の管理効率の比較という観点から探るものである。一般的な通念に反して本研究は、大規模灌漑に属する農家が小規模灌漑に属する農家と比べて有意に高い単収と利潤を実現していることを見いだした。

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