# Chapter 11
# Irrigation Scheme Size and Its Relationship to Investment Return: The Case of Senegal River Valley

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**Abstract** Despite the boost in rice production over the last decade in sub-Saharan Africa (SSA), increased production is required to satisfy the demand from rapidly growing urban populations. To enhance rice production in SSA, it is critically important to increase investment in irrigation, as it played a major role in advancing the rice Green Revolution in Asia. However, the question of whether large-scale irrigation is more efficient than small-scale projects has remained contentious. The objective of this chapter is to make a positive contribution to the debate by providing empirical evidence from the Senegal River Valley (SRV), where many irrigation schemes coexist. Based on a survey of 173 farmers' groups that use irrigation schemes of different sizes, OLS regression analyses are used to examine the association between the size of the irrigation scheme and investment performance, which is defined as annual rice income per hectare minus the annual depreciation cost of investment in the irrigation scheme per hectare. After controlling for factors that may influence investment performance, it is found that irrigation scheme size is positively associated with investment performance due to the economy of scale involved in the unit cost of investment. However, the positive association is non-linear and becomes negative beyond 1600 ha. The analyses also show that government-financed irrigation schemes perform worst. Therefore, even if investment in large-scale irrigation is justified, the questions of who will invest and how it will be managed are also important factors affecting the performance of large-scale irrigation schemes.

## 11.1 Introduction

Despite the boost in rice production over the last few decades in sub-Saharan Africa (SSA), increased production is needed to satisfy the demand from rapidly growing urban populations (Arouna et al. 2021). During the five-year period after the food crisis (2007–2012), rice production in SSA grew at 8.4% per year—much higher

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than the 3.2% from 2000 to 2007—with 71% of this growth attributed to yield increase (Saito et al. 2015). Cross-country regression analyses showed that the share of irrigated rice area among the total rice area was one of the factors contributing to the recent increase in yield (Saito et al. 2015). However, the growth rate of rice yield declined between 2012 and 2018 following the cessation of the emergency response to the food crisis. This can be seen in the decrease in the growth rate of investment in agriculture per hectare, which fell from 3.28% between 2008 and 2012 to 0.91% between 2012 and 2018 (Arouna et al. 2021). Thus, to increase rice production in SSA, it is necessary to increase investment in agriculture again. The key question, however, is where to invest. In Asia, irrigation was almost a prerequisite for the rice Green Revolution (Estudillo and Otsuka 2012). However, it has remained underdeveloped in SSA. Therefore, a high priority should be given to considering investment in irrigation in SSA.

With respect to irrigation investments, a fundamental question concerns what kind of irrigation should be promoted, as many large-scale irrigation projects implemented in the latter half of the twentieth century have performed poorly—particularly in SSA (Adams 1992; Inocencio et al. 2007). Following this poor performance and increasing concern about the negative environmental impact from the construction of large-scale irrigation facilities, small-scale irrigation schemes (usually managed by farmers) seem to have been encouraged instead (World Bank 2005, 2007). However, large-scale irrigation projects have been revived because of the food crisis in 2008 and also encouraged by recent advances in yield-increasing technologies that require irrigated conditions.

Despite the resurgence in interest, the prospect of a revival in larger scale projects has evoked negative reactions (Kikuchi et al. 2021). This debate is relevant to considering ways of enhancing rice production through investment in agriculture. Therefore, the objective of this chapter is to contribute to this debate by providing relevant empirical evidence from the Senegal River Valley (SRV). The SRV provides an ideal study site to test whether large-scale irrigation schemes are better targets for investment than small-scale irrigation schemes, as there are many coexisting irrigation schemes of different sizes in this region that produce rice using similar technologies.

To assess investment performance, the approach typically used in the literature is internal rate of returns (IRRs). Based on IRRs from 314 large-scale irrigation projects, Inocencio et al. (2007) showed a significant positive association between project size and IRR. The positive association was due to a strong scale economy of project size in the unit cost of irrigation projects. Their analyses seemed to support larger scale projects, but since their data did not include small-scale irrigation projects, they could not conclude that large scale is more advantageous. To answer this remaining question, Fujiie et al. (2011) conducted a similar analysis, including small- and micro-scale irrigation projects in SSA, confirming that a strong scale economy exists within each scale category, i.e., large (>100 ha), small (5–100 ha), and micro (<5 ha), respectively. However, Fujiie et al. (2011) also found a positive association between project size and unit cost of the project and a consequent negative association between project size and IRR if they combine all the scale categories. Based on this finding, Fujiie et al. (2011) suggested a need to promote small- or micro-scale irrigation projects in

SSA. However, since many factors, such as production technologies and irrigation management, differ between large-scale irrigation projects and small/micro-scale irrigation projects, the observed negative association between project size and IRR may be caused by factors other than size.

In addition, since IRRs are usually reported at the time of project completion, both Inocencio et al. (2007) and Fujiie et al. (2011) implicitly assumed that the product price and production technologies do not change over time—an unrealistic assumption. In this regard, Kikuchi et al. (2021) considered the economic viability of a large-irrigation scheme (Mwea Irrigation Scheme) in Kenya if it were newly constructed now (i.e., in 2017).[1] This means that they used rice price and rice productivity observed in 2017 while investment cost was converted to a 2017 price to calculate the current IRR rather than the IRR at the time of project completion. According to the authors, rice production intensity increased from one crop/year in 1960 to two crops/year, including ratoon harvesting in 2017, while the rice yield per season did not change significantly during this period. Kikuchi et al. (2021) concluded that, with this high rice productivity, if rice price increases to the level reached during the period of the 2008 food crisis, the IRR of the Mwea project will become high enough to justify the investment compared with the opportunity cost of the investment fund. However, since Kikuchi et al. (2021) did not compare the estimated IRR of the Mwea Irrigation Scheme with other irrigation projects, we cannot know if smaller scale irrigation projects perform better under the same assumptions.

Thus, this chapter, adopting Kikuchi et al. (2021)'s approach of incorporating the change in production technologies, compares economic returns among irrigation schemes of different sizes, like that undertaken by Fujiie et al. (2011). However, unlike Fujiie et al. (2011), this chapter tries to control for factors that may be correlated with size and economic performance through regression analyses. Since such comparisons are not found in the literature, it will be a novelty of this study. As mentioned above, such analyses are possible because there are many irrigation schemes with different sizes in the SRV.

To examine the relationship between size and investment performance, both investment cost and output must be considered. With respect to investment cost, by controlling for other factors, unlike Fujiie et al. (2011), it is expected that scale economies in the unit cost of investment will not disappear even if small-scale irrigation schemes are included. Thus, if output does not depend on investment size, investment in large-scale irrigation should perform better than small-scale irrigation due to the economies of scale. However, regarding output, it is not known which kind of irrigation scheme—large-scale or small-scale—generates more income per hectare. Consequently, the relationship between irrigation scheme size and investment performance is an empirical question to which this study seeks an answer.

The structure of this chapter is as follows. Sect. 11.2 describes the study site. Data and methodology are presented in Sect. 11.3, and regression results follow in

[1] See also Chap. 10, which is a revised version of Kikuchi et al. (2021).

Sect. 11.4. Based on the findings that irrigation scheme size is positively associated with investment performance in the previous section, Sect. 11.5 offers some concluding comments and discusses policy implications.

## 11.2 Study Site

### *11.2.1 Irrigation Schemes in the SRV*

The study site is located in the SRV (Fig. 11.1). The Senegal River, originating in the highlands in Guinea, forms an 800 km-long boundary between Mauritania to the north and Senegal to the south. While irrigation schemes for rice production exist on both sides of the river, this study focuses only on the Senegalese side, where the total area supported by irrigation schemes reached about 110,000 ha in 2012 (Manikowski and Strapasson 2016).

The construction of large-scale irrigation schemes started in 1960 after independence. In particular, the construction of two dams (the Diama and Manantali Dams shown in Fig. 11.1) in 1988 made it possible for this country to develop large irrigated rice fields along the river (Manikowski and Strapasson 2016). A governmental agency called SAED (Société Nationale d'Exploitation des Terres du Delta du Fleuve Sénégal et des Vallées Sénégal et de la Falémé) was established in 1965 and has been responsible for the development of irrigation schemes in the SRV.


**Fig. 11.1** The Senegal River valley

Currently, irrigation schemes in the SRV can be classified into three types based on the investors involved in construction, and hence the three scheme types are considered to be an investment category to be explained below. The first one comprises the schemes that the government has invested in. In these cases, the scheme size is relatively large and is usually equipped with multiple irrigation and drainage pumps as well as canal networks. They were formerly managed directly by SAED (i.e., publicly owned and managed), but since 1987 the management has been transferred to farmers' organizations (Diouf et al. 2015). Each scheme is divided into many sections with feeder canals, and a group of 20–30 farmers is responsible for the water distribution and feeder canal maintenance within a section. The second type consists of village-based irrigation schemes managed and operated by village-level management committees. They are smaller scale irrigation schemes constructed by SAED in collaboration with villagers.

The third type comprises privately funded schemes. In response to the liberalization of the agricultural market, private investment in irrigation increased during the 1980s in the SRV, reaching 42,600 ha in total in 1993. It then declined due to the devaluation of the CFA Franc in 1994, which led to decreased incentives for continuing rice production due to the increased prices of imported inputs, such as fertilizer and fuel (Dia 2001). Stimulated by the food crisis in 2008 and encouraged by a new government policy (GOANA, Grande Offensive in Agriculture for Food and Abundance) initiated in April 2008, private investment in irrigation schemes has been growing again. In general, privately funded schemes are the smallest among the three.

### *11.2.2 Rice Production and Scheme Size*

Irrigated rice production in the SRV is known for its high productivity in SSA (Nakano et al. 2012; Sakurai 2016). In fact Tanaka et al (2015) reported that the mean yield in the wet season over the nine-year period from 2002 to 2010 was 5.0–5.6 t/ha depending on the location. However, the yield had stagnated (i.e., had not increased during the nine-year period) and remained short of reaching agronomically attainable yields by 2.2–3 t/ha (Tanaka et al. 2015). Tanaka et al. (2015) showed that delayed sowing was the primary factor leading to yield reduction and that the major reasons for delayed sowing were related to the availability of credit, machinery, and irrigation water. By contrast, rice yield in the dry season was higher than the wet season, and increased from 5.9 to 6.8 t/ha during the same period as the wet season data discussed above (from 2002–2006 to 2008–2011).[2] Brosseau et al. (2021), using data obtained in 2017, showed that some farmers are shifting rice single cropping in the wet season to the hot dry season, whereas other farmers are adopting two cropping—namely

[2] There are three differentiated seasons in the SRV: humid and hot (wet season, about 200 mm rainfall) from July to October, dry and cool (cool dry season) from November to February, and dry and hot (hot dry season) from March to June (Haefele et al. 2002).

rice in the hot dry season and vegetables in the cold dry season. They also pointed out that the rice double cropping area would not increase or even decrease even if rice double cropping was strongly promoted by the Senegalese government.

Borgia et al. (2013) compared small-scale and large-scale irrigation schemes on the Mauritanian side of the SRV, finding that the mean yield did not differ much (3.50 and 3.77 t/ha).[3] The mean yield on the Mauritanian side is much lower than on the Senegal side, although they likely grow rice in similar production conditions. These comparisons may help when considering the kinds of irrigation schemes that could be promoted—large scale or small scale. However, unlike the analyses in this chapter, they do not take account of investment costs.

## 11.3 Data and Methods

### *11.3.1 Data*

One hundred and eighty farmers' groups were randomly sampled from the list of 3304 farmers' groups provided by SAED. They are located along the Senegal River in Dagana and Podor departments (Fig. 11.1). From each group, five rice producers were randomly selected from the member list. The interviews commenced in March 2021 and continued until December 2021. Because the enumerators could not identify some of the sampled groups and because some of the sampled groups rejected the interview, data were collected from 174 groups out of the initially sampled 180 groups. In addition, one group was dropped from the analysis due to missing values. Thus, this study used data from 173 farmers' groups to investigate the performance of investments in irrigation schemes. Since the SAED's list of farmers' organizations did not include any information on the investment category explained in the previous section, the random sampling did not consider the distribution of the investment category in the sample. As shown in Table 11.1, out of the 173 sample farmers' groups, 63 were under government-funded schemes, 69 managed village-based schemes, and 41 managed privately funded schemes.

It is important to explain the relationship between farmers' groups and irrigation schemes. In this chapter, "scheme" refers to the unit of irrigation investment or the whole structure of irrigation. Thus, in village-based and privately funded irrigation schemes, each group has a corresponding irrigation scheme that the group is managing. On the other hand, in the case of government-funded irrigation schemes, the farmers' group is not the unit of investment since the investment is made at the scheme level.

Table 11.1 compares key characteristics of farmers' groups by investment category. This categorization is based on the information obtained in group interviews of each farmers' group, i.e., farmers' own perceptions. Note that village-based and

[3] Borgia et al. (2013) do not specify the cropping season, but it can be assumed that production data were collected in the wet season.

**Table 11.1** Characteristics of farmers' groups by investment category

| | Government funded | Village-based | Privately funded |
|---|---|---|---|
| *Main investor for initial construction* | | | |
| Government | 1 | 0.42 | 0.07 |
| Villagers[a] | 0 | 0.48 | 0.22 |
| Private funds[a] | 0 | 0.10 | 0.71 |
| Size of the irrigation scheme (ha)[b] | 588 (664) | 44.8 (41.8) | 28.7 (24.5) |
| Number of the groups in the scheme[c] | 20.0 (24.7) | 1 | 1 |
| Command area managed by the group (ha) | 38.8 (37.4) | 44.8 (41.8) | 28.7 (24.4) |
| Canal length managed by the group (m) | 573 (279) | 856 (905) | 598 (421) |
| Years since the creation of the group | 26.5 (9.07) | 28.1 (9.08) | 27.5 (9.23) |
| Number of members in the group | 42.7 (43.0) | 54.3 (88.2) | 29.3 (53.0) |
| Male members | 38.9 (40.2) | 43.8 (72.4) | 18.6 (33.1) |
| Female members | 3.81 (6.63) | 10.5 (20.7) | 10.7 (26.2) |
| Group was formed based on a family (1 = Yes, 0 = No) | 0.03 | 0.07 | 0.12 |
| Number of farmers' groups | 63 | 69 | 41 |

Standard deviations are in parentheses
[a] Including loans from financial institutions and government subsidies
[b] The scheme is the unit of irrigation construction and hence is considered as the unit of investment.
[c]Even if a group is physically attached to a large irrigation scheme, if the construction was done independently, the group does not belong to the large scheme. In such cases, the number of the groups in the scheme is 1

privately funded irrigation schemes did not exclusively depend on villagers' contributions or private funds for the initial construction because the government and donors subsidized the scheme construction. As for the scheme size, the size of government-funded schemes is more than ten times larger than the other type of schemes, and the average number of farmers' groups that belong to a government-funded scheme is about 20. Otherwise, at the group level, the three categories of farmers' groups are not very different, although privately funded ones tend to be smaller in terms of command area and the number of members. In addition, for unknown reasons, the number of female members is significantly smaller in farmers' groups from government-funded irrigation schemes.

### *11.3.2 Methodology*

As mentioned above, the objective of this chapter is to examine the relationship between the size of the irrigation project and the performance of investments in project. Specifically, the size of the irrigation scheme described above is used as the project size in this chapter. As for investment performance, this study adopts the idea of Inocencio et al. (2007) and Fujiie et al. (2011), who used IRR as an indicator of the investment performance of irrigation projects. However, this study uses annual return—to be defined below—instead of IRR. Taking account of the initial investment cost by using annual depreciation cost, annual return per hectare of farmers' group $i$ is given as follows:

$$R_i = \sum_s (\omega_{is} p_s Y_{is} - C_{is}) - D_i \tag{11.1}$$

where $R_i$ is annual return per hectare of the command area of the farmers' group $i$, $Y_{is}$ is rice (paddy) yield of farmers' group $i$ in season $s$, $\boldsymbol{p}_s$ is the market price of paddy in season $s$,[4] $\boldsymbol{\omega}_{is}$ is the exploitation rate of farmers' group $i$ in season $s$ (to be defined shortly), $C_{is}$ is the production cost of farmers' group $i$ in season $s$ including membership fee, and $D_i$ is the annual depreciation cost per hectare, to be defined by Eq. (11.2), which is implicitly incurred by the farmers' group $i$. Rice yield ($\boldsymbol{Y}_{is}$) was obtained as the mean of farmers in group $i$ who actually grew rice in season $s$. Although rice yield was generally high compared with the standard in SSA as mentioned above, most farmers' groups did not fully use their land for rice production. To capture this inefficiency, the exploitation rate ($\omega_{is}$) is introduced in Eq. (11.1). The exploitation rate of farmers' group $i$ is defined as the proportion of rice harvested area divided by total irrigation command area of farmers' group $i$ in season $s$. Thus, $\boldsymbol{\omega}_{is}\ \boldsymbol{Y}_{is}$ is exploitation rate adjusted yield.

Depreciation cost ($D_i$) consists of three kinds of investment in this study:

$$D_i = \frac{1}{N} K_i + \frac{1}{M} B_i + \frac{1}{M} E_i \tag{11.2}$$

where $K_i$ is initial investment cost per hectare to construct the irrigation scheme to which farmers' group $i$ belongs.[5] Since investment is made at the scheme level, total investment cost was divided by the size of irrigation scheme. Then, the value was converted to the 2021 price by using the Senegalese consumer price index (CPI). $B_i$ is rehabilitation investment per hectare. It is also converted to the 2021 price. The last term, $E_i$, is the total value of pumps used by farmers' group $i$. The values were estimated by respondents to answer the question "How much would it be if you bought it now?" for each pump they were using. By adopting a straight-line depreciation method with no salvage value, $\boldsymbol{N}$ and $\boldsymbol{M}$ are the number of usable years of the

[4] The market prices are constructed by averaging sample farmers' sale prices of paddy in each season.

[5] Investment in common infrastructure is not considered in this initial investment. The most important common infrastructure in the SRV is comprised of the Diama and the Manantali dams (Fig. 11.1). The former dam was designed to stop saline water intrusion, and the latter dam was designed to maintain river water levels throughout the year. The construction of the two dams at a total cost of UD$830 million brought a potential of 240,000 ha of irrigated agriculture to the SRV and electricity to Senegal (Manikowski and Strapasson 2016).

investment. For rehabilitation ($B_i$) and pumps ($E_i$), lifetime was uniformly assumed to be ten years, and hence $\boldsymbol{M} = 10$. On the other hand, for the initial investment ($K_i$), two different lifetimes were assumed. The first consists of "high depreciation" (or, short lifetime), where the lifetime of the initial investment is assumed to be 30 years for hard (compacted) structures and ten years for soft (non-compacted or partially compacted) structures. Hence, $\boldsymbol{N} = 10$ or 30 depending on the structure. The second refers to "low depreciation" (or long lifetime), where the lifetime of the initial investment is assumed to be 30 years regardless of the structure. Hence, $\boldsymbol{N} = 30$. In the low depreciation case, particularly for soft structure, $D_i$ tend to be smaller than in the high depreciation case, and consequently $R_i$ becomes larger.

Then, to investigate the association between irrigation scheme size and investment performance, annual return defined in Eq. (11.1) and other performance indicators such as exploitation rate, rice yield, etc., were regressed on the size of the irrigation scheme. Thenִ regression model is given below.

$$R_i = \alpha + \beta_1 S_i + \beta_2 S_i^2 + \beta_3 V_i + \beta_4 P_i + X_i \gamma + \varepsilon_i \tag{11.3}$$

where $S_i$ is scheme size and ${S_i}^2$ is its square. Since the relationship between scheme size and return is expected to be non-linear, the squared term is included. $V_i$ and $P_i$ are binary dummy variables for village-based and privately funded irrigation schemes, respectively. As discussed above, they are correlated with scheme size but may have different influences on the economic return, so they are used as control variables. $\boldsymbol{X}_i$ is the vector of other control variables, which are a binary dummy for construction quality (a dummy for hard structure), the number of years since the creation of the farmers' group, how the groups were formed (a dummy variable taking 1 if the group was based on a family), the number of male members, and the number of female members. $\alpha$ is constant and $\varepsilon_i$ is an error term. Equation (11.3) is estimated by OLS. In addition, to examine if the relationship between scheme size and return is observed in each investment category, interaction terms between size variables and investment category dummies are incorporated in the following specification

$$\begin{aligned} R_i = {} & \alpha + \beta_1 S_i + \beta_2 S_i^2 + \beta_3 V_i + \beta_{31} V_i \cdot S_i + \beta_{32} V_i \cdot S_i^2 \\ & + \beta_{41} P_i + \beta_{41} P_i \cdot S_i + \beta_4 P_i \cdot S_i^2 + X_i \gamma + \varepsilon_i \end{aligned} \tag{11.4}$$

## 11.4 Results

### *11.4.1 Descriptive Statistics of Investment*

Table 11.2 compares the three categories of irrigation schemes in terms of investment. The share of hard construction and initial investment cost per hectare are higher in government-funded irrigation schemes than in other irrigation schemes. However,

**Table 11.2** Investment in irrigation facilities by investment category

| | Government funded | Village-based | Privately funded |
|---|---|---|---|
| *Construction type (share in each category)* | | | |
| Hard (compacted) | 0.254 | 0.029 | 0.073 |
| Soft (not compacted/partially compacted) | 0.746 | 0.971 | 0.927 |
| Initial investment for the construction (million FCFA/ha)[a] | 2.3 (5.4) | 2.1 (3.3) | 0.8 (0.7) |
| *Farmers' contribution (share in each category)* | | | |
| Monetary contribution | 0.032 | 0.217 | 0.341 |
| Labor contribution | 0.016 | 0.174 | 0.073 |
| No contribution | 0.952 | 0.609 | 0.585 |
| Farmers' monetary contribution toward construction ($10^3$ FCFA/ha)[a] | 0.003 (0.02) | 0.020 (0.11) | 0.18 (0.58) |
| Total monetary investment (million FCFA/ha)[a] | 2.3 (5.4) | 2.1 (3.3) | 1.0 (1.1) |
| In USD/ha[b] | 4138 | 3802 | 1825 |
| Rehabilitation, monetary investment (million FCFA/ha) | 0.026 (0.13) | 0.035 (0.15) | 0.026 (0.11) |
| Rehabilitation, farmers' contribution (million FCFA/ha)[a] | 0.006 (0.027) | 0.005 (0.016) | 0.004 (0.012) |
| Total value of pumps ($10^3$ FCFA/ha)[c] | 5.1 (14.2) | 1.2 (7.3) | 0.3 (0.6) |
| Number of farmers' groups | 63 | 69 | 41 |

Standard deviations are in parentheses
[a] Values are converted to 2021 prices using the Consumer Price Index
[b] The exchange rate of 1 FCFA = 0.0018 USD in 2021 is applied
[c] The values were estimated by farmers who were asked how much the price of each pump would be if they purchased it now

the difference in initial investment between government-funded irrigation schemes and village-based ones is not as large, even without farmers' monetary contributions (2.3 million versus 2.1 million FCFA/ha). This may be because SAED designed and constructed both government-funded and village-based irrigation schemes. In the case of privately funded irrigation schemes, the cost is about half of the other two categories. Since farmers' monetary contributions are relatively small compared with total investment cost, the inclusion of their contributions does not change the tendency. The Senegalese government used 3 million FCFA/ha as the cost of creating a new irrigation scheme for the SRV in its rice development plan (Ministère de l'Agriculture 2009). As it would be about 3.4 million FCFA/ha in 2021 prices, the estimated investment cost in this study is much lower. As for rehabilitation, the investment cost is much lower than the initial investment, not only because it comprises rehabilitation but also because many irrigation schemes have not implemented any rehabilitation activities since construction, i.e., the actual rehabilitation cost is zero. If only positive observations are considered, the average rehabilitation investment (the sum of monetary investment and farmers' contributions) will increase from 35,000 to 122,000 FCFA/ha. However, these are still much lower than the planned government rate of 600,000 FCFA/ha (Ministère de l'Agriculture 2009). Finally, it is important to note the huge difference in the value of pumps. In the case of government-funded irrigation schemes, since the scheme size is large, high-capacity pumps are required not only for irrigation but also for drainage. Thus, even if the value is divided by the scheme size, the unit cost is much higher than the other types of irrigation schemes. On the other hand, privately funded irrigation schemes mainly seem to use small, inexpensive pumps.

### *11.4.2 Descriptive Statistics of Rice Production and Its Investment Return*

The first part of Table 11.3 compares several indicators of the intensity of rice production at the farmers' group level. The first one is the number of times rice was produced during the last seven seasons, beginning in the hot dry season of 2019 and extending to the hot dry season of 2021—a total of three hot dry seasons, the most favorable season for rice production. Thus, if the value of this indicator is 3, the group is considered to produce rice once a year. The value exceeds 3 only in the case of farmers' groups in government-funded irrigation schemes, while the values of other groups are just above 2, indicating farmers' groups in village-based and privately funded irrigation schemes use their fields less frequently.[6] The second aspect is the average exploitation rate over the last seven seasons, where the exploitation rate is defined as the ratio of area under rice production to total command area given to the farmers' group. The average exploitation rate of farmers' groups in government-funded irrigation schemes is 0.32, which is much higher than that of the other two categories. The exploitation rates by season show that the exploitation rates are more than 0.4 in all the investment categories in a hot dry season. However, in other seasons, which are less favorable for rice production, most of the farmers' groups in village-based or privately funded irrigation schemes do not produce rice at all. It is not because of the shift from rice to vegetables because vegetable production in cold dry season is not so popular among farmers' groups in village-based or privately funded irrigation schemes either, as shown in the table.

The second part of Table 11.3 provides rice yield. Rice yield (kg/ha/season) at the farmers' group level was calculated from household survey data that also covers seven seasons from the hot dry season 2019 to hot dry season 2021.[7] Thus, the rice

[6] This indicator is for group-level intensity and does not capture plot-level intensity—namely, how many times a year the same plot is used for rice production. In fact, even if a farmer produces rice two times a year, the farmer may use different plots in each season.

[7] In some cases, no one among the five sample farmers in a farmers' group produced rice in a particular season, even though the group reported that it was a positive area for producing rice in

**Table 11.3** Performance of rice production

| | Government funded | Village based | Privately funded |
|---|---|---|---|
| Number of seasons in which rice was produced in the last 7 seasons[a] | 3.35 (1.54) | 2.23 (1.29) | 2.07 (1.46) |
| Average share of rice area in total area[b] | 0.32 (0.17) | 0.21 (0.15) | 0.22 (0.18) |
| In hot dry season (Feb/Mar–June/July) | 0.50 (0.39) | 0.42 (0.32) | 0.40 (0.36) |
| In rain season (July/Aug–Nov/Dec) | 0.24 (0.36) | 0.08 (0.19) | 0.13 (0.24) |
| In cold dry season (Oct/Nov–Mar/April) | 0.14 (0.27) | 0.03 (0.12) | 0.05 (0.14) |
| Average share of other crop areas in total area[c] | 0.06 (0.11) | 0.01 (0.03) | 0.01 (0.06) |
| Rice yield (kg/ha/season) in planted area[d] | 5374 (1107) | 5380 (1342) | 5821 (1087) |
| Rice production cost ($10^3$ FCFA/ha/season)[d] | 267 (412) | 333 (394) | 349 (347) |
| Rice income ($10^3$ FCFA/ha/year)[e] | 551 (544) | 322 (813) | 265 (309) |
| Membership fee ($10^3$ FCFA/ha/season) | 4.48 (16.3) | 67.7 (259) | 41.3 (137) |
| Annual depreciation cost, high rate ($10^3$ FCFA/ha/year)[f] | 713 (1550) | 312 (760) | 128 (128) |
| Annual depreciation cost, low rate ($10^3$ FCFA/ha/year)[g] | 585 (1437) | 190 (732) | 64.2 (74.8) |
| Annual return, high depreciation ($10^3$ FCFA/ha/year) | −167 (1604) | −59.8 (1160) | 90.6 (360) |
| Annual return, low depreciation ($10^3$ FCFA/ha/year) | −38.9 (1533) | 62.2 (1115) | 154 (333) |
| Number of farmers' groups | 63 | 69 | 41 |

Standard deviations are in parentheses

[a] There are three seasons in a year at the study site: hot dry season, rain season, and cold dry season. Using irrigation water, rice can be grown in any season, but the hot dry season is the best because of the high temperature and sunlight. The 7 continuous seasons include 3 hot dry seasons, two rain seasons, and two cold dry seasons. Although rice can be produced three times a year in one irrigation scheme, it does not necessarily mean that the same plots are used three times a year due to the overlapping of seasons

[b] The share is land area planted to rice over the total land area managed by a farmers' group

[c] The share is land area planted to other crops over the total land area managed by a farmers' group.

[d] Rice yield and rice production cost are the average from plots where rice was planted. Note that most farmers' groups use only some part of the land they are managing, as shown in the table

[e] Rice income is the average for the group. That is, it takes account of the exploitation rate

[f] For the initial investment (construction), the lifetime of the structure is assumed to be 30 years for a hard (compacted) structure and 10 years for a soft (non-compacted/partially compacted). The lifetime of rehabilitation investment and pumps is assumed to be 10 years. Annual depreciation is the value divided by the number of lifetime years

[g] In the case of a low depreciation rate, the lifetime of the initial investment is assumed to be 30 years regardless of the structure. The lifetime of other investments is the same as the high depreciation, i.e., 10 years

yield shown in the table is that of farmers who actually produced rice.[8] Rice yield is generally high, consistent with previous reports such as Nakano et al. (2012), Sakurai (2016), and Tanaka et al. (2015). Farmers' groups in privately funded irrigation schemes show the highest average yield. This is because farmers in such groups tend to produce rice only during the most favorable, hot dry season.

Next, using the rice production data at the farmers' group level, adjusted by the intensity and the exploitation rates as explained above, group-level annual rice income per hectare is estimated. As shown in Table 11.3, annual income is the highest in the farmers' groups in government-funded irrigation schemes, reflecting their higher intensity and exploitation rates, particularly in unfavorable seasons. The group-level rice income does not include income from vegetable production, although it has become an important part of household income (Brosseau et al. 2021; Manikowski and Strapasson 2016). The exclusion of vegetable income can be justified by the fact that vegetable production was not so popular among the sample farmers collected from a wide range of SRV areas. Vegetable production was mainly done by farmers' groups in government-funded irrigation schemes, as shown in Table 11.3. Moreover, the objective of the government's investment in irrigation schemes in the SRV was to enhance rice production to make the country self-sufficient in rice.

The last part of Table 11.3 shows the annual depreciation cost and return per hectare. There are two important observations. First, the depreciation cost is the highest in the farmers' groups in government-funded irrigation schemes and the lowest in privately funded irrigation schemes, with those in between comprising village-based irrigation schemes, regardless of depreciation rate. Second, the annual returns are in the opposite order among the three investment categories. The first observation may imply that there are no economies of scale in the unit costs of irrigation investment. The second observation may suggest that investment performance is higher in smaller scale irrigation projects. That is, despite the highest income of farmers' groups in government-funded irrigation schemes, the return to investment is the lowest due to their higher depreciation cost. These observations seem to be consistent with the findings of Fujiie et al. (2011). However, although scheme size is correlated with the three investment categories, from these simple mean comparisons, it is unclear whether the significant differences in depreciation costs and the return to investment in irrigation schemes are due to scheme size or investment category. Therefore, regression analyses will be conducted in the next section.

that season (i.e., other farmers produced rice). Such cases are not included in the calculation of rice yield in the table. However, for the regression analysis, an expected rice yield obtained from similar farmers' groups in the same season is used.

[8] Since most of the farmers' groups do not use the command area fully for rice production, as discussed above, the rice yield obtained from farmers who actually produced rice must be adjusted by the exploitation rates in each season in order to calculate the rice production per hectare for each farmers' group.

### *11.4.3 Regression Analyses*

Table 11.4 presents the estimation results of Eq. (11.3). Columns (1)–(5) show that irrigation scheme size has no significant association with current rice production, i.e., rice production intensity, exploitation rate of irrigation command area, rice yield, rice production cost per hectare, and rice income per hectare. However, as shown in columns (6) and (7), irrigation scheme size has a significant, negative correlation with depreciation cost per hectare regardless of depreciation rate, suggesting economies of scale in the unit cost of investment. Consequently, there is a positive relationship between scheme size and annual return, as shown in Columns (8) and (9), which favors larger sized irrigation schemes. However, because of the negative coefficient for the squared term of quadratic function, the positive association is diminishing and becomes negative after 1730 ha in the case of a high depreciation rate or 1560 ha in the case of a low depreciation rate.

Regression results provided in Table 11.5 examine if the positive association between scheme size and annual return is also found in each investment category. As shown in Columns from (6) to (9), coefficients for irrigation scheme size and its square are similar to those in Table 11.4, and their interaction terms with investment category dummies do not have any significant association on depreciation cost or annual return to investment. Thus, the results suggest that the positive association between scheme size and annual return does not differ among the investment categories.

In addition to the relationship between scheme size and investment performance, the regression analyses provide some interesting findings about investment category. The most important one is that the depreciation cost is significantly higher in the government-funded investment in irrigation schemes regardless of depreciation rate, as shown in Columns (6) and (7) of Table 11.4. Farmers' groups in government-funded irrigation schemes generate more income per hectare due to more intensified rice production and a higher rate of exploitation (Columns (1), (2), and (5)). However, at the same time, the investment performance of government-funded schemes is lower than other investment categories, as shown in Columns (8) and (9).

## 11.5 Conclusions

The objective of this chapter is to investigate the relationship between the size of irrigation scheme and the return to investment using farmers' group data collected in the SRV. The SRV is suitable for this purpose because, unlike other places, there are many irrigation schemes of differing sizes coexisting in similar environments. This question is relevant to considering whether investment in large-scale irrigation projects can be justified in circumstances that require the enhancement of agricultural production. The regression analyses of this study, after controlling for several factors, including investment categories, found an economy of scale in the unit cost of investment in irrigation schemes and a consequent positive association between

**Table 11.4** Determinants of investment return

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Number of rice productions in 7 seasons (number) | Share of rice planted area in the scheme (share) | Rice yield, group level (kg/ha/season) | Rice production cost, group level ($10^3$ FCFA/ha/season) | Rice income, group level ($10^3$ FCFA/ha/year) | Annual depreciation, high rate ($10^3$ FCFA/ha/year) | Annual depreciation, low rate ($10^3$ FCFA/ha/year) | Annual return, high rate of depreciation ($10^3$ FCFA/ha/year) | Annual return, low rate of depreciation ($10^3$ FCFA/ha/year) |
| Irrigation scheme size (ha) | $9.22*10^{-4}$ ($7.52*10^{-4}$) | $0.30*10^{-4}$ ($0.71*10^{-4}$) | −0.26 (0.98) | 0.032 (0.056) | −0.18 (0.22) | −1.74 $(0.56)^{***}$ | −1.55 $(0.27)^{***}$ | 1.59 $(0.55)^{***}$ | 1.38 $(0.53)^{**}$ |
| Scheme size squared ($ha^2$) | $-3.69*10^{-7}$ $(2.06*10^{-7})^{*}$ | $-2.35*10^{-8}$ ($1.90*10^{-8}$) | $-1.01*10^{-4}$ ($2.72*10^{-4}$) | $-0.10*10^{-4}$ ($0.14*10^{-4}$) | $0.09*10^{-4}$ ($0.58*10^{-4}$) | $0.46*10^{-3}$ $(0.16*10^{-3})^{***}$ | $0.41*10^{-3}$ $(0.15*10^{-3})^{***}$ | $-0.46*10^{-3}$ $(0.16*10^{-3})^{***}$ | $-0.41*10^{-3}$ $(0.15*10^{-3})^{***}$ |
| *Investment category (dummies)* | | | | | | | | | |
| Village-based | −0.84 $(0.37)^{**}$ | −0.11 $(0.04)^{**}$ | −916 (772) | −0.067 (32.5) | −316 $(153)^{**}$ | −1227 $(435)^{***}$ | −1119 $(412)^{***}$ | 850 $(442)^{*}$ | 741 $(430)^{*}$ |
| Privately funded | −1.02 $(0.42)^{**}$ | −0.10 $(0.05)^{**}$ | −802 (988) | −9.97 (34.6) | −327 $(141)^{**}$ | −1506 $(468)^{***}$ | −1345 $(449)^{***}$ | 1146 $(471)^{**}$ | 985 $(463)^{**}$ |
| *Construction quality (dummies)* | | | | | | | | | |
| Hard structure | 0.99 (0.34) | −0.02 (0.04) | −1291 $(612)^{**}$ | −47.2 $(25.2)^{**}$ | −72.1 (96.4) | −651 $(249)^{**}$ | −506 $(240)^{**}$ | 603 $(245)^{**}$ | 458 $(241)^{*}$ |
| Years since the creation of the group | 0.01 (0.01) | 0.00 (0.00) | 27.0 (35.3) | 3.22 $(1.22)^{***}$ | −1.98 (6.60) | 18.1 (12.7) | 17.5 (12.7) | −20.8 (14.6) | −20.2 (14.6) |
| Group based on a family (dummy) | −0.53 $(0.30)^{*}$ | −0.68 (0.42) | −141 (728) | −31.6 (22.8) | −73.0 (86.8) | 1100 (757) | 1174 (768) | −1235 (767) | −1309 (807) |
| Number of male members | −0.00 (0.00) | −0.00 (0.00) | 12.9 (12.1) | −0.31 (0.22) | 1.72 (1.28) | −2.02 $(1.16)^{*}$ | −1.98 $(1.11)^{*}$ | 3.85 $(1.97)^{**}$ | 3.82 $(1.86)^{**}$ |

(continued)

**Table 11.4** (continued)

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Number of rice productions in 7 seasons (number) | Share of rice planted area in the scheme (share) | Rice yield, group level (kg/ha/season) | Rice production cost, group level ($10^3$ FCFA/ha/season) | Rice income, group level ($10^3$ FCFA/ha/year) | Annual depreciation, high rate ($10^3$ FCFA/ha/year) | Annual depreciation, low rate ($10^3$ FCFA/ha/year) | Annual return, high rate of depreciation ($10^3$ FCFA/ha/year) | Annual return, low rate of depreciation ($10^3$ FCFA/ha/year) |
| Number of female members | −0.00 (0.01) | −0.00 (0.00) | −27.0 (35.3) | −0.37 (0.47) | −3.55 (2.09) | 2.22 (2.14) | 2.66 (2.06) | −5.30 (3.00)* | −5.74 (2.88)** |
| Constant | 2.83 (0.48)*** | 0.32 (0.06)*** | 3965 (921)*** | 28.4 (37.9) | 670 (193)*** | 1114 (283)*** | 874 (250)*** | −438 (308) | −198 (288) |
| $R^2$ | 0.19 | 0.13 | 0.05 | 0.08 | 0.06 | 0.26 | 0.26 | 0.18 | 0.17 |
| Number of observations | 173 | 173 | 173 | 173 | 173 | 173 | 173 | 173 | 173 |

Robust standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

**Table 11.5** Effect of irrigation scheme size

| | (1) Number of rice productions in 7 seasons (number) | (2) Share of rice planted area in the scheme (share) | (3) Rice yield, group level (kg/ha/season) | (4) Rice production cost, group level ($10^3$ FCFA/ha/season) | (5) Rice income, group level ($10^3$ FCFA/ha/year) | (6) Annual depreciation, high rate ($10^3$ FCFA/ha/year) | (7) Annual depreciation, low rate ($10^3$ FCFA/ha/year) | (8) Annual return, high rate of depreciation ($10^3$ FCFA/ha/year) | (9) Annual return, low rate of depreciation ($10^3$ FCFA/ha/year) |
|---|---|---|---|---|---|---|---|---|---|
| Irrigation scheme size (ha) | $7.84*10^{-4}$ ($7.77*10^{-4}$) | $0.41*10^{-4}$ ($0.73*10^{-4}$) | 0.11 (0.98) | 0.032 (0.058) | −0.13 (0.23) | −1.76 (0.57)*** | −1.54 (0.54)*** | 1.64 (0.57)*** | 1.42 (0.55)** |
| Scheme size squared (ha$^2$) | $-3.24*10^{-7}$ ($2.09*10^{-7}$) | $-2.67*10^{-8}$ ($1.94*10^{-8}$) | $-2.16*10^{-4}$ ($2.73*10^{-4}$) | $-0.10*10^{-4}$ ($0.15*10^{-4}$) | $0.08*10^{-4}$ ($0.60*10^{-4}$) | $0.46*10^{-3}$ ($0.16*10^{-3}$)*** | $0.40*10^{-3}$ ($0.15*10^{-3}$)*** | $-0.47*10^{-3}$ ($0.16*10^{-3}$)*** | $-0.42*10^{-3}$ ($0.16*10^{-3}$)*** |
| *Investment category (dummies)* | | | | | | | | | |
| Village-based | −1.63 (0.53)*** | −0.15 (0.06)** | −325 (1448) | −31.8 (48.4) | −151 (275) | −1001 (490)** | −845 (468)* | 854 (536) | 698 (524) |
| Village-based x scheme size | 0.03 (0.01)** | 0.02 (0.01) | −5.46 (33.2) | 1.49 (1.29) | −4.44 (5.72) | −9.0 (8.5) | −10.8 (8.4) | 1.67 (10.7) | 3.46 (10.4) |
| Village-based x scheme size sq | −0.00 (0.00)** | −0.00 (0.00)** | −0.07 (0.14) | −0.01 (0.01) | 0.01 (0.02) | 0.05 (0.04) | 0.06 (0.04) | −0.02 (0.05) | −0.03 (0.05) |
| Privately funded | −1.36 (0.63)** | −0.12 (0.08) | −1203 (984) | −79.2 (41.5)* | −193 (176) | −1516 (541)*** | −1408 (523)*** | 1194 (572)** | 1087 (563)* |
| Privately funded x scheme size | 0.02 (0.02) | 0.03 (0.03) | 45.3 (40.3) | 4.28 (2.10)** | −4.92 (5.10) | 1.15 (6.49) | 2.41 (5.84) | −1.81 (9.99) | −2.13 (9.43) |
| Privately funded x scheme size sq | −0.00 (0.00) | −0.00 (0.00) | −0.54 (0.31)* | 0.04 (0.02)** | 0.01 (0.04) | 0.04 (0.05) | −0.00 (0.04) | −0.06 (0.07) | −0.02 (0.07) |
| Other control variables | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

(continued)

**Table 11.5** (continued)

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Number of rice productions in 7 seasons (number) | Share of rice planted area in the scheme (share) | Rice yield, group level (kg/ha/season) | Rice production cost, group level ($10^3$ FCFA/ha/season) | Rice income, group level ($10^3$ FCFA/ha/year) | Annual depreciation, high rate ($10^3$ FCFA/ha/year) | Annual depreciation, low rate ($10^3$ FCFA/ha/year) | Annual return, high rate of depreciation ($10^3$ FCFA/ha/year) | Annual return, low rate of depreciation ($10^3$ FCFA/ha/year) |
| Constant | 2.96 (0.48)*** | 0.31 (0.06)*** | 3875 (1019)*** | 30.3 (40.2) | 621 (217)*** | −644 (248)*** | 846 (267)*** | −469 (336) | −221 (315) |
| $R^2$ | 0.21 | 0.15 | 0.07 | 0.11 | 0.08 | 0.26 | 0.26 | 0.18 | 0.18 |
| Number of observations | 173 | 173 | 173 | 173 | 173 | 173 | 173 | 173 | 173 |

Robust standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

scheme size and return to investment. This finding is consistent with Inocencio et al. (2007) and Kikuchi et al. (2021). In addition, this study made two contributions to the debate on the relationship between irrigation size and investment performance. First, this study found that the positive relationship between irrigation size and investment performance is non-linear and disappears once the irrigation scheme becomes more than a certain size. In our empirical case, the peak exists around 1600–1700 ha. Second, this study found that the investment performance of government-funded irrigation schemes is poorer than that of village-based and privately funded irrigation schemes because of the significantly higher depreciation costs of government-funded schemes.

Thus, this study suggests that the promotion of investment in large-scale irrigation schemes is not unconditionally recommended. We should pay attention to the negative association between government-funded irrigation schemes and return to investment. Government-funded irrigation schemes have better facilities (more compacted structure), higher pump capacity, and as a consequence, can be intensified (i.e., a larger amount of rice production in a year). They also have a higher exploitation rate, are more diversified (increased vegetable production), and produce more income per hectare. Nevertheless, due to the high investment costs—particularly in pumps—its investment performance is worse than village-based and privately funded irrigation schemes. In other words, the rice productivity of government-funded irrigation schemes is not sufficiently high enough to cover their high investment costs. Thus, although large-scale (but not too large) irrigation should be promoted, excessive investment per hectare must be avoided.

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