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Centering around the Estimation of Construction Costs of Mwea Irrigation Scheme in Kenya

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Economic viability of large-scale irrigation construction in 21st century sub-Saharan Africa: Centering around the estimation of construction costs of Mwea Irrigation Scheme in Kenya

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Abstract

The main reason for the success of the 20th century Green Revolution in Asia was the development of large-scale irrigation projects. But, since the late 1990s, these investments were out of the development agenda, partly because the success of the Green Revolution reduced the need for such irrigation development and partly because the lower-than-expected performance of many large-scale irrigation projects resulted from difficulties in designing, constructing, operating, and managing large-scale irrigation schemes. This was the case in sub-Saharan Africa (SSA) as well. During the past decade, however, large-scale irrigation development seems to be coming back in SSA as a means to promote a Green Revolution there. This revival has evoked heated discussion as to whether the conditions that made the large-scale irrigation projects an infeasible option have been overcome. This paper examines whether large-scale irrigation construction in SSA is economically feasible by estimating how much it would cost if the Mwea Irrigation Scheme in Kenya, one of the best performing irrigation schemes in SSA, were to be constructed today as a brand-new scheme. The results show that the new construction of the Mwea Scheme may be economically viable if the shadow price of rice is as high as the world price that prevailed during the mini-rice crisis in 2008-2013; however, the viability is marginal, by no means robust. The project costs per unit of beneficiary irrigated area of our 'Mwea Project' and a few 21st-century large-scale irrigation projects under planning or under construction are two to four times higher than those of 20th-century counterparts. For such expensive projects to be economically viable, the agricultural performance of these projects must be two to four times higher as well, which means, in terms of rice yield, 9 t/ha/year to 20 t/ha/year. There is certainly untapped potential in SSA for large-scale irrigation development, either construction of new schemes or rehabilitation of the existing ones, but the economically feasible potential remains limited. International donor agencies and national governments wanting to plan large-scale irrigation projects are recommended to assess seriously whether their plan is economically and technologically feasible and indisputably superior to other types of irrigation development, many of which were not available during the construction boom in the 20th century but are available now.

I. Introduction

For enhancing food security and reducing rural poverty, sub-Saharan Africa (SSA) has long been awaiting a Green Revolution (Otsuka and Kalirajan, 2006; Diao et al., 2008; Ejeta, 2010; Pingali, 2012). There have recently been signs that an African Green Revolution has begun (Sanchez et al., 2009; Nakano et al., 2012; Otsuka and Larson, 2012). There were three technological bases that made the Asian Green Revolution possible in the second half of the last century, i.e., high-yielding varieties, chemical fertilizers, and irrigation (Diao et al., 2008; Estudillo and Otsuka, 2012). Among these, irrigation is by far the most basic technological foundation, as assured water supply is a prerequisite for effective fertilizer application, without which the high yielding potential of the seeds is not fully exploited. Among developing regions in the world, SSA is the region where irrigation has been least developed (Balasubramanian et al., 2007; Diagne et al., 2013), despite its rich endowment of fresh-water resources (You et al., 2010; Zwart, 2013; Xie et al., 2014). The rich water endowment is a possible blessing for the Green Revolution in SSA. However, there are many ways to tap water for crop production and there have been serious debates in the last few decades as to what type of irrigation developments SSA agriculture should seek.

A major mode of irrigation development during the 20th century Green Revolution was large-scale projects to construct, rehabilitate, or modernize irrigation infrastructure (irrigation ‘hardware’ such as dams, tanks, headworks, canal systems, and field development), funded by international donors, implemented by the government of recipient countries, and operated and maintained, after construction, by national irrigation agencies (Jones, 1995; Inocencio et al., 2007). Most of irrigation development in the latter-half of the 20th century was borne by these projects. Though they undoubtedly contributed to the Green Revolution, large-scale irrigation projects had nearly disappeared from the agricultural development agenda of developing regions in the world by the late 1990s, for good reasons. One of them was the success of the Green Revolution that brought about historic low prices of cereal crops by the end of the 20th century. In the case of rice, the world price in 2000 was as low as 25% in real terms of the level prevailing during the pre-Revolution period. Such low crop prices made it virtually impossible to justify large-scale irrigation projects which were generally costly (Jones, 1995; Inocencio et al., 2007).

A more serious reason was that many large-scale irrigation projects implemented in the latter half of the last century were full of problems and defects; inadequate designs, faulty construction, less-than-satisfactory achievements, and poor, dysfunctional operation and maintenance (O&M). When evaluated at the time of construction completion, one-third of the large-scale irrigation projects were 'failure' projects ('failure' if the *ex post* internal rate of return is less than 10%) (Belli, et al., 1998; Inocencio et al., 2007), and the risk of 'failure' increased to 50%, equivalent to the risk of failure in simple gambling such as coin-toss betting, when evaluated at six to eight years after completion (the World Commission on Dams [WCD], 2000). The mode of O&M of these schemes was so institutionally defective that many irrigation schemes constructed or rehabilitated, even non-failure projects, rapidly deteriorated (Adams, 1990; Ostrom, 1992; World Bank, 2005). Moreover, implementation of large-scale irrigation rehabilitation projects created and spread the 'build-neglect-rebuild' syndrome, depriving national irrigation agencies of incentives to maintain their irrigation systems well (Huppert et al., 2003; Lankford et al., 2016).

It became apparent that there was no reason to pursue large-scale irrigation projects of this type anymore, and good reason not to do so. Furthermore, growing environmental concerns worked against large-scale new construction projects involving the construction of large dams and relocation of inhabitants. The World Commission on Dams (WCD) as well as the World Bank proposed such agricultural development options as improving the performance and productivity of existing irrigation schemes through institutional reforms for O&M, small-scale farmer-led irrigation development, investing in micro-irrigation technology and in-field rainwater management, rather than resorting to large-scale irrigation projects (WCD, 2000; World Bank, 2005).

This virtual 'ban' on large-scale irrigation projects was most effective in SSA where the 20th century Green Revolution had not taken root, and the irrigation sector was characterized by more handicaps than any other developing regions. Moris (1986) argued, while enumerating one after another poorly performing large-scale irrigation projects implemented since the 1960s, that large-scale irrigation development in SSA led by donors and governments was always problematic because of poor design without due understanding of grass-root conditions, inadequate technology choice, and inefficient bureaucratic O&M; his arguments were so comprehensive that nearly all his arguments became the broad consensus by the end of the century. Biswas (1986) pointed out nine reasons why large-scale irrigation development projects in SSA were bound to be handicapped, resulting, almost without exception, in unsatisfactory performance or failure. FAO (1986), Oliveres (1989, 1990), Jones (1995), and Inocencio et al. (2007) denounced large-scale irrigation projects for their high costs and low performance. Moigne and Barghouti (1990) stated that large-scale irrigation schemes in SSA had run into many serious problems such that the confidence of potential investors had been shaken, and that new schemes should not even be considered unless lower-cost technologies or production systems with higher returns were identified. The shift of focus in the irrigation sector from large-scale projects led by donors and governments to farmer-led small-scale projects, from 'hardware / physical infrastructure' to 'software / institutions', and from gravity irrigation to micro-irrigation technology was apparent towards the mid-2000s (NEPAD, 2003; Rockström et al., 2007; World Bank, 2007; Lankford, 2009; Burney et al., 2013). By 2017 or so, "farmer-led irrigation" had become the dominant focus of efforts to expand irrigation in SSA (e.g. Woodhouse et al., 2017; Lefore et al., 2019; Thomas Reuters Foundation, 2018).

However, parallel to this development, large-scale irrigation projects, including projects to construct new schemes, have also gradually come back to center stage. For example, a loan agreement was signed in 2007 between Kenya and Kuwait Fund for Arab Economic Development for financing the Bura Irrigation and Settlement Scheme Rehabilitation Project (a rehabilitation/modernization project to increase the project area from 2,500 ha to 6,100 ha) (Reliefweb, 2007; NIB, 2018); a loan agreement was signed in 2010 between Kenya and Japan International Cooperation Agency (JICA) for financing the Mwea Irrigation Development Project (a rehabilitation/modernization project to increase the project area from 7,900 ha to 8,900 ha) (JICA, 2010); and the World Bank approved in 2017 a loan for financing the Shire Valley Transformation Program in Malawi (a new construction/rehabilitation project with project area of 42,000 ha) (World Bank, 2017a,b). Of these, the original Bura Irrigation and Settlement Project, implemented in 1979-1987, was the most infamous project in SSA for its disastrous failure (Moris, 1986; Adams, 1990; World Bank, 2007). The current rehabilitation project, which commenced in 2013 with the National Irrigation Board as implementing agency as before, was at only 30% completion as of 2018, 38 months behind the construction schedule (Business Today, 2018). The irrigation development in Shire Valley was first envisaged in the 1940s and its implementation has been considered a few times since then, but the construction plan has been abandoned every time because the construction costs were too high (Harrison, 2018).

Why have these types of irrigation investments been resurrected? Have there been any changes in the conditions that once made large-scale irrigation development an undesirable, infeasible option? One possible reason could be a food crisis in 2008 which pushed up all food prices sharply. In the case of rice, the world price (Thai 5% broken Bangkok FOB) soared up to US$ 650/t in 2008 from US$ 326/t in 2007, or from the historic low price of US$ 173/t in 2001 (year averages in current prices) (World Bank, 2019b). Such a surge in food prices may have reminded policy makers in SSA and international donors of the vulnerability of world's food production and the need to enhance food security by increasing domestic food production. This has perhaps prompted them to bring back large-scale irrigation projects as a quick and effective means to increasing food production (Lankford et al., 2016). Higher food prices push them towards that direction, *ceteris paribus*, by increasing the profitability of such projects.

Another reason could be recent advances in yield-increasing technology of food crops. In the case of rice, the present technology gives a yield of 6 t/ha, or even higher, if grown under good conditions; and farmers in some large-scale irrigation schemes in SSA are attaining that yield level for two crops per year (Tinsley, 2009; You et al., 2010; Nakano et al., 2012; Bartier et al., 2014). Since the availability of such technology also improves the *ex-ante* economic performance of large-scale irrigation projects, particularly when coupled with higher crop prices, policy makers in SSA could be encouraged to go for such projects.

The recent re-emergence of large-scale irrigation projects has evoked many heated reactions, mostly objecting to this trend (Burney et al., 2013; Lankford et al., 2016; Crow-Miller et al., 2017; Merrey and Sally 2017; Woodhouse et al., 2017; Harrison, 2018; Pittock et al., 2018). All of these studies share the same basic question, raised explicitly by Crow-Miller et al. (2017), that is, "do these new projects have different justifications from those of the past? (p.195)" The mode of large-scale irrigation development in the latter half of the last century was so defective that many projects failed to attain their planned level of performance. Unless national governments and international donors are sure that they have found effective remedies for the defects of large-scale irrigation projects of the mode in the 20th century, they surely would not go for new large-scale projects, -- or would they? The recent story of the Bura Rehabilitation Project in Kenya reported by Business Today (2018) is appalling because the problems- narratives, exactly same in nature, were found in so many project-completion and post-project-evaluation reports of failed large-scale irrigation projects implemented 20 to 40 years ago. As already mentioned, the original Bura Irrigation Settlement Project was a spectacular failure, but the failure had been anticipated before the project (Chambers, 1969; Moris, 1973), and the details of the failure were reported (Moris, 1986; Adams, 1990; World Bank, 1990a, 1990b). The recent Bura Project could be another example of 'informed amnesia', 'where the major actors involved in irrigation development tend to ignore past mistakes, despite ample proof of the futility of their efforts' (Veldwisch et al., 2009; p.21).

The purpose of this paper is to assess whether it is economically feasible to construct large-scale irrigation schemes in SSA, and if it is, under what conditions. We approach these questions through estimating the cost of constructing an existing irrigation scheme, the Mwea Irrigation Scheme in Kenya (abbreviated henceforth as Mwea Scheme), if it were constructed now. In the next section, we give an overview of large-scale irrigation projects implemented during the last four decades of the 20th century, mostly financed by the World Bank (WB), with special reference to the cost structure of these projects. We then present the estimated costs of Mwea Scheme construction project in the third section, followed by the fourth section which examines the economic viability of the project. Concluding remarks are in the fifth section.

II. Irrigation Projects in the 20th Century

We first review large-scale irrigation projects implemented in the last four decades of the 20th century with respect to their project costs. To fully understand the costs, we first need to know the characteristics of large-scale irrigation projects as public investments. Second, the cost of irrigation projects consists of two components, direct construction costs (hardware costs) and indirect overhead costs (software costs). The former costs are irrigation scheme specific, and therefore relatively easier to estimate. For the indirect overhead costs, we need to obtain information from past irrigation projects. Both are necessary to understand the investment costs.

1. Characteristics of 20th century irrigation projects

In order to understand the nature of the costs of large-scale irrigation projects, we examine 182 irrigation projects implemented during the latter half of the 20th century. These irrigation projects, selected from 314 irrigation projects in the database prepared by Inocencio et al. (2007), are those for which project costs are reported with appropriate breakdown. The sample projects include 59 new construction projects and the remaining 123 are rehabilitation projects (Table 1). Since SSA was a late comer to irrigation development in the 20th century, the sample projects include only 19 SSA projects, of which only eight are new construction projects.

The top part of Table 1 re-confirms the salient features of irrigation projects in SSA found by Inocencio et al. (2007): compared to other developing regions in the world, (1) the project size, measured by the total irrigated area benefited by a project, was smaller, on average, less than one fourth of the average size of non-SSA regions; (2) the unit project costs was higher in SSA: more than 60% more expensive to create new irrigated fields and nearly four times as expensive to rehabilitate existing ones; and (3) the risk of project failure was higher in SSA.

Cost over-run is an oft-mentioned problem of irrigation projects. Hirschman (1967) advanced, based on his observation of 11 World Bank development projects, the Hiding-Hand principle: policy makers and project planners underestimate the cost and the real risk of development projects, but, since they also underestimate their abilities to deal with risks and solve problems that bring about higher-than-expected project benefits, development projects of high costs and high risk, which would otherwise be never started, are tried out with good results for society. Challenging this Hirschman's principle by examining a sample of 2,062 public works projects, Flyvbjerg and Sunstein (2016) found that Hirschman's benevolent Hiding-Hand did not work in nearly 80% of the projects, which implies that, if any Hiding-Hand is behind the public works projects, it is usually a malevolent one, under which unrealistic optimism applies both to the estimation of difficulties/costs and to creativity/benefits, resulting in erroneously accepting non-viable projects. Whether the Hiding Hand is 'benevolent' or 'malevolent' depends, practically, on the degrees of cost-overrun and of under-estimation of the benefit of respective projects.

Large-scale irrigation projects under consideration are typical public works projects. In fact, Hirschman's sample of 11 projects includes three large-scale irrigation projects and more than 10% of Flyvbjerg and Sunstein (2016)'s sample projects are dam-construction projects. Our 'All data' show that 44% of projects had the cost-overruns (the bottom part of Table 1). At the same time, large numbers of projects experienced cost-underruns. However, the degree of overrun was much higher than that of underrun; for overruns 40% to 52% on average and as much as 176% to 254% for the maximum, whereas, for underruns 24% to 27% on average and 81% to 94% for the maximum (minimum), respectively for non-SSA and SSA. These patterns are quite similar to those of 258 transportation infrastructure projects studied by Flyvbjerg et al. (2002), who denounced the underestimation of project costs for not being able "to be explained by error but is best explained by strategic misrepresentation, i.e., lying (p.279)". There were quite a few such cases among the 20th century irrigation projects. The cost-overrun was a highly significant determinant of the project costs, but not of the internal rate of returns (IRR) (Inocencio et al., 2007).

Since the IRR is a discount rate that equates the present value of the benefit and the present value of the cost, a cost overrun reduces the *ex-post* IRR and so does a benefit over-estimation. Table 1 shows that an IRR over-estimation was far more common than an under-estimation, and this IRR over-estimation occurs in most cases either because benefit over-estimation occurs together with cost under-estimation or because the degree of benefit under-estimation is smaller than the degree of cost overrun. There were cases of IRR underestimation, but the number of such projects was smaller than that of projects that overestimated IRR, and the degree of underestimation was less than that of overestimation. These findings suggest that the malevolent Hiding Hand dominated in the 20th century irrigation projects: policy makers and planners of these projects had strong tendencies to overestimate the likelihood of success by underestimating costs and overestimating benefits. In particular, the optimistic and unrealistic estimation of benefits was the most serious defect of the majority of the irrigation projects. The *ex-ante* IRR based on such assumptions were "so misleading as to be worse than worthless, because decisionmakers might think they are being informed when in fact they are being misinformed" (Flyvbjerg and Sunstein, 2016; p.11).

However, it should be mentioned that, although the malevolent Hiding Hand was more common in public works projects, there were projects that were under the benevolent Hiding Hand. Flyvbjerg and Sunstein (2016) showed that the malevolent Hiding Hand dominated the benevolent one by a factor 3.5 to 1. For irrigation projects, this ratio was 2.3 to 1 in SSA and 2.7 to 1 in non-SSA, if we take the ratio of the number of IRR-overestimated projects to that of IRR-underestimated projects. A good example was the Office du Niger Consolidation Project implemented in Mali in 1989-1999, which recorded a cost overrun of 250% (3.5 times as much as appraised cost) and IRR underestimation of -90% (*ex-ante* 16% *versus ex-post* 30%) (World Bank, 1999), which implies that the rate of benefit underestimation was larger than that of the cost overrun; a typical benevolent Hiding Hand case. But such projects were a small minority.

2. Cost structure of 20th century irrigation projects

The cost of large-scale irrigation projects consists not only of direct construction costs but also of various indirect, overhead costs. In this section, the cost structure of public irrigation projects is examined based on the cost data of the 182 projects, by classifying the project cost into four cost groups:

(1) Costs or expenditures for civil works directly related to the construction of irrigation infrastructure, including materials and equipment used for these purposes, and indirect construction costs such as field administration and supervision, safety control, and contractor's profit (henceforth referred to as 'Civil-work' costs);

(2) Indirect or overhead costs or expenditures for management, including project preparatory surveys and studies, system designing and blueprints, engineering management and supervision during the implementation, and general project administration and management ('Management' costs);

(3) Overhead costs or expenditures for agricultural support, O&M equipment, O&M planning, and training of irrigation officials, water users' groups, and farmers ('Ag-support' costs); and

(4) Other overhead costs or expenditures, such as land acquisition, land compensation, relocation, construction of settlements and other social infrastructures ('Other-overhead' costs).

Three additional qualifications on these costs are to be added: First, equipment and vehicles used for the purpose of constructing irrigation infrastructures and facilities are included in 'Civil-work' costs, but those used for O&M are included in 'Ag-support' costs; second, many works, tasks, and services included in 'Management' and 'Ag-support' costs are carried out by consultants under Technical Assistance contracts; and third, costs for land acquisition and compensation and associated social infrastructure construction included in 'Other-overhead' cost could be important cost items particularly in new construction projects.

One thing clear in reading the project reports of irrigation projects is that there are few useful data or guidelines for engineering consultants / contractors to use for accounting these overhead costs while making budget proposals of irrigation projects. Certainly, there are 'guidelines' of some sort: "price and physical contingencies are to be 15% of the estimated costs", "general administration costs for a project are to be 5% of the total project costs", etc. How these guidelines are to be set and adjusted for according to specific conditions and environments is not clear. Of course, the diversity of conditions and environments under which an irrigation project is planned and implemented are so enormous that it is very difficult, or even impossible, to provide ready-made guidelines of general applicability. However, it would be useful to study what levels of indirect, overhead costs irrigation projects in the past incurred.

The four groups of project costs of 20th century irrigation projects are shown in Table 2 as percentage shares in the total project cost for SSA and other developing regions. The share of overhead costs in SSA was 39% on average and the ratio of the total project cost to Civil-work costs was 1.63, much larger than in other regions.

The unit total project cost and four unit-component-costs are all correlated negatively with project size (Fig. 1). The strong scale economy of irrigation project costs was pointed out by Inocencio et al. (2007) for the total project cost and by Fujiie et al. (2011) for some overhead costs. This study reveals that 'Civil-work' cost, which includes some indivisible inputs / elements, such as heavy construction equipment, dams, headworks, and reservoirs, also had a strong scale economy.

Using the data drawn in Fig. 1 together with some sample specific characteristics, regression equations are estimated for the unit-total-project-cost and four unit-component-costs (Table 3). The project size has a highly significant negative coefficient for all the unit costs. Scale-economy exists in all the component costs, including 'Civil-work' costs. Among the component costs, 'Management' cost was subject to the strongest degree of scale economy. Since the regression equations are of the double-log linear form with respect to project size, its coefficient is nothing but elasticity. 'Management' cost has the highest elasticity: a 10% increase in the project size decreases the cost by as much as 6.5%, closely followed by 'Ag-support' cost. As expected, the unit total project cost of rehabilitation projects is significantly lower than that of new construction projects, which is brought about by lower 'Civil-work', 'Management', and 'Other-overhead' costs, but not by 'Ag-support' cost. Failure projects have higher unit total project cost than successful ones, due to higher 'Civil-work' cost, and the overhead costs do not have any significant relation with 'failure'. There was a tendency that the newer the projects, the lower the unit 'Civil-work' and 'Management' costs, resulting in lower unit total project cost. This suggests that the performance of 20th century irrigation projects in terms of the unit cost to generate or to rehabilitate a unit of irrigated land was improved as project experience accumulated.

The most important result of the regression analyses is that the higher unit project cost to develop irrigation infrastructure in SSA was due wholly to the small size of the irrigation projects implemented there and not for SSA-specific reasons. The SSA regional dummy is not statistically significant in all the regression equations for the four component-costs, and therefore so was in the total project cost equation.

III. Estimation of Project Costs of Mwea Scheme

We try to estimate the project costs of Mwea Irrigation Scheme in Kenya, if the scheme as it is presently were constructed now as a brand-new scheme.

1. The Mwea Irrigation Scheme

Mwea Irrigation Scheme, situated 65 km south of Mt. Kenya, 90 km northeast of Nairobi, and 650 km northwest of Mombasa, is a river-diversion surface irrigation scheme, taking water from two of many tributaries in the Upper Tana basin on the heavily watered southeastern slopes of Mt. Kenya (Map 1). Such a favorable water potential, coupled with a gently sloping terrain and fertile black soil of volcanic origin in the plain, makes the Mwea plain an ideal physical environment to construct an irrigation scheme (Moris, 1973). The construction of Mwea Scheme was started in 1954 as a settlement scheme with the primary purpose of providing agricultural land for landless people, the number of whom was increasing due to population pressure and the effects of an emergency under Mau Mau Uprising (Chambers, 1969, 1973).

The ample water sources in the area have given the scheme resilient expandability. As shown in Table 4, starting from 2,000 ha of the first construction phase in the 1950s, the Scheme's net irrigable area increased to 5,000 ha by the early 1970s, and to 6,000 ha by the late 1980s. A modernization/rehabilitation project, implemented in 1989-1991with assistance from JICA (the first Mwea Irrigation Project; a JICA grant-aid project; henceforth referred to as Mwea Project 1990), expanded it to 8,500 ha, and the construction of the second Mwea Irrigation Development Project, another on-going modernization/rehabilitation project by JICA (henceforth referred to as Mwea Project 2017), is expected to expand the Scheme's irrigable area to as much as 8,910 ha, including the three out-grower sections developed by farmers themselves with assistance from the World Bank.

The favorable water and soil conditions have made the Mwea Scheme one of the best rice irrigation schemes not only in SSA but also in the world. The average farmers' rice yield at Mwea from 1961 to 1971 was as high as 6.4 t/ha (Veen, 1973). It should be noted that this high yield level was attained with Sindano, a japonica variety with some indica variety characteristics, which was a pre-Green Revolution variety. This was an exceptionally high yield level for irrigated rice in the 20th century. Even after the rice Green Revolution, 4 t/ha was the normal target yield of many irrigation projects, which was rarely attained. The Mwea Scheme was mentioned as the only successful irrigation scheme among many schemes in East Africa (Chambers and Moris, 1973), or even in Africa (Biswas, 1986).

The scheme experienced radical changes in the institutional framework for O&M at the turn of the century; the management of the Scheme by the National Irrigation Board (NIB) was taken over by farmers' groups in 1998 (Kabutha and Mutero, 2002) and the mode of O&M was further reformed in 2003 to a joint-management arrangement between NIB and farmers' groups (water-users associations) (Abdullahi et al., 2003). The farmers' takeover of the management was the result of their protest against the NIB management under which they had been treated as quasi slave tenants with virtually no discretion as to their rice production and marketing. Under joint management, NIB concentrates on O&M of the main systems, leaving the maintenance of the secondary and tertiary systems, rice production, and marketing to the farmers' discretion.

This joint management by the NIB and the farmers seems to have been successful to the extent that the reforms had no effect on the yield performance of the Scheme. The rice yield declined to 5 t/ha in the 1980s and further to a level less than 4 t/ha by the end of the 2000s (Table 4). This decline was due mainly to the shift in the rice variety to Basmati which was higher quality but lower yield than Sindano. If we look at the yield of Sindano, no declining trend had been observed for the five decades since the 1960s, and the average rice yield of the Scheme in 2017 was more than 6.2 t/ha with new recently developed high-yielding Basmati varieties. The cropping intensity of the Scheme has improved from the earlier intensity of 1.0/year to nearly 2.0/year by 2017, mainly resulting from the efforts to implement water rotations and to introduce rice ratoon harvesting. The Mwea Scheme as of 2017 with such a high level of productivity could be said to be a top-class irrigation scheme in SSA.

2. Project costs at the initial stage

Data on the expenditures for constructing the Mwea Irrigation Scheme at its initial construction phase from 1954 to 1968 are reported by Sandford (1973). By 1968, an irrigated area of 3,129 ha had been developed. Although the primary purpose of this study is to estimate the cost to construct the Mwea Scheme as operating in 2017, we examine, as a reference, the investment costs and its economic performance at the initial stage.

The expenditure data at the initial stage consists of capital and recurrent expenditures. Reflecting the fact that the construction project was implemented by the government as a settlement project and the scheme was owned by the government with all the settled farmers as tenants, recurrent expenditures included not only O&M expenditures but also all labor costs, including those related to the construction, such as engineering and project management, and costs for inputs used in current rice production, such as fertilizers and chemicals, rice sacks, and fuel for machinery. We exclude the recurrent expenditures for O&M and those for rice production and add the rest to the capital expenditures to obtain the total construction (project) cost for 1954 - 1968, which was US$ 4.12 million in current (nominal) prices or US$ 3.92 million in 1960 prices. The unit cost per ha was US$ 1,255 in 1960 prices. The recurrent O&M expenditure in 1968 was US$ 28,454/year, or US$ 9.09/ha/year, both in 1960 prices. Throughout this paper, we use the same deflator for project costs in US dollars, which is compiled by linking the Word Bank world GDP implicit deflator (1960-2017) (World Bank, 2019a) with the IMF's world export price index (1945-1960).

3. Project costs if the Scheme were newly constructed in 2017

Since 1968, the total irrigated area of the Mwea Scheme has increased to 8,500 ha, mainly because of the improvements made by the modernization/rehabilitation project implemented in 1989-1991 (Mwea Project 1990). In this study, we tried to estimate how much the construction costs of the Mwea Scheme would be, if the Scheme, with the present infrastructure and operating performance, were constructed as a brand-new scheme. The target scheme for the cost estimation is the one fully developed by Mwea Project 1990. Three out-growers' sections, for which the World Bank assisted farmers to construct paddy fields, are not included, mainly because data on the costs of irrigation and drainage canals and on-farm roads in these sections constructed by farmers are not available. This exclusion, however, has little effect on our cost-benefit analysis of this 'new construction' project. Our preliminary examination of the data related to the out-growers' sections shows that the cost-lowering effect of the inclusion of these sections is largely canceled out by the benefit-lowering effect of these sections due to lower yields and lower cropping intensity.

At first in this study, it was planned that an experienced international engineering consultant company (the Consultant, hereafter) would undertake the estimation of the project costs of the scheme. Later on, however, we found it better that the Consultant specialized in the estimation of 'Civil-work' costs, i.e., the costs directly related to the construction of irrigation infrastructures and irrigation facilities. Three groups of overhead costs were to be estimated based on the past experiences of irrigation projects implemented in developing regions in the world and of those of Mwea Scheme itself. Since levels of the overhead costs depend on various conditions and natural, social, and economic environments surrounding the irrigation scheme in question, it is very difficult to estimate them accurately. Therefore, we provide a few alternative levels of estimates of the overhead costs.

3-1. Estimation of direct construction costs

The direct construction costs, i.e., ’Civil-work’ cost, estimated by the Consultant are presented in Table 5. The basic method of estimation was by summing up the products of the quantity and the unit cost of each structure or facility for the entire irrigation infrastructures and irrigation facilities in the scheme. The quantities of structures and facilities were enumerated, measured, and identified by a detailed inventory survey conducted in the field in 2017-2018, while referring to detailed design drawings of the past projects implemented in the scheme (Mwea Project 1990 and Mwea Project 2017) (JICA and Nippon Koei, 2018). The unit costs are taken from JICA’s internal records for the on-going Mwea Project 2017. These unit costs include the contractor’s indirect costs, consisting of corporate overhead expenses, such as supervising construction works and security and safety control, and corporate profit. These indirect costs are estimated to be 25% of the direct unit cost comprising costs for labor, materials, and equipment.

Of the 15 irrigation infrastructures in Table 5, New Nyamindi Headworks (#1), Nyamindi Headrace (#3), and Link Canal-I (#8) were irrigation structures newly constructed by the Mwea Project 1990, so that their “quantities” must be the same as of the time of the cost estimation in 2017 (Link Canal-II was also newly constructed by Mwea Project 1990, but had some more additional construction works afterward). Since the Project Completion Report of Mwea Project 1990 (Nippon Koei, 1993) gives the actual construction costs of these structures, we can compare our estimated costs with actual ones. Although their “unit costs” could not be the same because the prices of the cost components, such as labor, concrete, iron bars, etc., have changed over time at different rates, the estimated costs must not be so different from the original construction costs if the changes in currency value are properly accounted for. Deflating the actual costs in 1990 prices to 2016 prices, the summation of the original construction costs of these three structures were US$ 6.65 million, which are compared to our estimate of US$ 6.35 million (#1 + #3 + #8). The difference of less than 5% suggests that the Consultant’s estimation of ‘Civil-work’ cost is reasonably accurate.

3-2. Estimation of overhead costs

Three sets of data are available for giving us reference information about how much of overhead costs a large-scale irrigation project generally needs.

The first data set is the cost structure of 20th century irrigation projects, which we have already seen in Table 2 for the sample means. The percentage shares of four component costs in the total project cost shown in Table 6 are computed, using their projected values obtained by inserting the project size of 8,500 ha into the respective estimated regression equations in Table

3. In spite of the existence of strong scale economy in the unit project cost, the cost structure of this size differs only slightly from that for over-all sample means. A salient feature of the cost structure of irrigation projects in SSA is that the overhead costs account for a higher percentage in the total project cost than in other developing regions. The shares of three overhead cost groups are all higher in SSA than in other regions with ample margins. As a result, the 'Total project cost / Civil work' ratio of SSA is 1.69 for successful new construction projects in SSA, which is higher than 1.44 in other regions. Reasons for this feature could be a result of the relatively shorter history of irrigation development in SSA. There are a relatively limited number of experienced construction engineers, irrigation engineers, consultants, and contractors in the region, which makes 'Management' costs higher. Little experience with irrigated agriculture and the O&M of irrigation schemes increases the need to support technology development, institution building, and training for farmers and irrigation officials, which makes 'Ag-support' costs higher.

The second data set is given by the project completion report of Mwea Project 1990 implemented in 1989-1992 and the third data set is of Mwea Project 2017. Both, reporting project costs with cost breakdowns (Nippon Koei, 1993 and JICA internal data), provide us with invariable project cost data, the former of *ex-post* and the latter of *ex-ante*, and thereby the structure of project costs, which are summarized in Table 7.

Mwea Project 1990 data set reports the direct construction costs separately from indirect project costs, but some of line items under the indirect project costs seem to be 'Civil-work cost' in our cost classification. If all indirect construction costs as reported are included in 'Management cost' (Cost structure i in Table 7), the total share of overhead costs is more than 50% and 'Civil-work' cost and 'Total project cost / Civil work cost' ratio is as high as 2.27. If an indirect cost item, which is supposed to belong to 'Civil-work', is adjusted for, the 'Total project cost / Civil work cost' ratio becomes 1.76 (Cost structure ii), which is at a comparable level as an average 20th century successful new construction project in SSA of the same size. If, in addition, another cost item seemingly belonging to 'Civil-work' cost is adjusted for, the ratio is further reduced to 1.52 (Cost structure iii), a level still higher than that of 20th century successful new construction projects in non-SSA regions.

As reported, the 'Total project cost / Civil work cost ratio' for the planned project costs of Mwea Project 2017 is also high, 1.93 (cost-structure iv in Table 7). This is partly because taxes (VAT and tariffs) and interests are included in the planned costs. Theoretically, taxes, subsidies, and interests are not to be included in the project costs as well as in the project benefits, since they are merely transfer of income, to be canceled out between payers and receivers. The cost structure that purges them from 'Other-overhead cost' is shown as cost structure v) in Table 7. The resulting 'Total project cost / Civil work ratio' is 1.73, which is close to the ratio of 20th century irrigation projects and of Cost structure ii of Mwea Project 1990.

3-3. Estimated project costs for constructing the Mwea Irrigation Scheme

Table 8 summarizes the estimated costs for constructing the Mwea Scheme today as a brand-new scheme and compares them with each other and with those of 20th century irrigation projects.

The unit project cost per ha at the initial construction phase of 1954-68 with the 3,000 ha of irrigated area is estimated to be US$ 10,071 in 2016 prices, which is higher than the average unit cost of 20th century successful new construction projects in SSA. The deflation of the dollar value over more than a half-century is a hazardous operation, particularly because for years before 1960 our deflator is linked with the IMF's World Export Price Index, which is said to have substantial bias as a world price index (Silver, 2007). However, the difference between them is large enough to allow an inference that the construction of the Mwea Scheme in the initial construction phase was costlier than the average 20th-century successful new construction projects not only in non-SSA but also in SSA.

The total project cost to construct the Mwea Scheme as of 2017 is estimated by assuming three levels of 'Project cost / Civil-work cost ratio'. For this ratio = 1.5 (low estimate), the unit project cost per ha is estimated to be US$ 13,706, which is substantially higher than that of the initial construction phase. This is expected because Mwea Project 1990 not only rehabilitated and modernized the existing irrigation infrastructures but also constructed many new ones, resulting in a large increase in the irrigated area. If the 'Project cost / Civil-work cost ratio' is higher as in the high estimate, the unit project cost would be US$ 18,275, which is more than twice as that of the 20th century 'successful' new construction projects in SSA.

IV. Economic Viability of Mwea Scheme (New) Construction

We examine the economic profitability of constructing the Mwea Scheme as of 2017 as a new scheme by estimating the internal rate of return (IRR) of the investment based on the project costs estimated thus far. Since the basic purpose of this study is to examine whether it is economically worth investing in large-scale irrigation projects financed and implemented by public institutions, such as national governments and international donor agencies, as a means to enhance food security in SSA, the IRR we estimate is the 'economic' IRR, as against 'financial' IRR that measures private profitability. Although the IRR was, and still is, an indicator which is most conveniently used in assessing the economic performance, *ex ante* as well as *ex post*, of large-scale irrigation projects, it has long been criticized for its many defects. As early as in the 1980s, Tiffen (1987) strongly warned against the use of the IRR as the single most decisive criterion in planning irrigation projects or in evaluating the post-project performance, for its defects. The most serious defect is its inability to assess the sustainability of projects. The IRR is a static indicator estimated, for example, at the time of project completion with an assumption that the benefit then lasts for the life-time of the project, but it may decline due to poor O&M. As explained earlier, this was indeed the case for many 20th-century irrigation projects (Tiffen, 1987; WCD, 2000). Another related defect is that the IRR, when it is higher than 10%, is insensitive to a project life span of more than 30 years, because the benefits of the distant future are discounted to nearly null. This feature of IRR makes it an inadequate criterion to assess project sustainability. The static nature of IRR also makes it difficult to cope with risk and uncertainty associated with the estimation of costs and benefits, resulting in under-estimation of costs and over-estimation of benefits. Tiffen (1987) states that, given the uncertainty attached to its estimation, the IRR of 8% or less should be ruled out as within the margin of error that could include a negative outcome. Although all these arguments still remain valid, we are going to use the IRR, while keeping these drawbacks in mind, because no better convenient alternative is available.

1. The internal rate of return (IRR)

The IRR is a discount rate that equates the present value of project costs and the present value of project benefits. In this study, the IRR is defined as r that satisfies the following equation:

$$(1+r)^m \mathrm{K} = \sum_{j=1}^{J} [j(R-c)/(J+1)]\,(1+r)^{J-j} + \sum_{n=1}^{N} (R-c)/(1+r)^n \qquad \text{Eq. (1)}$$

where K = project investment, R = returns from the investment, c = O&M cost, m = average gestation period of investment in years, J = the year a partial benefit starts accruing before the full benefit is attained, N = lifespan of the scheme in years, and r = internal rate of return. It is assumed that the partial benefits reach the full benefit linearly from no benefit in the year (J - 1) years before the completion of the project. The second term of the right-hand side of Eq. (1) can be written as:

$$\sum_{n=1}^{N} (R-c)\ /\ (1+r)^{n} = (R-c)\ \sum_{n=1}^{N} 1/(1+r)^{n}$$
$$= (R-c)\ [\ ((1+r)^{N} - 1)\ /\ r(1+r)^{N}\ ].$$

Inserting this to Eq. (1) and transferring the right-hand terms of the equation to its left-hand side, we obtain:

$$(1+r)^m K - \sum_{j=1}^{J} [j(R-c)/(J+1)]\ (1+r)^{J-j}$$
$$-(R-c)\ [\ ((1+r)^{N} - 1)\ /\ r(1+r)^{N}] = 0 \qquad \text{Eq. (2)}$$

‘r’ that satisfies Eq. (2) can be obtained by using any numerical computation software. The Goal Seek function of Microsoft EXCEL is the most easily available software to compute ‘r’. Readers can check the results of our IRR estimation easily by inserting Eq. (2) and assumed parameters in the Goal Seek function.

It should be noted that the cost and benefit in Eq. (1) are both confined to those directly related to the project. There are indirect costs, such as negative environmental effects, as well as indirect benefits, such as positive linkage and multiplier effects of increased agricultural production, both bought about by the project. These indirect costs and benefits, which must be included in the cost-benefit analysis of large-scale irrigation projects, are not included in this study, as the case for irrigation project reports in general, because of the difficulty in obtaining necessary data.

2. Assumptions on variables and parameters

We estimate the IRR for the 'initial construction phase project' (as of 1968) and the 'after-the-modernization project' (as of 2017). Both are 'new construction projects', the project costs of which are presented in Table 8.

2-1. Common assumptions

The returns from the investment (R): Since the Mwea Scheme is an irrigation scheme meant for rice production, we measure the return (R) in Eq. (1) as value-added (income) generated in the rice production in the irrigated area created by the project:

$$R = P \alpha \beta Y, \qquad \text{Eq. (3)}$$

where R = returns (US$/year), P = rice price (US$ / ton of milled rice), α = rice milling rate, β = value-added ratio, and Y = increase in rice (paddy) production (t/ha/year) due to the project, which may be expressed as $Y = \gamma y$, where y = rice (paddy) yield per season and γ = cropping intensity (no. of crops/year). Since Y is the increase in crop output due to the projects, the output in the Scheme area before the production, if any, must be deducted. However, since the area where Mwea Scheme was constructed had been vacant except for extensive stock grazing (Moris, 1973), we assume no output in the area before the project.

Value-added ratio (β): β is the ratio of the value-added to the value of total output in rice production, the value-added is the total output value less current inputs, and the current inputs are the inputs the entire value of which is transferred to the output within a production cycle, such as seeds, fertilizers, and fuel for tractors. If other non-land production factors used in the crop production after the project have some opportunity costs, they must be deducted from the value-added of the after-project crop production. This adjustment can be made through adjusting β. In this study, we assume two levels of β; 0.8 and 0.5. The former level is the value-added ratio with no opportunity costs for other non-land factors. The actual expenditures on current inputs in the Scheme took about 20% of the rice output value in 1964-68 (Sandford, 1973) as well as in 2016 (our survey), though the composition of current inputs differs between these two periods; a higher share of fertilizer in 2016 for the principal crop is counterbalanced by the ratooning that requires little fertilizer. The latter level is the opportunity-cost-adjusted value-added ratio obtained by assuming positive opportunity costs for labor and machine rental, evaluated at the market prices based on our survey in 2016. These opportunity costs could be subject to overestimation. The opportunity cost of labor may be much lower because the farmers who settled in the Scheme area were landless people who could not find productive employment opportunities in their original places (Chambers, 1973). In 1964-68, unlike in 2016, the costs of large farm machineries used for rice cultivation are included in the capital costs of the construction project in an inseparable way from heavy construction machineries. It can be expected, however, that the appropriate value-added ratio to be used in the estimation of the IRR certainly lies in the range bounded by these two value-added ratios.

Scheme's life span (N): It has been a convention in planning irrigation projects to assume a lifespan of 50 years for a newly constructed scheme. All people working in the irrigation sector know how fictional it is; virtually no irrigation scheme constructed in the second-half of the 20th century fulfilled this life-span. The Mwea Scheme, too, has had two modernization/ rehabilitation projects with about 20-year intervals since the initial construction phase, which means its lifespan was no more than 30 years. Also, the IRR of larger than 10% is nearly completely insensitive to the lifespan over 30 years, as explained earlier. These considerations lead us to assume a lifespan of 30 years in both projects.

Rice price (P): The rice price to be used in Eq. (2) is the shadow (or opportunity) price of rice that consumers in Kenya have to pay if there is no domestic rice production. It is economically justified for the governments and international donor agencies to help increase domestic rice production through constructing an irrigation scheme, only when the unit cost of producing rice in the scheme could be lower than the unit cost of importing rice from abroad. Although the price of rice varies greatly according to its quality, the public concern about the food problem as a basis for public investments on irrigation requires rice under consideration to be of ordinary quality. In this study, Thai 5% broken or Thai A1 super (broken rice) is taken as representative rice of ordinary quality in the world rice market. Thai 5% broken was considered as a relatively higher grade among various grades of rice in the second half of the 20th century, but in this century, particularly since the mid-2010s, rapid increases in the export of high-quality, high-grade rice, such as Jasmin (aromatic long-grain) rice, have made it a relatively low grade rice. This is demonstrated by changes in the price difference between Thai 5% broken and Thai A1: the FOB price at Bangkok of the former was more than 50% higher than that of the latter on average until the mid-1990s, but the difference reduced to only 3% in 2014-2018.

It should be noted that the shadow price has been subject to large fluctuations from 1948 to 2018 (Fig. 2). Here, we point out three salient features in the past trend of the world price in the 2016 constant prices, First, the world had experienced periodic sudden price soaring or food-crisis, from the one in the early 1950 due to the Korean War to the world food-crisis in 1974, until the end of the 1970s. However, except for these crisis periods, the price was at around US$ 600/t in constant prices. Second, the price began to decline in 1980 due to the Green Revolution and by 2001 reached a level as low as one-third of the pre-Revolution period. Third, the price in current prices jumped up to the historically highest level in the food-crisis of 2008, but its peak price was at the pre-Revolution period level of US$ 600/ton once deflated to the 2016 constant prices.

2-2. Initial construction phase project

Cost-side parameters

Average gestation period of investments (m): Since the irrigated area increased steadily year by year in the initial construction phase (Sandford, 1973), the average gestation period is assumed to be 1 year.

O&M cost (c): Assumed to be US$ 9.1/ha/year in 1960 prices, based on the O&M expenditures in 1968 (the last year of this ‘project’) as reported in Sandford (1973).

Benefit-side parameters

Cropping intensity (CI) after the project (γ): From the construction in the 1960s to 1989, rice was planted in the Scheme once a year during May-February (Veen, 1973; JICA, 1989), so the cropping intensity after the project was 1.0.

Increase in paddy production (Y): Veen (1973) reported that the average paddy yield (y) in the Mwea Scheme from 1961 to 1971 was 6.4 ton/ha/season, which, coupled with CI, gives $Y = \gamma y =$ 6.4 t/ha/year.

Rice milling rate (α): Assumed to be 65% based on IRRI (2013).

Rice price (P): Sandford (1973) assumed in his cost-benefit analysis 29 cent per lb. of shadow price while referring to the producers’ rice price in Tanzania, adjusted for transportation and marketing costs. This price was roughly equivalent to US$ 89/t in 1960 prices. In retrospect, this could have been an estimate that gives the lower-bound shadow price. The construction of the Mwea Scheme was planned in the early 1950s when the world rice price soared due to the Korean War (Fig. 2). The Bangkok FOB price of Thai 5% broken was US$ 138/t in 1960 prices on average from 1951 to 1954, which could be converted to the Mombasa CIF price of Thai A1 of US$ 105/t by adding the insurance and freight costs (to be explained in the next sub-section). Let us assume this as the higher-bound shadow price.

Year partial benefits start accruing (J): Since the gestation period of the construction investments is short, J is assumed to be null.

2-3. The ‘after-the-modernization’ project

Cost-side parameters

Average gestation period of investments (m): The average gestation period depends on the construction period of the project. The average construction period of the 20th-century irrigation projects in SSA was seven to eight years for new construction as well as rehabilitation projects, and the planned construction period of the on-going modernization project, Mwea Project 2017, is eight years. For this 'construction' project, we assume that the total project cost is equally distributed during the construction period of eight years, which leads to m = 4.5 years.

O&M cost (c): Assumed to be US$ 189 /ha/year in 2016 prices, based on JICA's field study conducted in Mwea Scheme in 2009 (unpublished). This cost includes recurrent expenditures for O&M and the depreciation cost of O&M equipment.

Benefit-side parameters

Cropping intensity after the project (γ): As in earlier years, the main rice crop in the Scheme is planted in the short-rain season from July to December. All farmers in the Scheme plant the main crop, about 90% of them harvest a ratoon crop in late-January to February, and about 10% of farmers plant the second main crop, instead of ratooning, from February to May. Including the ratoon crop, therefore, CI is 2.0/year.

Increase in paddy production (Y): Based on our field surveys conducted in the all sections of Mwea Scheme in 2016 and 2018, the average yields, 6.2 t/ha/crop for the main crop (first harvesting) and 2.8 t/ha/crop for ratoon crop, are assumed to be the paddy yields in the project. With the CI of 2.0, and assuming the same yield as the main crop for the second crop, the total paddy production is 9.3 t/ha/year. It should be noted that this yield performance belongs in the top group among large-scale irrigation schemes in SSA. Other irrigation schemes in the top group are the Kpong Irrigation Scheme in Ghana, attaining 13 t/ha/year (Tinsley, 2009), and the Senegal River Valley in Senegal (Nakano et al., 2011) and the Office du Niger in Mali (Bartier et al., 2014), both attaining 10t/ha/year.

Rice milling rate (α): Assumed to be 70% based on our survey.

Rice price (P): Referring to Fig. 2, we set three price-regimes: low, medium, and high. The low-price regime extends from 1986 to 2004 with the average world price of US$ 292 /t in 2016 prices, the medium price regime from 2014 to 2018 with the average price of US$ 386 /t, and the high-price regime from 2008 to 2013 with the average price of US$ 495 /t. These FOB prices at Bangkok are converted to the CIF prices at Mombasa, Kenya, of US$ 346 /t, US$ 440 /t, and US$ 549 /t, respectively, by adding the freight rate of US$ 45 /t, which is the average container freight rate from Asia to Africa over 2010-2017 in 2016 prices (data are from UNCTAD, 2018), and the insurance cost of US$ 10 /t (in 2016 prices; data are from our survey in Uganda). We assume US$ 350 /t, US$ 450 /t, and US$ 550 /t as the shadow prices, respectively.

Incidentally, the high-price level roughly corresponds to the farm-gate price of rice in

Mwea Scheme, if adjusted for the import tariff of 35% and the importers' handling charge of 10%. The average (paddy) rice price received by Mwea farmers in 2016 was Ksh 55/kg, or US$ 774 per one ton of milled rice with 70% of milling rate and the exchange rate of US$ 1 = Ksh 101.5, while the high-price regime Mombasa CIF price, when adjusted for the tariff (35%) and importers' handling charge (10%) to be ready to go into the Kenyan domestic rice market is US$ 798/ton in 2016 prices. This is not because the world price of ordinary rice in this year is high, but because many farmers in Mwea Scheme at present plant Basmati varieties which are non-ordinary varieties that command in the consumer markets in Nairobi a price higher than those of ordinary varieties. These data are also consistent with the data obtained from a Nairobi consumer market survey in 2008-09 by JICA (unpublished), which shows that the price of Thai long grain rice (Ksh 182 /kg) is slightly higher than that (Ksh 140-160 /kg) of Mwea ordinary, a popular brand of Basmati rice produced in Mwea Scheme.

Year partial benefits start accruing (J): Referring to other projects and You et al. (2010), J is assumed to be three years, i.e., partial benefits start accruing three years before the full benefits are realized.

3. Results of estimation

The results of IRR estimation for the two 'projects' are summarized in Table 9. In the latter-half of the last century, the World Bank, the Asian Development Bank, and other international donor agencies, adopting the interest rates of 10% - 12% for their loans, used these levels as the threshold levels of the IRR below which projects were considered unacceptable (Belli et al., 1998; Inocentio et al., 2007). The interest rate for lending has declined in this century; ranging at present mostly from 5% to 8% for countries in SSA, including 7.83% for Kenya (World Bank, 2019c). Considering the argument by Tiffen (1987) that the IRR less than 8% could be within the margin of error, it would be preferable for a project to have the IRR that is higher than 8%.

The 'As of 1968' project is an apparently 'successful' project, even for the lower shadow price of rice and the lower value-added ratio. Sandford (1973) estimated the NPV of the project with the rice price of US $ 89/t for three discount rates, 5%, 10%, and 15%. The NPV declines as the rate increases but remains positive at 15%, and its declining trend indicates that it would reach nil at the discount rate of about 18%, which is close to our estimation for β=0.8.

The results for the 'As of 2017' project show that the IRR is sensitive to the assumptions made on project cost, rice price, and value-added ratio. The sensitivity is particularly high for value-added ratio. If β=0.8, i.e., if no opportunity cost for non-land factors, the IRR is higher than 8% for the rice price of US$ 450/t or higher, regardless of the level of project cost. However, for β=0.5, i.e., if the opportunity costs are fully accounted for at the market prices, the IRR barely exceeds 8% only if the project cost is low and the rice price is high. All this suggests that the new construction of the Mwea Scheme with the irrigation infrastructure as of 2017 may be economically viable, but the viability is marginal, by no means robust.

It may seem strange that the ‘As of 1968’ project with the cropping intensity of 1.0 is apparently ‘successful’ whereas the ‘As of 2017’ project with a higher cropping intensity is only marginally ‘successful’. The difference stems primarily from the difference in the rice price relative to the project costs; it was higher for the former project in the high-rice-price era before the 20th-century Green Revolution than for the latter project in the low-rice-price era after the Revolution. Even during the mini-rice-crisis of 2008–2013, the rice price, once deflated, is lower than the non-crisis price level in the pre-Revolution period (Fig. 2).

4. Some large-scale irrigation projects in the 21st century

As stated repeatedly, the Mwea Scheme is one of the best irrigation schemes in SSA, in terms of water availability, rice yield, and cropping intensity. Though tapping water from two rivers, it is a simple river-diversion type of irrigation scheme, with no water storage capacity, and yet the investment project to construct it is only marginally successful. A straightforward implication is that there would be few large-scale irrigation construction projects in SSA which are economically viable.

For example, in the case of World Bank’s Shire Valley Transformation Program Phase 1 Project in Malawi, the planned unit project cost is US$ 15,000 /ha in 2017 prices (World Bank, 2018), the same level as the medium estimate for our Mwea Scheme new construction project. This project is not a pure new construction project with nearly 70% of the net irrigated area of private estates’ sugar-cane area which has been successfully irrigated by pumps (World Bank, 2017a). If the IRR of 11% for the investment is to be attained, as targeted in its Project Appraisal Report (World Bank, 2017b), the performance of irrigated agriculture in the Project area (mainly crops with some livestock and aquaculture) must be far better than that of the Mwea Scheme. Similar cases are irrigation developments being envisaged by the Millennium Challenge Corporation in Burkina Faso, Mali, and Senegal, the indicative unit project costs of which range from US$ 15,000 /ha to US$ 34,000 /ha (Merrey and Sally, 2017). Another example is supplied by the on-going Mwea Irrigation Development Project supported by JICA (the ‘Mwea Project 2017’ in this paper), which is a modernization/rehabilitation project, with the unit project cost of US$ 23,000 /ha in 2009 prices (JICA, 2010), which is higher than our high-estimate for new construction. For this JICA project, too, the IRR of the investment is expected to be 10.8%.

It should be noted that the unit project costs of these recent large-scale irrigation projects are far higher than those of the 20th century ‘success’ projects (Table 8). On the other hand, it seems that these 21st century large-scale irrigation projects aim at an IRR of more than 10% like their 20th century counterparts. The crop performance that satisfies the target IRR is accordingly higher than that of the last century. Some of the recent projects are non-rice schemes, but if we evaluate the performance of these schemes according to 'rice-scheme equivalent', the IRR of 10% for a new construction project under the high-price regime for the world rice price, with the opportunity-cost-adjusted value-added ratio of 65% (the median for the Mwea 'As-of-2017' project), and other basic parameters as in the Mwea 'As-of-2017' project, the unit project cost of US$ 15,000/ha and of US$ 30,000/ha require that the average rice yield of the scheme must be more than 9 t/ha/year and 20 t/ha/year, respectively; the former performance level is about the level of the Mwea Scheme's performance as of 2016-18 and the latter one is a high level that has thus far been achieved by few irrigation schemes in the world. Likewise, the IRR of 10.8% for the JICA's rehabilitation project mentioned above with 13% increase in the net irrigated area, shift from single cropping to the cropping intensity=1.9, 50% yield increase, and the opportunity-cost-adjusted value-added ratio of 65%, and under the high-price regime, the unit project cost of US$ 21,500/ha in 2016 prices (excluding interests and taxes but including price contingencies) requires the rice yield of 8.7 t/ha/season after the project. All these examples suggest that the irrigation project planners in the 21st century have the same strong tendency to over-estimate the project benefits as their 20th century counterparts.

You et al. (2010) examine how much irrigation potential Africa would have for large-scale irrigation development if a part of water stored by the existing dams were diverted for irrigation and find for SSA a potential area of 1.4 million ha if the investment cost is US$ 3,000/ha and IRR > 12%, and 5.6 million ha if the investment cost is US$ 8,000/ha and IRR > 0%. You et al. (2014) examine the same for Kenya and conclude "… under low-cost assumption, 58 dams of 73 are profitable. At high cost level, the number is 52. If we raise the IRR cutoff value to 12%, 32 dams are economically feasible. We showed that there is considerable scope for the expansion of … dam-based … irrigation in Kenya (p.34)". The first two statements on 'profitability' are based on IRR>0% and the third one on the low-cost assumption of US$ 5,000/ha (stated so in the text but data in the online supplementary material indicate it is US$ 3,300/ha). We wonder if it is at all meaningful to assume a level of construction cost as low as US$ 3,000/ha (or US$ 3,300/ha) without considering such overhead costs as agricultural supports or to adopt IRR > 0% as a criterion for profitability. If the civil-work cost alone is considered as the construction costs, the IRR of the Mwea 'As-of-2017' project is 10% or higher under all the assumptions except for the case under the low-price regime with β=0.5 (Table 9). However, such results, which are obtained not including other indispensable costs, such as scheme designing, engineering and project management, and planning and preparation for O&M after the completion of the project, are not only meaningless but, as pointed out by Flyvbjerg and Sunstein (2016), misleading.

V. Conclusions

The historical trends of the world rice price in Fig. 2 remind us of a fact that the boom in irrigation investment in the last quarter of the 20th century was induced and enhanced by repeated food crises in the 1960s and 1970s (Hayami and Kikuchi, 1978). The intermission in large-scale irrigation investment from the late 1990s to the 2000s might have been due more to the low-price regime in the world rice market resulting from the success of the Green Revolution, which made it difficult to justify costly irrigation projects, than to deliberate reflection about the poor performance of many large-scale irrigation projects implemented during the boom period. The fact that large-scale irrigation projects come back as soon as the 2008 rice crisis occurred seems to support this contention.

Our exercise to evaluate the economic viability of large-scale irrigation development by estimating the cost of constructing the Mwea Irrigation Scheme, one of the best irrigation schemes in SSA, as a brand-new scheme shows that the investment performance of such a project may exceed the acceptable IRR level of 8% to 10% when the high-price regime of 2008-2013 prevails in the world rice market and if the opportunity costs of the non-land production factors used in the crop production after the project are not high. The results imply that high rice prices, coupled with the high performance of irrigated agriculture, as high as 9 t/ha/year in terms of rice yield, would justify expensive large-scale irrigation development, the project cost of which is as high as US$ 15,000/ha or even more expensive. Though rare, there are some irrigation schemes in SSA which attain such high levels of crop performance. It is certain that there is untapped irrigation potential in SSA for large-scale irrigation development, construction of new schemes or rehabilitation of existing ones, and there would be some large-scale projects which are economically justified, even in SSA where such projects generally suffer from scale-diseconomy. Should we welcome them as promoting SSA's Green Revolution?

For the answer to this question to be 'Yes', many conditions must be satisfied. Above all, we would ask if we have invented a way to overcome the 'malevolent hand' that works in large-scale irrigation projects. Is it not that higher project costs and higher potential agricultural productivity of large-scale irrigation projects in this century creates much more room for the malevolent hand to maneuver for underestimating project costs and overestimating project benefits? How to break the vicious cycle of the 'build-neglect-rebuild' syndrome to prevent the moral hazard in scheme maintenance from occurring? What about appropriate institutional frameworks for effective O&M for scheme sustainability? The project overhead costs include the costs for planning, preparing, and training for O&M, which is one of the reasons for the escalation of the project costs in recent years. However, it is a necessary but not sufficient condition for effective O&M to be provided in an irrigation scheme with such costs. By now various methods in irrigation development, aside from large-scale irrigation, have been identified and elaborated in SSA, many of which could be more profitable than large-scale projects in terms of the IRR. When planning a large-scale irrigation project, a serious comparison must be made with these irrigation methods, based on detailed grass-root studies of the area planned for the project, which was rarely done in the 20th-century large-scale irrigation development.

Unless these problems and defects inherent in large-scale irrigation development are overcome, we conclude that the promotion of such projects results in a substantial waste of resources.

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Table 1. Characteristics of 20th century large-scale irrigation projects [a]

	Sub-Sahara Africa			Non-SSA regions		
	All data		Cost data	All data		Cost data
Number of projects						
New construction	26		8	100		51
Rehabilitation	19		11	169		112
Total	45		19	269		163
Mean project area (1000 ha)						
New construction	10		16	68		68
Rehabilitation	54		68	269		278
Mean unit project costs (US$ 1000/ha) [b]						
New construction	14.5		13.0	6.6		7.9
Rehabilitation	8.2		6.8	2.3		1.8
% failure projects [c]						
New construction	50		63	33		45
Rehabilitation	37		45	21		24
Cost overrun [d]		All data			All data	
No. of projects (%)		44			48	
Rate of overrun (%): mean (sd) max	52	(70)	254	40	(42)	176
Cost underrun						
No. of projects (%)		53			51	
Rate of underrun (%): mean (sd) max	-27	(21)	-81	-24	(20)	-94
IRR over-estimation						
No. of projects (%) [e]		62			71	
Rate of over-estimate (%): mean (sd) max	91	(67)	295	46	(35)	196
IRR under-estimation						
No. of projects (%)		27			26	
Rate of under-estimation (%): mean (sd) max	-44	(28)	-106	-33	(23)	-305

a) 'All data' consists of 314 irrigation projects analyzed by Inocencio et al. (2007), and 'Cost data' is a subset of this database, consisting of 182 projects, for which projects costs are reported in their Project Completion Report with an appropriate cost-breakdown. Irrigation projects are classified either in new construction or in rehabilitation projects.

b) In 2000 constant prices, from Table 6 of Inocencio et al. (2007)..

c) A project is 'failure' if the internal rate of returns (IRR) of the project investment, estimated at the time of project completion, was less than international donors' interest rate for lending (11%).

d) Rate of cost overrun = (project cost reported at completion - project cost at appraisal) / project cost at appraisal

e) Rate of IRR over-estimation = (IRR at appraisal - IRR at completion) / IRR at appraisal

Table 2. Cost structure of 20th century irrigation projects [a]

	SSA	Non-SSA
	…… % ……	
Civil-work cost	61	77
Management cost	27	14
Ag-support cost	8	4
Other-overhead cost	4	6
Total (total project cost)	100	100
Total project cost / Civil work cost [b]	1.63	1.30

a) The means for 182 large-scale irrigation projects, which is a subset of the projects studied by Inocencio et al. (2007). As to the cost components, see the text.

b) The ratio of the total project costs to Civil work cost.

Table 3. Results of regression analysis, regressing unit total project cost and unit component costs (US $ /ha; in logarithm) on total project area (in logarithm) and some project-specific variables [a]

	Ln Total project cost		Ln Civil work		Ln Management		Ln Ag. support		Ln Other overhead	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Ln Total area (1000 ha)	-0.512	2E-29	-0.486	6E-26	-0.650	6E-31	-0.648	1E-15	-0.380	0.013
Rehabilitation [b]	-0.688	8E-08	-0.684	3E-07	-0.559	3E-04	-0.149	0.528	-1.080	0.009
Failure [c]	0.420	0.001	0.458	7E-04	0.239	0.126	-0.135	0.577	0.257	0.562
Year started [d]	-0.026	0.003	-0.030	9E-04	-0.024	0.023	-0.001	0.971	0.002	0.963
Sub-Sahara Africa [e]	-0.070	0.712	-0.229	0.249	0.201	0.390	0.556	0.117	0.405	0.654
Intercept	60.788	4E-04	68.331	1E-04	54.994	0.008	8.299	0.803	3.373	0.960
R^2	0.731		0.701		0.707		0.480		0.267	
No. of observations	182		182		182		157		86	

a) For the definition of component costs, see Table 2.

b) A dummy variable that takes 1 if the project is rehabilitation project and 0 if new construction project.

c) A dummy variable that takes 1 if the internal rate of returns of the project is less than 11% and 0 if 11% or higher.

d) The year the project started.

e) A dummy variable that takes 1 if the project was of Sub-Saharan Africa and 0 if otherwise.

Table 4. Brief history of Mwea Scheme Development [a]

1954 - 1960	Constructed by the Kenyan government with assistances from the British and the US governments. Settler-farmers (tenants) were given 4 ac. of land.
1960	Irrigated paddy area = 2,000 ha; Rice yield = 6.4 t/ha (Sindano; average for 1961 - 1971); 1 crop/year
1963 - 1978	Step-by-step extensions of irrigation units with assistances from Kenyan government, UK Freedom from Hungers, and German aid agency of KFW.
1968	Irrigated paddy area = 3,129 ha
1972	Irrigated paddy area = 4,800 ha
1988	Irrigated paddy area = 5,900 ha; Rice yield = 4.8 t/ha (av.), Sindano (37%) 5.0 t/ha, Basmati (55%) 4.5 t/ha, BW 196 (8%, from IRRI) 6.0 t/ha; 1 crop/year
1989 - 1992	A modernization-rehabilitation project (JICA grant-aid project) was implemented (New Nyamindi Headworks and Link Canals I and II were newly constructed).
1997	Irrigated paddy area = 6,000 ha; Rice yield = 4.6 t/ha (Sindano (33%) 6.0 t/ha), Basmati (67%) 3.9 t/ha); 1 crop/year;
1998	Management of the Scheme, which had been fully by NIB (National Irrigation Board), was taken by two farmers' cooperatives.
2003	Joint management between NIB (from head works to the secondary distribution systems) and WUA (water-users' association; tertiary distribution system and below) was established.
2009	Irrigated paddy area = 7,900 ha ; Rice yield = Basmati 3.6 t/ha; ratooning 1.4 t/ha, Sindano 5.0 t/ha: 1.7 crops/year (1.0 for first-planting and 0.7 for ratooning
2007 - 2013	Natural Resource Management Project of World Bank was implemented (Paddy-fields in Nderewa North and Marura Out-growers sections were developed).
2017	Irrigated paddy area = 8,500 ha; Rice yield = 6.2 t/ha[b]; 2.0 crops/year (1.1 for first-harvesting and 0.9 for ratooning)
2017 -	A modernization-rehabilitation project (JICA loan-project) has been on-going (New Thiba dam and Link Canal III are to be constructed, Mutithi East area is to be expanded, and rehabilitation and improvements for other parts of the scheme. After completion; irrigated area = 8,910 ha including out-growers sections (12,400 ha according to our survey in 2017-2018).

a) Information sources are Chambers (1969), Chambers (1973), Veen (1973), JICA (1988; 1989; 1997), Nippon Koei (1993), Kabutha and Mutero (2002), Abdullahi et al. (2003), GIBB (2010), and our surveys in 2016 and 2018.

b) The weighted average in 2016 (weight = planted area by irrigation unit), based on our field survey.

Table 5. Direct construction cost of Mwea Irrigation Scheme estimated by the Consultant, in 2016 prices [a]

Structures / facilities / works	Quantity	Estimated cost	
		Ksh million	US $ million [b]
1 New Nyamindi Headworks		132.3	1.303
2 Thiba Headworks		58.5	0.576
3 Nyamindi Headrace	875 m	80.6	0.794
4 Nyamindi Main Canal	4,880 m	111.6	1.100
5 Nyamindi Branch Canal-1	6,460 m	99.6	0.981
6 Nyamindi Branch Canal-2	4,649 m	87.0	0.858
7 Nyamindi Branch Canal-3	3,560 m	39.4	0.388
8 Link Canal-I	10,887 m	431.3	4.250
9 Link Canal-II	3,509 m	152.8	1.505
10 Thiba Main Canal	9,417 m	428.9	4.226
11 Thiba Branch Canal-1	3,418 m	75.8	0.747
12 Thiba Branch Canal-2	4,900 m	74.7	0.736
13 Thiba Branch Canal-3	5,825 m	143.4	1.413
14 Thiba Branch Canal-4	16,100 m	382.9	3.772
15 On-farm Development	8,502 ha	5,586.3	55.037
Total		7,885.0	77.685

a) The irrigation infrastructures and facilities, the original construction costs of which were estimated, are of those that existed at the time of the project appraisal of Mwea Irrigation System by JICA for a modernization project. For details, see JICA and Nippon Koei (2018).

b) Exchange rate in 2016: US $ 1.00 = Ksh 101.50.

Table 6. Cost structure of 20th century irrigation projects at the project size of 8,500 ha[a]

	SSA	Non-SSA
	.... %	....
All projects		
Civil-work cost	60	71
Management cost	19	15
Ag-support cost	13	9
Other-overhead cost	7	6
Total project cost	100	100
(Total project cost / Civil work cost	1.66	1.42)
New construction projects		
Civil-work cost	60	70
Management cost	18	13
Ag-support cost	11	7
Other-overhead cost	11	9
Total project cost	100	100
(Total project cost / Civil work cost	1.67	1.42)
Successful new construction projects		
Civil-work cost	59	69
Management cost	19	14
Ag-support cost	12	8
Other-overhead cost	10	8
Total project cost	100	100
(Total project cost / Civil work cost	1.69	1.44)

a) The total project cost and component costs are first estimated at the project size of 8.5 (1000 ha) by using the regression equations obtained in Table 3 (inserting the means or the relevant values for the non-scale variables), and then the percentage compositions are computed. For the component costs, see the text and Table 2.

Table 7. Cost structures of Mwea Project 1990 and Mwea Project 2017

	Mwea Project 1990 [a] (actual costs)	Mwea Project 2017 [e] (appraised costs)
	i) As reported [b]	iv) As reported [b]
Civil-work cost (%)	44	51
Management cost (%)	41	15
Ag-support cost (%)	15	6
Other overhead cost (%)		29
Total (%)	100	100
Total project cost / Civil work cost	2.27	1.97
	ii) Adjustment 1 [c]	v) Adjustment [f]
Civil-work cost (%)	57	58
Management cost (%)	29	17
Ag-support cost (%)	15	7
Other overhead cost (%)		19
Total (%)	100	100
Total project cost / Civil work cost	1.76	1.73
	iii) Adjustment 2 [d]	
Civil-work cost (%)	66	
Management cost (%)	20	
Ag-support cost (%)	15	
Total (%)	100	
Total project cost / Civil work cost	1.52	

a) JICA grant-aid project implemented in 1989-1991 to modernize and rehabilitate the Mwea Scheme. Data are from Nippon Koei (1993).

b) The reported line-cost items are sorted out to direct construction costs and indirect /overhead costs as reported in the Report. None of 'other overhead' cost is reported.

c) Transfer 'packing & transport costs' of construction materials from overhead cost to 'civil-work cost'.

d) In addition to packing & transport costs, transfer 'common temporary infrastructure costs' from overhead cost to 'civil work cost'.

e) The on-going JICA loan-aid project to modernize the Mwea Scheme. Data are from JICA internal records.

f) Exclude 'interests', 'commitment charges', and 'taxes' (VAT and tariffs).

Table 8. Construction costs of Mwea Scheme at the initial construction stage and after the first modernization project, in comparison with those of 20th-century large-scale irrigation projects [a]

				Remarks
I.	Initial construction phase (as of 1968) [b]			
1.	Project cost [c]	US $ '000	3,925	In 1960 prices
2.	Project area	ha	3,129	Irrigated area developed by 1968
3.	Unit cost per ha	US $ / ha	1,255	In 1960 prices
		US $ / ha	10,071	In 2016 prices
II.	After the modernization phase (as of 2017) [d]			
1.	Project costs [e] :			In 2016 prices
	Civil-work cost	US $ million	77.69	From Table 6 of this paper.
	Low estimate	US $ million	116.53	Project cost / Civil-work cost = 1.5
	Middle estimate	US $ million	132.06	Project cost / Civil-work cost = 1.7
	High estimate	US $ million	155.37	Project cost / Civil-work cost = 2.0
2.	Project area	ha	8,502	Grant aid area in 2017
3.	Unit cost per ha :			In 2016 prices
	Civil-work cost	US $ /ha	9,137	
	Low estimate	US $ /ha	13,706	
	Middle estimate	US $ /ha	15,533	
	High estimate	US $ /ha	18,275	
III.	Unit cost of 20th-century 'success' projects in SSA [f]			In 2016 prices.
1.	New construction	US $ /ha	8,347	
2.	Rehabilitation	US $ /ha	5,085	

a) The deflator used is constructed by linking Word Bank's world GDP implicit deflator (1960-2017) with IMF's world export price index (1945-1960). For the years concerned, the deflator takes the following values: 2016 = 1.0000, 2000 = 0.6860, and 1960 = 0.1246.

b) Actual capital and construction-related recurrent expenditures for 1954 - 1968. Data are from Appendix tables of Sandford (1973).

c) Consists of civil-work costs, management costs, ag-support costs (tractors and vehicles for O&M, and other overhead costs (land acquisition and social infrastructure). Labor costs for O&M are also included because it was not possible to separate from other labor costs. Recurrent expenditures on current rice production are not included.

d) Project costs, which are the costs if the Scheme is constructed now as a brand-new scheme with irrigation infrastructure in place in 2017.

e) Three levels of 'Project cost / Civil-work cost' ratio are assumed, based on Tables 6 and 7.

f) Data from Table 7 of Inocencio et al. (2007), converted from 2000 prices to 2016 prices.

Table 9. Internal rates of return (%) to the investment for newly constructing Mwea Irrigation Scheme in 1968 (3,129 ha) and in 2017 (8,502 ha) [a]

I. As of 1968 (in 1960 prices) [b]	
1. β=0.8	
Rice price = US$ 89 /t	19.1
Rice price = US$ 105 /t	22.1
2. β=0.5	
Rice price = US$ 89 /t	12.1
Rice price = US$ 105 /t	14.3

II. As of 2017 (in 2016 prices) [c]	Low cost	Medium cost	High cost	Civil-work cost alone
1. β=0.8				
Rice price = US$ 350 /t	8.7	7.6	6.4	12.4
Rice price = US$ 450 /t	11.1	10.0	8.6	15.4
Rice price = US$ 550 /t	13.3	12.0	10.5	18.0
2. β=0.5				
Rice price = US$ 350 /t	4.6	3.8	2.8	7.5
Rice price = US$ 450 /t	6.7	5.8	4.6	10.0
Rice price = US$ 550 /t	8.5	7.5	6.2	12.2

a) For the estimation formula and assumptions, see the text.

b) For the 'initial construction phase project'. Unit cost data from Table 8. β = (opportunity-cost-adjusted) value-added ratio. For details, see the text. The low rice price is the one used by Sandford (1973) based on the rice price in Tanzania and the high rice price is the Mombasa CIF price of Thai A1 (1951-1956 average).

c) For the 'after the modernization phase project'. Unit cost data from Table 8. β = (opportunity-cost-adjusted) value-added ratio. For details, see the text. The rice price is the Mombasa CIF price of Thai 5% broken: low price (1986-2004 average), medium price (2014-2018 average), and high price (2008-2013 average).

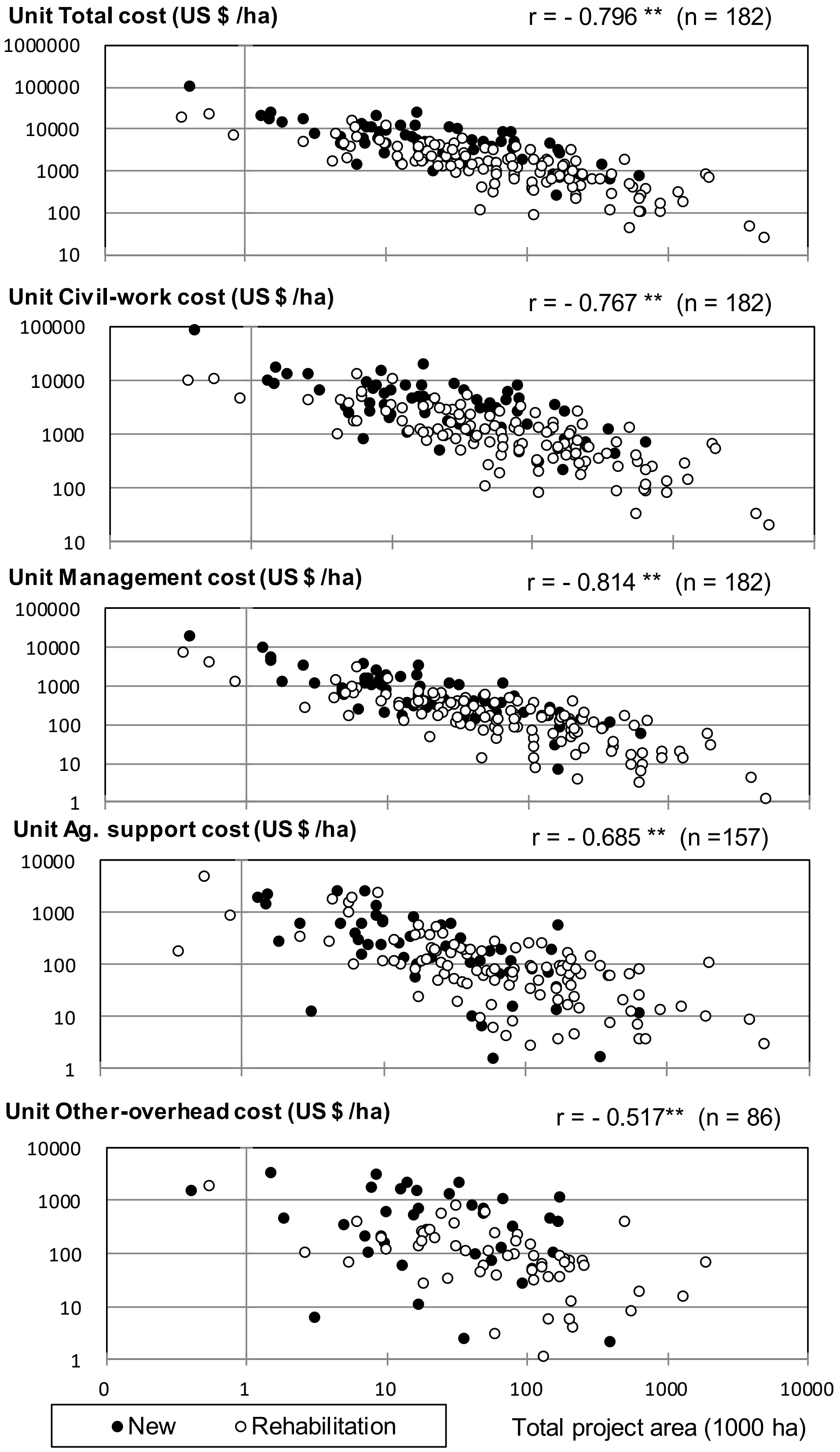

Fig. 1 Correlation between project-size (total area) and unit costs

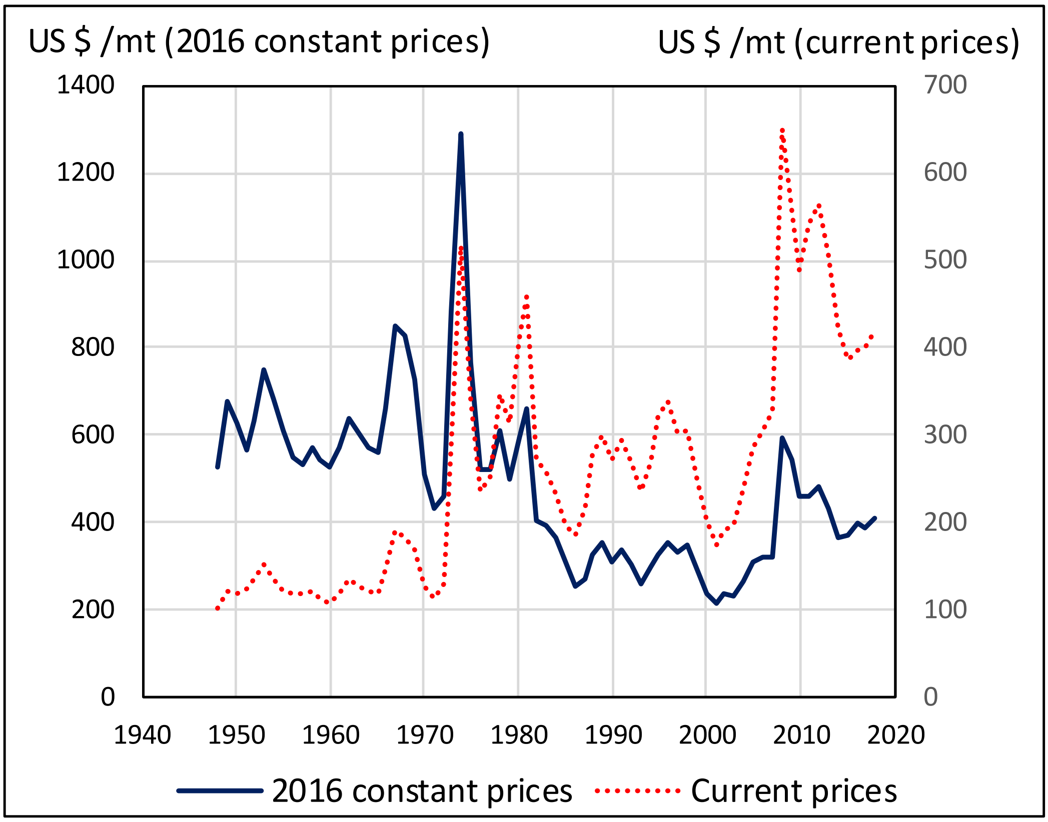

Fig. 2. World rice price (Thai 5% broken FOB Bangkok), 1948-2018

Data sources: For 1960-2018, World Bank Pink Sheet 1960-2018 (World Bank, 2019a) for both current and constant prices. Before 1960, the current price series compiled using the data from IRRI (2000) and Barker et al. (1985) is linked with the World Bank series, and deflated by the IMF World Export Price Index (1948-1960).