A comparative analysis of water pricing options on two large-scale irrigation schemes in West Africa

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Abstract:

Large-scale irrigation schemes producing food and commercial crops in West Africa typically charge a flat rate per hectare for water use. Economic theory suggests that this pricing system is ineffective in promoting efficient water use practices that value water as an economic good. With looming water scarcity partly due to climate change and partly because of growing demands for water due to population, urbanization and industrial-sector growth, there is mounting pressure for implementation of pricing systems that would promote efficiency and cost recovery on irrigation schemes. This paper evaluates the merits of volumetric water pricing system, as an alternative, to the flat rate area-based pricing system currently in use in Office du Niger (ON) irrigation scheme in Mali and Bagré irrigation scheme in Burkina Faso. Results showed that, in contrast to the current situation, adoption of a uniform volumetric water pricing system will enable both schemes to cover the cost of water supply but impact on total water consumption and farmers' profit will differ by scheme, with Bagre scheme adversely affected. Adoption of an increasing block tariff volumetric system in Bagre will ameliorate the negative effects, suggesting the need for context-specific rather than blanket prescription of a water pricing system.

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Abstract

Large-scale irrigation schemes producing food and commercial crops in West Africa typically charge a flat rate per hectare for water use. Economic theory suggests that this pricing system is ineffective in promoting efficient water use practices that value water as an economic good. With looming water scarcity partly due to climate change and partly because of growing demands for water due to population, urbanization and industrial-sector growth, there is mounting pressure for implementation of pricing systems that would promote efficiency and cost recovery on irrigation schemes. This paper evaluates the merits of volumetric water pricing system, as an alternative, to the flat rate area-based pricing system currently in use in Office du Niger (ON) irrigation scheme in Mali and Bagré irrigation scheme in Burkina Faso. Results showed that, in contrast to the current situation, adoption of a uniform volumetric water pricing system will enable both schemes to cover the cost of water supply but impact on total water consumption and farmers' profit will differ by scheme, with Bagre scheme adversely affected. Adoption of an increasing block tariff volumetric system in Bagre will ameliorate the negative effects, suggesting the need for context-specific rather than blanket prescription of a water pricing system.

Introduction

Irrigation holds significant potential for agricultural growth, food security and poverty reduction in Africa. Governments across the continent have invested in large-scale irrigation schemes as a means of achieving their ambitious food security and rural development objectives. However, these schemes are plagued by three interrelated problems. First, is the wasteful and inefficient use of water that often leads to problems of waterlogging, secondary salinization and poor productivity. Second, is inadequate cost recovery to cover expenditure on operations and maintenance activities. Third, is the inability of the management of these schemes to expand irrigated area beyond only a fraction of available irrigable land. These problems are partly attributable to inappropriate pricing of water.

This paper focuses on two contrasting large-scale irrigation schemes in the semi-arid zone of West Africa: the Office du Niger (ON) irrigation scheme in Mali and Bagré irrigation scheme in Burkina Faso. ON was established in 1932 to grow cotton for the French textile industry but is now mainly used for the cultivation of rice and sugarcane. Bagré irrigation scheme is relatively more recent. It was established in 1989 in a development zone, Bagrépole area, purposefully created to promote modern agricultural production capable of creating jobs and attracting private investment. The Bagré dam is a multi-purpose dam designed to produce electricity and water for irrigation. Rice is widely grown on this irrigation scheme. On both ON and Bagré irrigation schemes, a flat-rate per hectare pricing system is currently used to value water, despite economic theory and empirical analysis evidence which suggest that this pricing system is ineffective in reflecting the scarcity value of water. An extensive body of literature suggests that other appropriately designed water pricing systems can be used to achieve a wide variety of water management objectives and resolve the inter-related problems described earlier (Dinar, 2000; Johansson, 2000; Johansson et al., 2002; Rogers et al., 2002).

The main objective of this paper is to evaluate and compare the effects of adopting a uniform volumetric water pricing system, instead of the prevailing flat-rate per hectare water pricing system, on water demand, agricultural production, farmers' profit and water supply cost recovery on two large-scale irrigation schemes in West Africa. By analyzing the effects and implications of this linear volumetric pricing system across two contrasting large-scale irrigation schemes, lessons will be drawn for water price policy formulation in other schemes.

Methodology

Description of study areas

Office du Niger

The ON, created in 1932 by the French colonial administration, refers to both the area of the inner delta of River Niger in Mali (about 1, 000, 000 ha) and the semi-autonomous government agency in charge of the management and development of the land and water resources in the area (INSTAT, 2012). Water from the Niger River is diverted into a system of canals at the Markala dam and used for irrigation in smallholder plots as well as large scale farms (Coulibaly, 2006). The main crops presently grown are rice and sugarcane although the area was intended for cotton production for the French textile industry. The ON has experienced major difficulties over the years and went through several reforms in the 1990s resulting in the cutting back of the monopoly power of the agency over agricultural production and marketing of cereals (Hertzog et al., 2012). All production activities that it used to undertake have now been privatized. The ON is now limited to the management of land and water and provision of agricultural advisory services. The agency uses a flat rate per hectare water pricing system called "redevance eau". (Kéita et al., 2002). It is mandated to cover only the management, maintenance and operation costs.

The choice of the ON area for this analysis is motivated by its strategic importance for Mali's socioeconomic development (Djiré and Kéita, 2010), its attractiveness to foreign and domestic investors and its rich ecological profile (wetlands, aquatic animals and rich biodiversity). The government in recent years leased land to investors on this scheme, including Malibya (100,000 ha) for rice cultivation, N Sukala (15,000 ha) and Sosumar (20,000 ha) for sugarcane production. There are two major growing seasons: the wet season from June to September, the main agricultural season, and the dry season which starts in October. Most local people are poor semi-subsistence farmers, heavily reliant on natural resources and vulnerable to the vagaries of climate (Michigan State University, 2011). Figure 1 shows the location of three major schemes in the ON.

Insert Figure 1 here

Bagré Irrigation area (BIA)

Bagré Irrigation Area is relatively recent compared to the Office du Niger. It was created in 1989 as part of the Bagré Development Zone, an initiative of the Burkina Faso Government based on the Accelerated Growth and Sustainable Development Strategy. Its objective is the creation of an economic growth pole in the Bagré area based on increased agricultural production that is capable of attracting private investment and creating jobs.

The development zone covers about 500,000 hectares around the Bagré Dam. The Bagré Dam is a multipurpose dam aimed at producing electricity and providing water for irrigation. The dam is designed to generate 16 megawatts for the national grid. Irrigable land area is estimated at 57,800 hectares, 7,400 hectares of which can be irrigated through gravity (Venot et al, 2017). So far, only 3,380 hectares have been developed. Plans to develop an additional 4,400 ha is underway with funding from the World Bank and African Development Bank. Other investments in the area include a fish-farming facility, an animal food production plant, and an ecotourism center (World Bank, 2011).

Bagrepole is the institution in charge of the management of the BIA. Bagré irrigation scheme represents the single largest irrigation ambition in Burkina Faso. It carries a strategic importance in Burkina's development policy. However, the Bagrepole has been facing challenges in the operation and maintenance (O&M) of irrigation infrastructure resulting in low water use efficiency. It is also facing financial problems caused by low water fee level and poor water levy collection rates. As such, the institution remains reliant on government subsidies (Bagrepole, 2013).

Model description

A bio-economic model coupling a crop growth model with a farm-level microeconomic model was used. The crop growth model, AquaCrop, simulates yield as a function of irrigation water, while the economic model generates farmers' profit, irrigation manager's revenue and gross production value. AquaCrop is an agronomic model developed by FAO that has been validated under various conditions in sub-Saharian Africa (Khoshravesh et al., 2013; Steduto et al., 2009). This model was used to build a dataset specifying irrigation water quantities and the corresponding yield. It was calibrated for Office du Niger and Bagré Irrigation Area. The dataset was then used to estimate production functions (see Appendix A and B for further details). With respect to the economic model, the objective of the farmer is to maximize profit while the objective of the manager is to maximize agricultural production factoring in water availability and budget constraints. The profit of the farmer is defined as the value of agricultural production less variable costs, including the cost of water and other production costs (land preparation, weeding, harvesting etc.). Farmers grow rice in Bagré Irrigation Area in the wet season and in the dry season. In the ON, they grow sugarcane in addition to rice.

This modeling approach used in the paper has been widely validated in the economic and water management literature (Stoorvogel et al., 2004; Reynaud, 2009; Sidibe et al., 2012; Sidibe and Williams, 2016). In this paper, the bio-economic simulation model was used to conduct a comparative analysis of the effects of two alternative water pricing systems: a) the current flat rate per hectare pricing, and b) a uniform volumetric pricing system on water demand, agricultural production, farmers' profit and water supply cost recovery in ON and BIA. The effects were considered under a baseline scenario that mimics current land allocation to smallholder farmers' and their production patterns and under a second scenario of irrigated land area expansion.

Data sources

For the crop growth model, agricultural and climatic data from various previous studies in the ON and technical studies in the Bagre Irrigation Area were used to estimate and calibrate the model (Kuper and Tonneau, 2002; Tangara, 2011). Soil data from the Harmonized World Soil Database (HWSD) combined with soil type-specific default values of AquaCrop were used (FAO/IIASA, 2012). Climatic data were extracted from the FAO ClimWat Database (CLIMWAT, 2011). Economic data on prices and costs were obtained from AMASSA, 2014; Mather and Kelly, 2012 and confirmed through recent interviews with ON managers[1].

Two scenarios were tested. Scenario 1 mimics the baseline conditions in terms of area under different crops and average yields. Scenario 2 assumes expansion of irrigated land area through implementation of currently known production plans of investors in ON and government expansion plan in BIA

Effects of alternative pricing systems in Office du Niger

Scenario 1: Baseline

The baseline scenario resembles current irrigated land allocation and observed farming patterns of smallholder farmers. The average rice yield is estimated at 6.2 t/ha with 6.5 t/ha in the rainy season (on 96,000 ha) and 4.5 t/ha in the dry season (on approximately 22, 000 ha). The associated water demands are 10,900m^3/ha and 10,200m^3/ha, respectively. Average sugarcane yield is about 74.5 t/ha on 9,000 ha (Tangara, 2011, FAOSTAT, 2014), with a water demand of approximately 15,060m^3/ha. With an irrigation efficiency of 0.4 (Kuper and Tonneau, 2002), aggregated annual water demand at the ON level amounts to 3.52 billion m^3 (Table 2). This simulated result approximates with a high degree of accuracy (about 2% difference) the actual irrigation water withdrawal in the ON (based on official ON data) demonstrating the validity of our model[2].

Table 1: Baseline scenario: economic output per ha[3]

[1] Methodological details and data are available from the authors on request
[2] Assuming water use is proportional to area cultivated, we projected water withdrawal for the presently developed area based on data from (Traore, 2008).
[3] The current water price is US$ 138/ha for rice and US$ 276/ha for sugar cane. The water price of sugarcane is double that for rice because sugarcane takes 2 seasons to mature while rice matures in one season.

	Yield (T/ha)	Production[4] (US$/ha)	Water demand (m^3/ha)	Farmer's Net profit (US$/ha)	ON Revenue (US$/ha)
Rice Wet season	6.5	2601.07	10900	1756.58	138
Rice Dry season	4.5	1798.40	10200	1156.58	138
Sugarcane	74.5	2980.01	15060	2104.01	276

Water price is US$ 138/ha for rice and US$ 276$/ha for sugar cane. The price of water for sugar cane production is double that for rice because sugarcane takes 2 seasons to mature while rice matures in one season. FCFA 500 = US$ 1 according to BCEAO 03/09/2014. Market price for rice and sugarcane are US$ 400 and US$ 40, respectively. The other production costs (apart from water) are US$ 568.5 and US$ 600, respectively

Table 2: Aggregate economic output for the ON under Baseline Scenario

	Area ('000 ha)	Production (US$million)	Water demand (million m^3)	ON Revenue (US$ million)
Rice Wet season	96	250	2,616	13
Rice Dry season	22	40	563	3
Sugarcane	9	27	339	2
Total	127	316	3,518	18

The total revenue that can be potentially collected through water fees under scenario 1 is US$ 18.8 million per year. This amount is 3 times lower than the ON's annual budget (US$ 54.7 million according to Maliweb (2014)) without considering the fact that the fee recovery rate is only 90%. The budget deficit is covered by the state and development partners every year.

Scenario 2: implementation of production plans of investors

In this scenario, we assume that large-scale investments in rice cultivation by Malibya (100,000 ha) and N Sukala (more than 15,000 ha) and sugarcane production by Sosumar (20,000 ha) are implemented. This will bring the area under rice cultivation to 196,000 ha and the area under sugarcane to 44,000 ha. It has been noted that rice yields under improved agronomic practices in this area can reach up to 7.5 t/ha in the wet season and 5.5t/ha in the dry season[5] (Brondeau, 2011; Tangara, 2011).

With increased irrigated area, it is likely that the budget requirement of ON will also increase as a result of infrastructure development (roads, canals etc.). Assuming that the increase in budget is roughly proportional to the developed irrigated area, the ON budget will be almost US$ 154 million per year.

Tables 3 and 4 below show two different water pricing options, a flat rate per ha water pricing and a volumetric linear pricing system.

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[4] As at the time of the study, FCFA 500 = US$ 1.

[5] It is assumed that with the continuous improvement in rice yields, these values will be reached under the present pricing system.

With slightly less amount of water abstracted from the river, the volumetric water pricing (US$ 0.045154/m^3) allows an increase in the value of agricultural production by about US$ 2 million. This is because volumetric pricing allows an efficient reallocation of water between rice and sugarcane. While the rice yield in dry season remained virtually unchanged and only a slight decrease in wet season rice yield (about 0.1 t/ha), sugarcane yield increases from 75 t/ha to 81.8 t/ha (an augmentation of 6.8T/ha). Obviously, the marginal value of water is higher under sugarcane production compared with rice production.

With uniform volumetric water pricing, fees collected exceeds by a wide margin the annual budget requirement due to increase in water demand (approximately 15.38 billion m^3). Based on the analysis of the long term (1982-2007) cumulative probability distribution of available water volume in Markala Dam and taking into account the evaporation of the river (0.57 billion m^3), the minimum environmental flow requirement is estimated at 1.5 billion m^3 (MCA, 2009; Zwarts et al., 2005). This environmental flow requirement will not be met once every 10 years under the flat rate per hectare pricing system, but it could be met with a purposefully designed volumetric pricing system as shown in Table 4.

Table 3: Scenario 2: Economic output per ha with irrigated area expansion

Flat per ha water pricing (138$/ha for rice and 276$/ha for sugar cane)					
	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer's Net Profit (US$/ha)	ON Revenue (US$/ha)
Rice Wet season	7.5	3000.73	18100	2156.24	138
Rice Dry season	5.5	2199.83	15800	1355.34	138
Sugarcane	75	2999.57	15365	2017.08	276
Volumetric water pricing (0.045154$/m^3)					
	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer's Net Profit (US$/ha)	ON Revenue (US$/ha)
Rice Wet season	7.4	2956.73	17096	1616.28	771.96
Rice Dry season	5.5	2189.53	15569	918.03	703.01
Sugarcane	81.8	3270.98	20478	1639.83	924.66

Table 4: Scenario 2: Aggregate economic output for the ON with irrigated area expanson

Flat per ha water pricing (138$/ha for rice and 276$/ha for sugar cane**)**				
	Area ('000 ha)	Production (US$ million)	Water demand (million m^3)	ON Revenue (US$ million)
Rice Wet season	196	588	8,869	27

Rice Dry season	122	269	4,822	17
Sugarcane	44	132	1,690	12
Total	362	989	15,381	56
Volumetric water pricing (0.045154 US$/m^3)				
	Area ('000 ha)	Production (US$ million)	Water demand (million m^3)	ON Revenue (US$ million)
Rice Wet season	196	580	8,377	151
Rice Dry season	122	267	4,752	86
Sugarcane	44	144	2,253	41
Total	362	991	15,382	278

Bagre Irrigation Area (BIA)

Scenario 1: Baseline

The baseline scenario in Bargepole is based on observed yields for rice on existing developed irrigation area. Average rice yield is 5.02 t/ha in the wet season on 3380 ha and 4.5t /ha in the dry season on 676 ha (Bagrepole, 2011). Sugar cane is not grown in BIA. Associated water consumptions are 15,435 m^3/ha and 10,055 m^3/ha respectively at plot level (Table 5) and 21,438 m^3/ha and 13,965 m^3/ha respectively at Bagre dam level. The difference between the volume of water diverted from the dam and that applied at the plot level is explained by the relatively low efficiency of transport and distribution estimated at 0.72 (Ouedraogo, 2017). Although, this efficiency is much higher than the level in ON, it is still lower than the level of efficiency expected from an irrigation network completely lined with concrete[6]. This represents a cumulated water demand approximating 82 million m^3 (Table 6). With the currently used flat rate pricing system, the total revenue Bagrepole can potentially collect is about USD 101, 400 annually. However, as noted earlier, water fees collection rate is particularly low and variable fluctuating between 10 to 52 percent. Additionally, the water fee level necessary to full recover of O&M costs is estimated at USD 180/ha (compared with US$25/ha that is currently being charged) implying that Bagrepole is far behind meeting its O&M cost recovery.

[6] The transport and distribution efficiency of concrete lined irrigation networks is usually between 0.80 and 0.90

Table 5: Baseline scenario: economic output per ha in Bagré

	Yield (T/ha)	Production (US$/ha)	Water demand[7] (m^3/ha)	Farmer net profit (US$/ha)	Bagrepole Revenue (US$/ha)
Wet-season rice	5.02	2007.53	15,435	785.53	25
Dry-season rice	4.55	1819.44	10,055	597.44	25

Table 6: Aggregate economic output under baseline scenario in Bagré.

	Area ('000 ha)	Production (US$ million)	Water demand[8] (million m^3)	Bagrepole (US$ million)
Wet-season rice	3.38	7	72	0.0845
Dry-season rice	0.676	1	9	0.0169
Total	4.056	8	82	0.1014

[7] This represents water demand at plot level

[8] This represents aggregate water derived from Bagre dam taking into account water transport and distribution efficiency of 0.72

Scenario 2: implementation of the plans of LSIALs

In this scenario, we assume that ongoing investments including the development of 4,400ha has been completed. This area includes gravity-fed land that will be allocated to small-holder farmers and land that requires pumping which will be allocated to large scale agricultural firms. It is also assumed that with the arrival of large scale commercial farmers in the area, there will be an increase in rice yield owing to better agronomic practices.

In this scenario, flat rate pricing would not be efficient and would not ensure full O&M cost recovery (Table 7). If Bagrepole adopts a uniform volumetric water pricing system, O&M costs will be fully recovered (Tables 7 & 8). However, the use of the flat rate or uniform volumetric pricing would lead to a substantial increase in water withdrawal (316 million m^3) as yield increase will mean a larger water demand (Table 8). Increased water withdrawal for irrigation will intensify competition with electricity production.

Table 7. Scenario 2: economic output per ha in Bagré under planned irrigated area expansion

Flat rate water pricing (USD 25/ha)

	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer net profit (US$/ha)	Bagrepole Revenue (US$/ha)
Wet-season rice	5.99	2394.05	25,932	1172.05	25
Dry-season rice	5.17	2066.29	16,740	844.29	25

Volumetric water pricing (USD 0.0267/ha)

	Yield (T/ha)	Production (US$/ha)	Water demand (m3/ha)	Farmer net profit (US$/ha)	Bagrepole Revenue (US$/ha)
Wet-season rice	5.99	2394.05	25,932	529.64	692.41
Dry-season rice	5.17	2066.29	16,740	447.32	446.97

Table 8. Scenario 2: Aggregate economic output in Bagré under planned irrigated area expansion

Flat rate water pricing (USD 25/ha)

	Area ('000 ha)	Production (USD millions)	Water demand (million m3)	Bagrepole (USD millions)
Wet-season rice	7.78	19	280	0.389
Dry-season rice	1.556	3	36	0.0778
Total	9.336	22	316	0.4668

Volumetric water pricing (USD 0.0267/ha)

	Area ('000 ha)	Production (USD millions)	Water demand (million m3)	Bagrepole (USD millions)
Wet-season rice	7.78	19	280	5.39
Dry-season rice	1.556	3	36	0.70
Total	9.336	21.84	316.40	6.08

Raising the uniform volumetric water price may potentially help to moderate excessive water use. Increasing price from US$ 0.0267/m^3 to US$ 0.03568/ m^3 (34 percent increase) would reduce water use from 316 million m^3 to 250 million m^3 (21 percent decrease) (Table 9). However, it would also considerably affect farmers' profit in the wet season, decreasing it from US$529/ha (Table 7) to US$ 324/ha (39 percent decrease) (Table 9) by reducing yield and increasing net water costs. Similar profit reduction would be observed in the dry season. Such pricing may not be socially acceptable.

Table 9. Scenario 2: Economic output per hectare and aggregate economic output in Bagré under increased uniform volumetric water price

Volumetric water pricing application in Bagré (USD 0.03568/ha)

	Yield (T/ha)	Production (USD/ha)	Water demand (m3/ha)	Farmer net profit (USD/ha)	Bagrepole Revenue (USD/ha)
Wet-season rice	5.57	2226.66	20,476.05	323.89	730.77
Dry-season rice	4.90	1960.86	18,484	314.01	474.84

Volumetric water pricing (USD 0.03568/ha)

	Area ('000 ha)	Production (USD millions)	Water demand (million m3)	Bagrepole (USD millions)
Wet-season rice	7.78	17	221	0.389
Dry-season rice	1.556	3	29	0.0778
Total	9.336	20	250	0.4668

In this situation, two different solutions appear feasible. One solution that Bargepole can consider to avoid competition with electricity production is to increase the efficiency of water transport and distribution for irrigation currently estimated at 72 percent. In concrete lined canals, this efficiency can reach 90% with adequate O&M. However, Bagrepole irrigation system has experienced severe degradation leading to water leakages through the network. An increase of efficiency from 72 percent to 90 percent would bring water diversion from the dam to a more acceptable level of 250 million m^3 with no impact on farmers' income and limited impact on electricity production.

Another solution would be to implement another system of volumetric water pricing, i.e. Increasing Block Tariff (IBT). As shown in Table 10, Bagrepole can control total water consumption by farmers, recover full O&M cost with limited impact on farmers's profit using IBT. To achieve this, the price of the first block is fixed in such a way to recover O&M costs. The water amount of the first block is selected to be equal to the water demand of farmers given availability constraint and the price of the second block is equal to the marginal value of water. The first block can be fixed at US$ 0.008791/m^3 and the volume of water per ha for the first block set at 20,476m^3/ha for the wet season and 13,305m^3/ha for the second block. The first block would allow Bagrepole to recover full O&M costs estimated at US$ 180/ha/year. The second block would be fixed at USD 0.035692/m^3. This second block which is equal to the marginal productivity of water will provide incentive to farmers to rationalize the use of water.

Table 10: Scenario 2. Economic output per hectare and aggregate economic output in Bagré under increased block tariff pricing

Volumetric water pricing application in Bagré (First Block Price: US$ 0.008791/m^3 Second Block Price: USD 0.035692/m^3)

	Yield (T/ha)	Production (USD/ha)	Water demand (m^3/ha)	Farmer net profit (USD/ha)	Bagrepole Revenue (USD/ha)
Wet-season rice	5.57	2226.48	20476.05	920.37	109.11
Dry-season rice	4.90	1960.74	13305.05	692.84	70.89

IBT water pricing application in Bagré (First Block Price: USD 0.005328/m^3 Second Block Price: USD 0.035692/m^3)

	Area ('000 ha)	Production (USD millions)	Water demand (million m^3)	Bagrepole (USD millions)
Wet-season rice	7.78	17.32	159.30	0.85
Dry-season rice	1.556	3.05	20.70	0.11
Total	9.34	20.37	180.01	0.96

Discussion

The results presented above indicate that both ON and BIA will not be able to improve water use, cover the cost of water supply and raise sufficient revenue to improve their services to farmers if they continue to use a flat rate per hectare water pricing system. Both schemes would also need to revisit their current pricing system in order to expand irrigated area.

However, adoption of a linear volumetric water pricing would not lead to the same result in both cases, suggesting that a one-size fits all pricing recipe will not work. While the results show that a uniform volumetric water pricing system will improve irrigation water allocation to different crops and reduce total water demand with only limited reduction in farmers' profit in ON, the same pricing system will substantially reduce farmer's profit in Bagré. It will also lead to massive increase in water demand leading to heightened competition for water between agricultural production and electricity generation. Thus, simple uniform volumetric pricing will be inadequate to address the water management problems in Bagré. The analysis showed that an increasing tariff block pricing system will moderate excessive water demand and use in Bagré without unduly reducing farmer's profit.

The results reported for each irrigation scheme are obviously influenced by the choice of crops grown under irrigation, experience of farmers with irrigation and management of water at the field level. This suggests the need for context-specific water pricing systems that address the underlying biophysical, cultural and socioeconomic conditions in each irrigation scheme.

Given the low irrigation water transport and distribution efficiency in both schemes, both will benefit from efforts made to irrigation water conveyance and distribution efficiency.

There is one important limitation to the approach used in this paper. The bioeconomic model used is a simplfication of reality as it assumes that water pricing aff ects only water use and influences yield mainly through changes in irrigation water applied. In practice, water pricing may also affect the use of other inputs. However, other studies suggest that subsitution between water and other inputs tend to be limited ((Lehmanna & Finger, 2014).

Conclusions

In this paper, we have demonstrated that volumetric water pricing systems that allow the marginal value of water to be refelected in water allocation decisions can help address the inadequacies of the current pricing system on two large-scale irrigation schemes in West Africa. A linear volumetric pricing system was used first as an alternative to a flat rate per area pricing system. But the shortcomings of this simple volumetric pricing was seen in the case of Bagré clearly demnstrating that other innovative forms of volumetric pricing may be more suited to the conditions in Bagré. This underscores the need to avoid prescribing a single volumetric water pricing system as a panacea in all situations.

Despite its appeal on economic efficiency and equity grounds, problems associated with the implementation of volumetric water pricing should not be overlooked (Easter and Liu, 2005). Meters to measure the volume of water delivered will have to be installed. Volumetric water pricing can be justified as long as the cost of installing measuring devices, monitoring water use and managing a billing system is not a high percentage of the value of production and revenue collected. For larg-scale schemes, it may be easier to install meters than in small-scale where the transaction costs may be high.

A much more serious issue is that water pricing is a politically sensitive topic in many African countries. However, there is a growing realization among African political leaders that the looming water crisis can only be averted by adopting appropriately designed water pricing systems that balance efficiency, equity and environmental sustainability concerns. The endorsement of the sustainable development goals (SDGs) by African governments will also help to establish the case for efficient water allocation and use through a valuation system. Approaches that encourage participation of water users in the design of water pricing systems will also make the prices derived much more acceptable to them.

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Appendix A: Economic model and estimation of climate-dependent rice and sugarcane production functions

Economic model

A traditional microeconomic model is used. The objective of the farmer is to maximize profit while the objective of the manager is to maximize agricultural production taking into account water availability and budget constraints. The problem can be viewed as a Stakelberg Game where the manager is the Leader and the farmer the Follower. Crops (rice and sugarcane) are sold at their respective market prices. Crop growing requires water and other inputs that have costs (land preparation, harvesting etc). A production function "tells" how much yield is obtained for how much water (Steduto et al, 2009).

Farmer's problem with uniform volumetric pricing

The objective of the rational farmer is to choose the irrigation water use that will maximize his/her profit. The profit is defined here as the value of the agricultural production minus the water cost and other farm costs. The rational farmer's problem can be written as follows:

$$\max_{w_i}\left(p_{y_i}Y_i(\pi + w_i) - p_w w_i - c\right)A_i$$

$Y_i(\quad)$ represents the production function for crop *i*. it is assumed to be an increasing and concave function ($Y_i'>0$ and $Y_i''<0$). This functional form is confirmed when Y_i is estimated. The estimation procedure is explained in a subsequent section.

A_i is the area under crop i.

w_i is the irrigation intensity of crop i (i=1 for rice and i=2 for sugarcane)
c represents other farm costs (land preparation, harvesting etc)
π is the average rainfall level.

p_{y_i} is the market price of crop i

p_w is the unit water price

The solution to this problem is given by the first order condition:

$$w_i = Y_i^{'-1}\left(\frac{p_w}{p_{y_i}}\right) - \pi$$

Farmer's problem under IBT

The IBT pricing system can be mathematically formalized as follows:

$$T(W) = \begin{cases} p_1 W \ if \ W \leq W_l \\ p_1 W_l + p_2(W - W_l) \ if \ W > W_l \end{cases}$$

With $p_2>p_1$, where p_1 is the price level of the first block and p_2 the price level of the second block, W_l the volume limit for the first block.

W is the total water use of the farmer. Since the farmer has a total area of A, the total water use is $W = A \times w$, where w represents the per hectare water demand.

$$\max_{w_i}\left(p_{y_i} Y_i(\pi + w_i) - c\right)A_i - T(A \times w) \qquad (0)$$

This problem can be solved by solving two related problems:

$$\max_{w_i}\left(p_{y_i} Y_i(\pi + w_i) - c\right)A_i - p_1 A_i w_i \qquad (1)$$

$$\max_{w_i}\left(p_{y_i} Y_i(\pi + w_i) - c\right)A_i - p_1 W_l - p_2(A_i w_i - W_l) \qquad (2)$$

$w_{i1} = Y_i^{'-1}\left(\frac{p_1}{p_{y_i}}\right) - \pi$ is the solution to (1) while $w_{i2} = Y_i^{'-1}\left(\frac{p_2}{p_{y_i}}\right) - \pi$ is the solution to (2). If $A_1 w_{i1} \leq W_l$ then w_{i1} is the solution to (0), but if $A_1 w_{i1} > W_l$ and $A_1 w_{i2} > W_l$, then w_{i2} is the solution to (0). But if $A_1 w_{i1} > W_l$ and $A_1 w_{i2} < W_l$, then W_l is the solution to (0).

It can be denoted that the parameters (W_l, p_1 and p_2) of IBT may be chosen in such a way that the IBT performs at least as much as the uniform pricing in terms of water conservation and efficiency. In fact by choosing W_l=0, and p_2 for IBT equal to p for the uniform pricing, IBT becomes exactly a uniform pricing system. The advantage of IBT is that it permits to achieve multiple objectives.

Water manager problem

The water manager's problem is to choose the water prices p_w in order to maximize a social welfare function that takes into account the objectives of all user groups.

$$\max_{p_w} \sum_{i}^{n} A_i p_{y_i} Y_i(\pi + w_i)$$

Under the following constraints:

Water availability constraint

$$\sum_{i}^{n} A_i w_i \leq W - W_E$$

Budget constraint

$$\sum_{i}^{n} A_i p_w w_i \geq B$$

Where

- n is the number of farms.
- W is the total water availability while W_E represents the environmental water requirement.
- B represents the part of costs or budget that the manager wants to recover.

The Lagragian of this equation can be written as follows:

$$\max_{p_w} L(p_w, \lambda_w, \lambda_B) = \max_{p_w} \sum_{i}^{n} A_i p_{y_i} Y_i(\pi + w_i) - \lambda_w \left(\sum_{i}^{n} A_i w_i - (W - W_E) \right) + \left(\sum_{i}^{n} A_i p_w w_i - B \right)$$

The first order conditions give:

$$\sum_{i}^{n} A_i \left(\frac{p_w}{p_{y_i}} Y_i^{'-1'} \left(\frac{p_w}{p_{y_i}} \right) - \lambda_w \left(\frac{1}{p_{y_i}} Y_i^{'-1'} \left(\frac{p_w}{p_{y_i}} \right) \right) + \lambda_B \left(Y_i^{'-1} \left(\frac{p_w}{p_{y_i}} \right) + \frac{p_w}{p_{y_i}} Y_i^{'-1'} \left(\frac{p_w}{p_{y_i}} \right) \right) \right)$$

The water constraint is binding when $\lambda_w > 0$ and $\lambda_B = 0$. In that situation, we have $\lambda_w = p_w$ implying that the water price perfectly reflects water scarcity across all crops. The budget constraint is binding when $\lambda_w = 0$ and $\lambda_B > 0$. We then have:

$$\lambda_B = -\frac{\sum_i^n A_i Y_i^{'-1}\left(\frac{p_w}{p_{y_i}}\right)}{\sum_i^n A_i \frac{p_w}{p_{y_i}} Y_i^{'-1'}\left(\frac{p_w}{p_{y_i}}\right)} - 1$$

The next step is to estimate Y(w).

Estimation of crop production functions

As previously explained, the AquaCrop crop growth model (Steduto et al, 2009) is used to estimate the crop production functions. Based on insights from previous works, a flexible functional form that is suitable for most crops and climatic conditions is used to estimate crop yield functions for given levels of irrigation. The functional form is specified as:

$$Y(w) = \alpha_1(w + \alpha_2)^{\alpha_3}$$

α_1, α_2 and α_3 are regression coefficients to estimate.

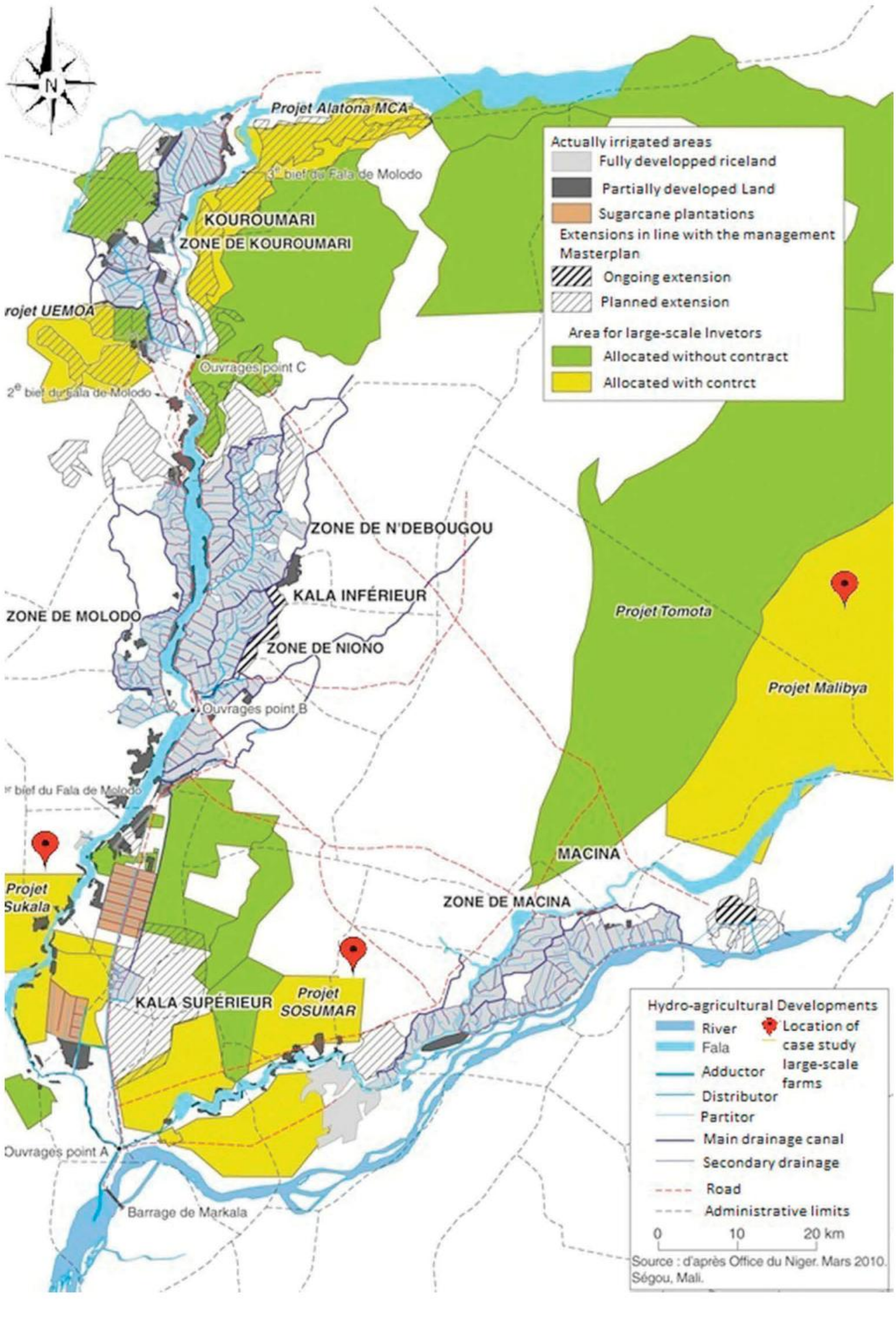
Table A.1 reports the estimated values of the regression coefficients for wet season rice, dry season rice and sugarcane. The model passed the χ^2 and Fischer test at 95%, χ^2 tests the hypothesis that the observed distribution is consistent with the assumed functional form while the Fischer value tests the significance of the coefficients.

Table A.1: production function coefficients

	Office du Niger			**Bagre Irrigation Area**	
	Wet Rice	**Dry Rice**	**Sugarcane**	**Wet Rice**	**Dry Rice**
$\boldsymbol{\alpha_1}$	1.11	1.40	11.53	0.84	1.23
$\boldsymbol{\alpha_2}$	-4000.00	-8450.29	-10599.48	-8000	-4900
$\boldsymbol{\alpha_3}$	0.200	0.153	0.204	0.200	0.153

These functions are then used as inputs in the economic model presented in the previous section. An optimization module is then used to simulate the different output variables. The following table (table A.2) summarizes the main economic assumptions used.

Map: Office du Niger Irrigation Area


Projet Alatona MCA
3e bief du Fala de Molodo
KOUROUMARI
ZONE DE KOUROUMARI
rojet UEMOA
Ouvrages point C
2e bief du Fala de Molodo
ZONE DE N'DEBOUGOU
KALA INFÉRIEUR
ZONE DE MOLODO
ZONE DE NIONO
Projet Tomota
Projet Malibya
Ouvrages point B
er bief du Fala de Molodo
MACINA
ZONE DE MACINA
Projet Sukala
KALA SUPÉRIEUR
Projet SOSUMAR
Ouvrages point A
Barrage de Markala
Actually irrigated areas
Fully developped riceland
Partially developed Land
Sugarcane plantations
Extensions in line with the management Masterplan
Ongoing extension
Planned extension
Area for large-scale Invetors
Allocated without contract
Allocated with contrct
Hydro-agricultural Developments
River
Fala
Adductor
Distributor
Partitor
Main drainage canal
Secondary drainage
Road
Administrative limits
Location of case study large-scale farms
0 10 20 km
Source : d'après Office du Niger. Mars 2010. Ségou, Mali.

Map: Bagré Irrigation Area