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Valuation of water in large-scale agricultural land investments in Mali: Efficiency and equity trade-offs

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Abstract

Recent large-scale investments in agricultural land that are coupled with irrigation present opportunities for increased food production in sub-Saharan Africa. However, to achieve this objective two management issues must be addressed: efficient water use in the face of a looming water scarcity and equity in the sharing of the resource between large-scale investors and smallholder farmers. Focusing on the Office du Niger, one of the largest irrigable areas in Africa this paper compares the performance of three alternative water valuation methods: the currently used flat rate area-based pricing, uniform pricing and increasing block tariffs. Results show the limitations of the current pricing system in economic efficiency and equity terms and in terms of generating sufficient revenue to meet water supply costs. The paper shows that volumetric water pricing avoids these shortcomings and allows the water decision maker to weigh the efficiency-equity trade-offs in irrigation water management.

Keywords: Large-scale agricultural land investment, water pricing, bioeconomic simulation, trade-off analysis, poverty, equity, efficiency

JEL codes: Q12, Q18, Q310, Q570, Q250, Q240

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1. Introduction

The recent interest of large-scale investors in agricultural land in sub-Saharan Africa (SSA) presents several potential opportunities. Investments in agricultural land can make positive contributions to the economy of many African countries that are still largely dependent on agriculture (Lavers, 2012; Collier, 2008; Cotula et al., 2009). Through the introduction of capital, new technology and knowledge, such investments can improve agricultural production and national food security. The decline in Official Development Assistance to the agricultural sector between 1987-2005 (OCDE, 2010; Djiré et al., 2012) combined with vulnerability to food crisis and the need to provide employment for a growing population have led several African countries to undertake policy reforms to welcome foreign investments in agricultural land (Lavers, 2012; Collier, 2008; Cotula et al., 2009; German et al., 2012).

Although land is the target of these investments, water and other ecosystems cannot be ignored as they are interlinked resources (Ogilvie et al., 2010; Kizito et al., 2012; Williams et al., 2012). Several crops grown on these investment schemes, including rice and sugarcane, require large amounts of water to be fully productive (Zwarts et al., 2005). Thus, in order to take full advantage of the potential benefits of the large-scale investments in agricultural land (LSIAL), the implementation of effective water resource management is indispensable. Failure to do so may lead to inefficient water use and significant misallocation and conflicts between different water users, e.g. large-scale investors and smallholder farmers. (Brown and Lall, 2006). Water pricing is a management approach that takes into account efficiency and equity issues that are most salient in public policy (Grand Le, 1990). Indeed, an extensive body of literature suggests that water pricing can be used to achieve a wide variety of water management objectives (Rogers et al., 2002; Johansson, 2000; Johansson et al., 2002, Dinar, 2000).

In reality, there exists inherent trade-offs between efficiency and equity objectives in water pricing. Identifying the magnitude of these trade-offs is probably one of the most important contributions that economics can make to the evaluation of policies affecting natural resources (Browning and Johnson, 1984). Other equally important objectives of water management include cost recovery and environmental protection. To address these array of objectives, decision makers in the irrigation sector are compelled to explore new ways to manage water resources (Dinar, 2000). Well-designed water pricing systems can help to address these complex management problems and provide enlightening insights regarding the trade-offs.

The Office du Niger (ON) is a large irrigable area covering more than one million hectares in the inner delta of the Niger River in Mali, stretching from Ségou in the south to parts of Mopti in the north. ON is also the name of the semi-autonomous agency in charge of the development of the area. Since 2000, the Malian Government has deliberately promoted a policy of opening up access to land in the ON to investors with the intention of making the country the "Food basket" of West Africa. (Kuper and Tonneau, 2002; Brondeau, 2011). This has led to large-scale land acquisition by foreign and national investors amounting to more than 200, 000ha. With the potential pressure on water resources that is likely to result, the effectiveness of the current water pricing system in the ON is highly questionable as observed by other researchers (Brondeau, 2011; Hertzog et al., 2012). Aware of this limitation, the ON is looking for alternative management systems (Brondeau, 2014). This study is a contribution towards finding a solution.

Focusing on the Office du Niger (ON), the objectives of this paper are threefold: First, in light of large-scale investments in agricultural land that are coupled with irrigation, to compare the effects of different pricing methods on agricultural production, water demand and indirectly environmental flows. Second, to highlight the inherent trade-offs involved in irrigation water management and how they can be addressed and, third, to provide recommendations that can be applied in the ON area and in similar irrigation schemes in SSA.

2. Methodology

2.1. Case study area

The Office du Niger in Mali is selected for this study because of its strategic importance for Mali's socioeconomic development (Djiré and Kéita, 2010), its attractiveness to private investors and its rich ecological profile (wetlands, aquatic animals, rich biodiversity). It is one of the largest and oldest irrigation schemes in West Africa. It is located approximatively at the center of the country in the inner delta of the Niger River (Figure 1). It starts from the Markala Dam and extends to Segou and Mopti Regions. Identified in 1920, the area was planned to become a vast irrigated zone with 960 000 ha developed (510 000 ha for cotton and 450 000 ha for rice). In 1932, the Office du Niger agency was created to supply the French textile industry with cotton. With Mali's independence in 1960, cotton production was replaced by sugarcane and then by rice production. A series of reforms, including the restructuring of 1994, led to a considerable reduction in the responsibilities of the ON - now limited to the management of the water network and the collection of water fees. A flat rate, area-based pricing system is implemented currently. The ON is not directly in charge of environmental management but it may intervene if water supply is threatened due to environmental issues. The ON is located in a semi-arid zone where average annual rainfall is around 433 mm. Soils are predominantly arenosols featuring on deep aeolian alluvial sands with a sandy loam texture (Kizito et al., 2012). There are two major growing seasons: the wet season from June to September is the main agricultural season. The second agricultural season (dry season) starts from October. The average annual available water at the Markala dam is estimated at 25 billion m^3 (Traore, 2008). Most local people are poor smallholder farmers with land plots ranging from 0.5 and 2.5 ha. However, there are also relatively well-off farmers with average land plot of about 10 ha (Bélières et al., 2011). The ON presently seems to be balancing two approaches to land management: on the one hand it promotes large-scale investments in agricultural land, while on the other hand it supports smallholder family-based farming as demanded by the Malian agricultural policy (Loi d'orientation agricole). The success of ON in balancing these 2 approaches is likely to depend on the ability to engage in judicious land reform and water and environmental management. In the past, the ON has shown its capacity to undergo difficult but necessary reforms and may be able to do so again.

Insert Figure 1 here.

2.1.Modelling approach

A biophysical model that combines a production function approach with a microeconomic farm level model that depicts the water use behavior of representative farmers was developed. This approach has often been referred to as econometric process simulation model (Antle et al., 2001; Stoorvogel et al., 2004). This type of model is able to simulate the impact of policy on different relevant variables (water use, production, incomes etc.) both within and outside the range of observed data in a way that is consistent with economic theory and with bio-physical constraints and processes (Antle et al., 2001). In contrast with purely empirical economic production models, the approach presented avoids biased and inconsistent parameter estimation by incorporating biophysical processes (Mundlak and Hoch., 1965).

The bio-economic simulation model is used to analyze the effects of different pricing systems on agricultural production, water use and environmental flows and to undertake trade-off analysis between different objectives, especially equity and efficiency, under different scenarios. Here, efficiency is defined as the total agricultural production given the amount of technical capacity and water available for the ON. Equity in water management is defined in terms of a management system that does not affect "too much" the profit of farmers particularly the less land-endowed ones. It is up to the decision makers to decide what they think to be "too much" given the efficiency loss this would entail.

Trade-off curves provide powerful tools to decision makers who have to make a compromise between different desirable policy objectives. The basic idea of trade-offs between different policy objectives is that for a given set of resources, one has to forgo a certain amount of a desirable outcome to obtain more amount of another one. Trade-off curves thus show the relationship between two relevant variables and highlight the opportunity cost of changing one in terms of the other. Previous water sector studies have demonstrated the possible trade-offs between efficiency and equity (Ruijs, 2009; Browning and Johnson, 1984). Trade-offs curves were drawn using Data Envelopment Analysis (DEA) technique (Golany and Tamir, 1995; Cooper et al., 2011). The algorithms used select in the equity-efficiency set, points for which it is impossible to find other points that improve both efficiency and equity.

The economic model is a traditional microeconomic farm-level model. It is assumed that 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 production requires water and other inputs that have costs (land preparation, harvesting etc). Before presenting the mathematical model, the alternative pricing systems analyzed are first presented.

*2.2.*W*ater pricing systems*

Three water pricing systems, comprising of one flat rate area-based pricing and two variants of volumetric pricing are considered. The two volumetric pricing systems are: a uniform pricing system and the Increasing Block Tariffs (IBT). A brief description of each pricing system follows.

Flat rate pricing

Flat rate per area pricing is the system currently in use in the ON. A fixed amount is paid per season. This pricing method does not explicitly take into account the amount of water consumed. Therefore, it provides no incentive to save water and does not send the right signals to water users to inform them of the relative scarcity of the resource. It only influences the decision to irrigate or not irrigate. Any user who has decided to irrigate would continue to do so as long as using water increases agricultural production (Johansson, 2000). With this system, farmers cannot properly assess the marginal value of the water used. Consequently, water allocation is not necessarily optimal because the pricing system does not rely on value considerations and do not prioritize the allocation of water to the most productive farmers.

Uniform pricing

Marginal cost uniform pricing allows for the most efficient allocation in the sense that it maximizes the overall economic surplus of water users (farmers) and of the seller (the manager) (Garcia and Reynaud, 2004). There is a wide consensus among economists that marginal cost pricing ensures an efficient use of the resource (Tsur and Dinar, 1995). However, it does not guarantee a balanced budget especially when fixed costs are high relative to variable costs, as is often the case with irrigation water management (Montginoul, 1997). The funds collected through marginal cost pricing may be lower than the fixed costs resulting in a budget deficit (Tsur et al., 2004; Elnaboulsi, 2008). Average cost pricing is often put forward as a solution to the problem of budget deficits that may be created through the use of marginal cost pricing method. Average cost pricing enables the manager to break even. However, it leads to a second-best optimum, which implies a loss of welfare compared to the first-best optimum obtained by using marginal cost pricing (Tsur et al., 2004). Also uniform water pricing is not well suited for equity considerations as it has an indiscriminate effect on all user groups.

Increasing Block Tariffs (IBT)

IBT is a progressive tariff system. It provides different prices for two or more pre-specified blocks of water use (Rogers et al., 2002). Here, we consider an IBT with two blocks. IBT pricing with two blocks involves three types of decision: defining the volume of water use associated with the first block, the price level associated with the first block and that associated with the second block. IBT allows water managers to provide a low rate to the poor and charge higher prices for use beyond a defined minimum volume. The subsidy incorporated in the pricing mechanism lessens the burden on incomes of poor farming households. Thus IBTs are acclaimed for improving equity (Rogers et al., 2002; Groom et al., 2008). Also because of its flexibility, IBT can be used to analyze trade-offs between different policy objectives. According to Groom et al. (2008), while a uniform tariff, despite its efficiency qualities, may have profoundly negative income effects on the poorest segment of the population, the IBT system may alleviate these problems by shifting the financial burden from users using less water to users using high volumes of water.

2.3.Mathematical formalization

Here, we present the main mathematical features of the economic model[1].

Farmer's problem

Farmer's problem under flat rate

The flat rate can be represented as follows:

$$T(w) = c_w$$

Farmer's problem

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

T(w) is the water tariff for water amount w. w_i is the irrigation intensity of crop i (i=1 for rice and i=2 for sugarcane), c_w is the the flat rate.

$Y_i(\ \ )$ represents the production function for crop i. it is assumed to be an increasing and concave function (Y_i' >0 and Y_i''<0). The type of data used to estimate Y_i come from a crop growth model described in the subsection "Model estimation and calibration". Further information can be provided upon request.

w_i is the irrigation intensity of crop i (i=1 for rice and i=2 for sugarcane)

c represents other farm costs

π is the rainfall level.

Theoretically, the solution to this maximization problem is infinite: The farmer will choose to use all the available water amount. But, practically the farmer is limited by his/her water abstraction capacity. That is why with per area flat rate pricing, investors with higher abstraction capacity (through large canals and pump stations) may potentially abstract most of the resource to the detriment of smallholder farmers with limited capacity.

Farmer's problem under uniform pricing

The uniform price can be represented as follows:

$$T(W) = p_w W$$

Where p_w is the water unit price

[1] More details can be provided upon request

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:

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

$Y_i(\ \ )$ represents the production function for crop i. it is assumed to be an increasing and concave function ($Y_i'>0$ and $Y_i''<0$). The type of data used to estimate Y_i are summarized in the Appendix. Further information can be provided upon request.

w_i is the irrigation intensity of crop i (i=1 for rice and i=2 for sugarcane)
c represents other farm costs
π is the 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 trade-off analysis.

Water manager's problem

The water manager's problem is to choose the water prices $T(w)$ 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

$$\sum_{i}^{n} T_i(A_i w_i) \geq B$$

Where

- 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.

For IBT the water manager problem was simulated as a "if what?" model (no maximization), in order to identify the effects of different IBT structures.

2.4. Model estimation and calibration

The model is estimated and calibrated using agricultural and climatic data from previous studies in the ON (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[2]. AquaCrop is a crop growth model developed by FAO to simulate crop growth from sowing to harvest on a daily time scale (Steduto et al., 2009). It simulates the crop growth process as a function of the climate and the farmer's technical decisions (irrigation, soil management practices, etc.). Aquacrop has been validated in various conditions in the sub-Saharan Africa context (see Khoshravesh et al., 2013 for example). It was used to estimate production functions. Climatic data were obtained from the FAO ClimWat Database (CLIMWAT, 2011). Economic information on prices and costs were obtained from Diarra (2008); Mather and Kelly (2012) and AMASSA (2014) completed and confirmed through recent interviews with ON top managers. Rice and sugarcane are considered here as the main intended crops in LSIAL and the most water demanding.

Disaggregated data on farmer types was used to categorize farmers according to their land endowment (Bélières et al., 2012). Disaggregated data is necessary to analyze the differential impact of IBT. IBT allows us to address equity concerns by fixing the price of the first block low (below marginal value) and the price of the second high (above marginal value). However, this leads to a trade-off between equity and efficiency. To address this issue, simulations of different IBT structures were performed in order to obtain equity (farmers' profit) and efficiency (agricultural production) trade-off curves. Table 1 presents the categorization of farmers according to ON's classification.

Insert Table 1 here.

SIAON stands for « superficie irriguée attribuée par l'Office du Niger » referring to the land plots allocated by the ON. As may be expected, the yields vary according to farm size. Roughly, small farms have lower average yields than large ones. However, farmers with average farm size of 2.5-5.0 ha recorded the highest yields (even higher than farms with a size higher than 5 ha). Nevertheless, the variation in yield is not considerable and the highest gap is less than 18%.

3. Simulation results

For the simulation modelling, three scenarios were considered.

Scenario 1, the baseline scenario, is constructed based on current yields and land allocation in the ON area. The average rice yield is about 6.2t/ha with 6.5t/ha in the rainy season (on 96,000 ha) and 4.5t/ha

[2] Soil and crop parameters are available from the authors on request

in the dry season (on approximately 22, 000 ha) (Tangara, 2011). The average yield of sugarcane is about 74t/ha on an area of 9,000ha. Total irrigation efficiency, defined as the amount of water brought to plants at field level relative to the amount diverted from the river, is about 0.4 in the ON area (Kuper and Tonneau, 2002).

Scenario 2 assumes that the production plans of the now known large-scale land investors are carried out. The concerned large-scale investments include Malibya (100,000ha) for rice, N Sukala (15, 000ha) and Sosumar (20,000ha) for sugarcane (Oakland Institute, 2011). This will bring the area under rice cultivation in the rainy season to 196, 000ha and the area under sugarcane to 44, 000ha.

Scenario 3 assumes that additional investments are implemented compared to scenario 2. Considering the strong interest of large-scale investors in the area and planned expansion activities of the ON itself, more investments in the ON area are to be expected and are plausible (Ogilvie et al., 2010). These investments will translate into more land being developed and increased water use. This scenario assumes that an additional 100,000 ha compared to scenario 2 is put to rice production in the rainy and dry seasons through various future projects (for example the Millenium Challenge Account project and ON's own investment). Table 2 summarizes the main characteristics of each scenario.

Insert Table 2 here.

The simulations conducted under these scenarios address the following questions. How do different water pricing systems compare in terms of their effects on production and net profit of farmers, overall agricultural production, ON revenue and water conservation? What are the trade-offs between efficiency and equity objectives for the different categories of smallholder farmers and large-scale investors? Who is losing what? Answers to these questions are subsequently translated into policy recommendations.

For the different scenarios, flat rate water pricing is compared to uniform water pricing in terms of farmer's profit, amount of water required for environmental needs, and ON's revenue. IBT cannot be directly compared to the two other pricing systems because it is structurally different. It is analyzed mainly in terms of efficiency-equity trade-offs. The trade-offs are presented only for smallholder farmers (average farm size <10ha) although the overall analysis included large-scale farmers (average farm size > 1000ha). This is because, in the Malian agricultural policy, equity considerations target smallholder farmers (and not large-scale farmers). Nevertheless, large-scale land use for irrigated crops has tremendous implications for water resources as shown below.

3.1.Baseline scenario

Under this scenario, annual water demand is about 3.52 billion m^3. This simulated result is close, with a high degree of accuracy (about 2% difference), to the actual irrigation water withdrawal in the ON (based on official ON data, Traore, 2008) reflecting the validity of the model[3]. Environmental requirement of the inner delta of the Niger has been estimated at 1.5 billion m^3/year (Zwarts et al., 2005). Tables 3, 4 and 5 summarize production, water demand and farmers' profits for the baseline scenario.

Insert Table 3 here.[4]

Insert Table 4 here.

Insert Table 5 here

The total amount of water fees that is potentially collectible by the ON is US$ 18.8 million per year (Table 3). This amount is 3 times lower than the ON 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 met by the State and other technical partners. In this baseline scenario with no large-scale investor, water resources are adequate and sufficient to cover all demands (estimated at 3.5 billion m^3 in Table 4) given that the average annual available water at the Markala dam is about 25 billion m^3 (Traore, 2008). Table 5 shows the profits of the different types of small scale farmers at the ON.

3.2.Scenario 2: Implementation of currently known LSIAL

Flat rate pricing vs uniform pricing

With increased irrigated area, it is likely that the budget required for ON operations will also increase due to the need to build more roads, canals etc. and maintain them. If we assume that the increase in budget is roughly proportional to the developed irrigated area, the ON budget will be US$ 154 million/year. With the current flat rate water pricing system, ON's revenue will only be US$ 56 million/year (Table 6), suggesting a huge shortfall in ON's budget requirement.

Insert Table 6 here.

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[3] Assuming water use is proportional to area cultivated, we projected water withdrawal for the presently developed area based on data from Kuper and Tonneau. 2002 who used ON official data.

[4] The current water price is 138$/ha for rice and 276$/ha for sugar cane. The water price of sugar cane is double that for rice because sugarcane takes 2 seasons to mature while rice needs only one. Put the two footnotes here directly underneath the relevant tables.

The uniform volumetric water pricing compared to the flat rate pricing allows an increase in the value of overall agricultural production by about US$ 2 million due to the efficient reallocation of water from rice to sugarcane (Table 6). While the rice yield in dry season remained virtually unchanged, and only a slight decrease in wet season rice yield (about 0.1T/ha), sugarcane yield increases from 75T/ha to 81.8T/ha (an augmentation of 6.8T/ha), leading to an increase in the value of sugarcane production of about US$12 million. Clearly, the marginal value of water is higher under sugarcane than rice production.

However, while uniform water pricing improves water use efficiency and gives the maximum net agricultural production value, it significantly affects farmers' profits. Compared to flat rate pricing currently implemented, smallholder farmers profit will decline by about 25% (Table 7). Moreover, all farmers are treated similarly by the uniform pricing system. This may not be a desirable outcome, given Mali's government aim of supporting smallholder family farms. It is therefore necessary to explore mechanisms that ensure some degree of efficiency while ensuring that incomes of smallholder farmers are not too adversely affected.

Insert Table 7 here.

IBT pricing: trade-off curves

Insert Figure 2 here

Table 8 shows the different trade-off points for a "SIAON Small "farmer. Option A is associated with the highest profit for the farmer but would lead to the lowest total agricultural production. Option B leads to a slightly lower profit for the farmer (0.3%) and a slightly higher total production (0.06%) than A. Compared to B, C would increase total production by 0.36%, but considerably reduces the profit of the farmer by more than 10%. Also option D would only slightly increase total production by 0.2% while decreasing farmer profit by 3% compared to C. A manager with a concern for equity would probably prefer B to C and D. The manager will then implement an IBT pricing system that fixes the first block price at US$ 0.020 the second block price at US$ 0.052 and the volume of the first block at 35,150.1 m^3. On the other hand a manager with a very strong efficiency concern would probably prefer C or D and implement the corresponding IBT values. Similar trade-offs can be made for other farmer categories. Figure 2 provides a visual representation of the trade-offs curves that might be easier to interpret and use as a tool to make a decision on the preferred equity-efficiency balance of a water manager.

Insert Table 8 here.

3.3. Scenario 3: Additional new LSIAL

This scenario clearly shows the limitations of the current flat rate water pricing system. The water required for agricultural production increases dramatically to 24 billion m^3 (Table 9) and nearly matches the average annual available water at the Markala dam of 25 billion m^3. This scenario will not leave much water to satisfy the environmental requirements and will most likely result in conflicts between different types of users: the large-scale farmers with considerable water abstraction capabilities will likely appropriate the major share of the resource to the detriment of smallholders. At a volumetric price of 0.056$/m^3$, water use will come down to about 20 billion m^3 (Table 9). This will have limited effect on agricultural production, but will help to reduce conflicts among water users and environmental needs will be covered (estimated at 1.5 billion m^3/year Zwarts et al., 2005). The water pricing system can be designed to even better cover the environmental needs. However, when it comes to equity considerations, uniform volumetric pricing performs poorly with profit of smallholder farmers declining by about 35% as compared to the flat rate (Table 10). Furthermore, all smallholder farmers are treated equally by the pricing system.

Insert Table 9 and Table 10 here

IBT pricing: trade-off curves

Insert Figure 3 here

In this scenario, IBT can be useful as well. For example, Table 11 shows the trade-off points for "SIAON Small farmers" representing different options for the water decision maker of the ON. For options A, B and C, the IBT pricing will not decrease the small farmer's profit whereas D, E and F would decrease it compared to a flat rate pricing. However the decrease of D as compared to the current water pricing will be only 6.5%. If uniform pricing was applied the decrease would be up to 35%. Subject to the equity concerns of the water manager or the policy maker, option D represents only 0.4% efficiency loss compared to uniform marginal pricing.

Insert Table 11 here

4. Recommendations and conclusion

The recent wave of large-scale investments in agricultural land simultaneously present opportunities for increased agricultural production and challenges for water management in sub-Saharan Africa. In this paper, we analyzed the effects of three alternative water pricing systems in the ON under a situation of increasing land and water use. The results indicate that, with increased investments in agricultural land in the ON, the currently used water pricing method will not allow a) an efficient allocation of water, b) recovery of water delivery cost, and c) leave much water to satisfy environmental requirements. Conversely, adoption of a marginal uniform pricing system will allow these shortcomings to be addressed, but at the expense of equity considerations. Although marginal uniform pricing would lead to the maximum possible agricultural outcome in the ON, it would also have significant negative impacts on farmers' profits (decrease of 25% to 35%). This would primarily affect the less land-endowed farmers. From a political economy perspective, this pricing system may not be acceptable to poor smallholder farmers. Consequently, water managers and policy makers may be reluctant to adopt it. For this reason, the possibility of increasing block tariffs (IBT) was considered. A bioeconomic simulation tool was developed to understand the potential trade-offs between efficiency and equity and to explore the implications for different farmer groups. The results suggest that IBT can be a powerful redistributive tool by cross subsidizing between blocks. It highlights a clear trade-off between equity and efficiency and provides an array of pricing options to water managers/policy makers that define varying degrees of efficiency and equity.

Nonetheless, a number of critical issues related to IBT must be discussed. First, IBT has been criticized as being too complex for water managers or water users to use since it involves three parameters in contrast to the uniform pricing system that involves only one (Boland and Whittington, 1998). However, we argue that the extra parameters make the pricing system more flexible and adequate to simultaneously meet different objectives. As shown here, visual representation of the effects of this method can make it easier to use. Furthermore, Sidibe et al. (2012) showed that farmers are able to understand seemingly more complex nonlinear water pricing systems.

Another perceived limitation is the absence of metering systems in most irrigation schemes in developing countries. In the specific case of the Office du Niger, the managers are already exploring ways to implement water metering at least in some areas of the irrigated scheme (PIA, 2011). Volumetric water pricing in developing countries is also encouraged by development partners including the World Bank (Tsur et al., 2004b). Studies need to be conducted to demonstrate the benefits of volumetric pricing before the widespread installation of meters in irrigation schemes can be expected. Such studies can provide the basis for comparing the efficiency gains with the cost of implementing metering systems.

Also and more pertinently, in some cases IBT may have unintended effects on the poor for example if poor households happen to have more family members and smaller plots than richer farmers (Cardone and Fonseca, 2004). However, a study by Bélières et al. (2011) suggests that this is not the case in the Office du Niger. Moreover, more sophisticated IBT that include options for tariffs specifically designed to reduce the bills of large poor households may be considered (Barberán and

Arbués, 2009). Also future climate change and the related uncertainties can be taken into consideration.

Finally, the trade-off analysis presented here is 2-dimensional. It balances equity against efficiency. In reality, trade-offs may be multi-dimensional given the many uses of water, even in the agricultural sector alone. Consequently, more studies will be required to provide sophisticated tools that can account for multiple tradeoffs.

In conclusion, harnessing water resources can play a fundamental role in economic growth and poverty alleviation in developing countries (Irz and Roe, 2002). With this realization, policymakers are interested in exploring new ways to improve the management of water resources (Dinar, 2000). Water pricing, especially irrigation water pricing, is a sensitive issue in several parts of the world because it often affects the incomes of vulnerable populations (Molle and Beker, 2007). Innovative pricing systems are necessary to limit the impact on the poor and account for political considerations. Also pricing should be presented to water practitioners and planner in a user-friendly manner to engage them and to clearly illustrate the potential benefits.

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Appendixes: Production function estimation

We used the AquaCrop crop growth model (Steduto et al, 2009) to estimate the production functions. AquaCrop is a FAO developed agronomic model with a strong water component designed to simulate crop growth from sowing to harvest on a daily time scale. It simulates the crop growth process as a function of the climate and the farmer's technical decisions (irrigation, soil management practices, etc.) on a daily basis. Aquacrop has been validated in various conditions in the Sub-Saharan Africa context (see Khoshravesh et al, 2013 for example). AquaCrop allows building a dataset specifying irrigation water quantities and the corresponding yield. The next step consists of estimating the crop yield function based on this dataset. We first need to specify a functional form. Based on insights from previous works, we use a flexible functional form that is suitable for most crops and climatic conditions:

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

α_1, α_2 and α_3 are regression coefficients to estimate. 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[5].

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 assumptions are based mainly on Diarra (2008); Mather and Kelly (2012) and AMASSA (2014).

[5] Production coefficients are available from the authors upon request.

Tables and Figures

Tables

Table 1: Categorization of farmers by area irrigated

Category	Large-Scale farmers > 1000ha[6]	SIAON Large > 5ha	SIAON Medium 2.5 to 5 ha	SIAON Small < 2.5ha	Very Small 0.6ha
Average irrigated area (ha)		9.46	4.14	2.08	0.6
Yield (T/ha) in 2003[7]		3.6	3.8	3.25	3.15
Average wet season annual yield (T/ha)		6.9	7.3	6.2	6.0
Average dry season annual yield (T/ha)		4.8	5.1	4.3	4.2
Percentage of farmers (%)		10.2	23.4	46.1	20.3

Source: Belieres et al (2002)

Table 2: Area under different crops by scenario.

	Rainy season rice area (ha)	Dry season rice area (ha)	Sugarcane area (ha)[8]
Scenario 1: Baseline	96 000	22 000	9 000
Scenario 2	196000	122080	44000
Scenario 3	296000	222080	44000

Table 3: Baseline scenario: economic output per ha without LSIAL

	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer Net Profit (US$/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

The current water price is 138$/ha for rice and 276$/ha for sugar cane. The water price of sugar cane is double that for rice because sugarcane takes 2 seasons to mature while rice needs only one. Conversions from FCFA to USD was made on the basis of 500 FCFA = 1 US$ 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.

[6] Large-scale investors have not started production activities as for now.

[7] 2003 was an exceptional year with low yields. Average annual wet and dry season yields for different farmers categories were computed here assuming that the average annual yield for the different categories are proportional to the yield they obtained in 2003.

[8] While rice is grown twice a year, sugarcane is grown only once.

Table 4: Aggregate economic output for the ON without LSIAL

	Area ('000 ha)	Production (million US$)	Water demand (million m^3)	ON Revenue (million US$)
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

Table 5: Profit per ha by farm size

Farmer Typology / Net Profit US$/ha	**SIAON Large > 5ha**	**SIAON Medium 2.5 to 5 ha**	**SIAON Small < 2.5ha**	**SIAON Very Small 0.6ha**
Wet season rice	2050.451	2222.684	1782.804	1706.334
Dry season rice	1203.392	1322.631	1018.098	965.1571

Table 6: Secnario 2: Aggregate economic output for the ON under current LSIALs

	Flat per ha water pricing			
	Area ('000 ha)	Production (million US$)	Water demand (million m^3)	ON Revenue (million US$)
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 aUS$/$m^3$)			
	Area ('000 ha)	Production (million US$)	Water demand (million m^3)	ON Revenue (million US$)
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

(Flat per ha water price: US$ 138/ha for rice and US$ 276/ha for sugar cane)

Table 7: Scenario 2: Profit per ha profit by farm size and pricing system

Farmer Net Profit in US$	Typology	SIAON Large > 5ha	SIAON Medium 2.5 to 5 ha	SIAON Small < 2.5ha	SIAON Very Small 0.6ha
Wet rice	FR	2473.98	2672.71	2165.16	2076.92
	U	1891.63	2087.71	1586.92	1499.86
Dry rice	FR	1626.92	1772.66	1400.45	1335.74
	U	1189.92	1335.66	963.45	898.74
Year	FR	4100.90	4445.37	3565.61	3412.66
	U	3081.55	3423.37	2550.37	2398.60

R= Flat Rate U=Uniform

Table 8: Scenario 2: Tradeoff analysis for a "SIAON small" farmer

Points	Price block 1	Price block 2	Volume block 1 (m3)	Total production Millions USD (Efficiency)	SIAON Small farmer profit USD (equity)
A	0.02	0.054	39,796.2	984.2	3,784.2
B	0.02	0.052	35,150.1	984.8	3,777.8
C	0.02	0.048	17,231.2	988.6	3,384.9
D	0.02	0.046	12,294.3	990.5	3,275.0

Table 9: Aggregate economic output for the ON with additional LSIAL

Flat rate per ha water pricing (138US$/ha for rice and 276US$/ha for sugar cane)				
	Area ('000 ha)	Production (million US$)	Water demand (million m^3)	ON Revenue (million US$)
Rice Wet season	296	888	13,394	41
Rice Dry season	222	489	8,772	31
Sugarcane	44	132	1,690	12
Total	562	1,509	23,856	84
Volumetric water pricing (0.055815US$/m^3)				
	Area ('000 ha)	Production (million US$)	Water demand (million m^3)	ON Revenue (million US$)
Rice Wet season	296	830	10,395	232
Rice Dry season	222	468	7,732	173
Sugarcane	44	136	1,873	42
Total	562	1,434	20,000	447

Table 10: Per ha profit for different categories of farmers Flat rate and Uniform marginal cost pricing scenario 3.

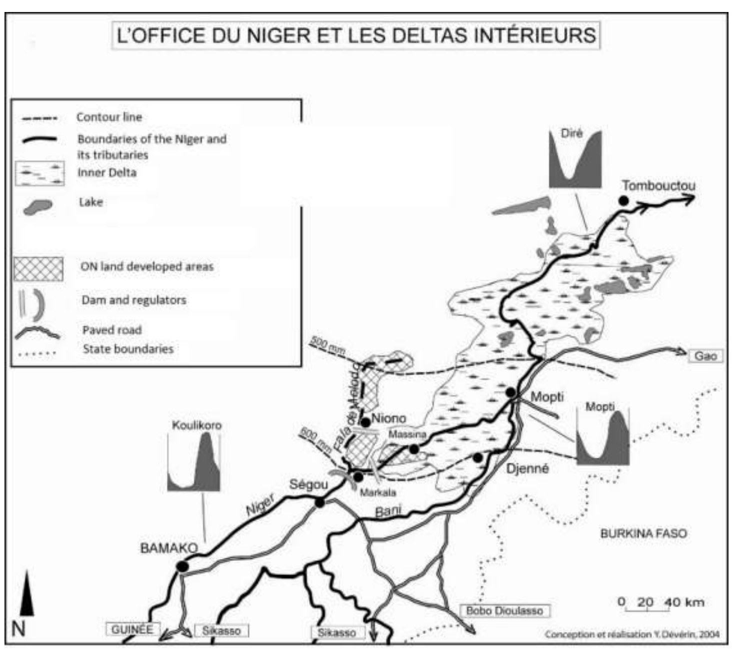
	Typology	SIAON Large > 5ha	SIAON Medium 2.5 to 5 ha	SIAON Small < 2.5ha	SIAON Very Small 0.6ha
Farmer Net Profit ($/ha)	FR	2473.981	2672.711	2165.157	2076.92176
Wet rice	U	1722.2159	1907.698	1433.981	1351.628
Farmer Net Profit ($/ha)	FR	1626.922	1772.657	1400.451	1335.74529
Dry rice	U	1105.2159	1245.652	886.9806	824.6276
Farmer Net Profit ($/ha)	FR	4100.902	4445.368	3565.608	3412.66706
Year	U	2827.4318	3153.35	2320.961	2176.255

Table 11: tradeoff "SION small" farmer scenario 3

Points	Price block 1	Price block 2	Volume block 1 (m3)	Total production Millions USD (Efficiency)	SIAON Small farmer profit USD (equity)
A	0.02	0.068	40597	1,419	3,784
B	0.02	0.066	36077	1,420	3,780
C	0.02	0.064	31240	1,421	3,762
D	0.02	0.06	18478	1,425	3,373
E	0.02	0.058	13687	1,428	3,203
F	0.02	0.056	8905	1,430	3,053

Figures

Figure 1: Map of the Office du Niger



Source: modified from Y Deverin, 2004.

Figure 2: tradeoff curves for scenario 2 under IBT

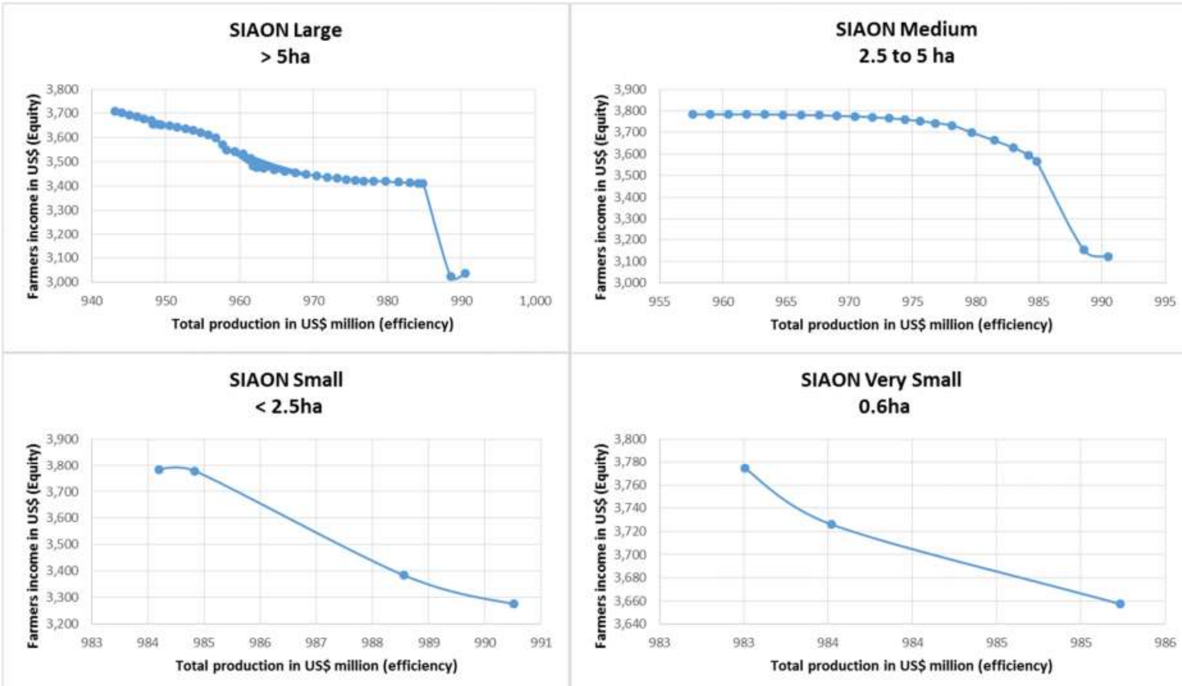


Figure 3: tradeoff curves for scenario 3 under IBT