Agricultural land investments and water management in the Office du Niger, Mali: Options for improved water pricing

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(Received 31 December 2014; accepted 31 March 2016)

Large-scale agricultural land investments in Africa are often considered solely from the land perspective. Yet land, water and other natural resources are closely interlinked in agricultural production and in sustaining rural livelihoods. Such investments involving irrigation will potentially have implications for water availability and utilization by other users making it imperative to regard water as an economic, rather than a free good. Focusing on a vast irrigable area in Mali with recent large-scale investments, we used a bio-economic model to demonstrate that an improved water valuation system is needed to balance different water users' needs while ensuring adequate environmental flow.

Keywords: water scarcity, efficiency, equity, environmental flows, Mali

Introduction

Large-Scale Investments in Agricultural Land (LSIAL) in Africa that have featured prominently in public discourse over the last few years essentially focused on land alone (Woodhouse, 2012; Kizito et al., 2012). However, land and water are closely interlinked resources (Williams et al., 2012). For crops such as rice and sugarcane, irrigation is needed to avoid crop failure and to increase productivity (Fraiture and Wichelns, 2010). Water and land sustain ecosystem services – provisioning, regulating, supporting, and cultural – that are important to rural populations who rely on them for livelihood in several African countries (Cotula and Vermeulen, 2011; Kizito et al., 2012; OCDE, 2002). The International Water Management Institute (IWMI), through the Challenge Programme on Water and Food and the more recent CGIAR Research Programme on Water, Land and Ecosystems, has always underscored the critical importance of sustainable land and water management in addressing the challenges affecting food production and the underlying natural resources and ecosystems in Africa (IWMI, 2014).

Yet, water is the ignored dimension in large scale land deals. It is hardly explicitly included in many land acquisition contracts and when included, it is inadequately valued[1]. The water rights of smallholder farmers and the potential impacts of large-scale land use, occasioned by the agricultural production activities of investors, are other dimensions that are not adequately

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considered when lands are leased out (Cotula, 2011). Poor management of water on large-scale irrigation schemes, can lead to negative consequences, including wasteful and inefficient water use, early degradation of infrastructure and environmental damage (Deininger, 2011a and 2011b; Djire et al., 2012; Sindayigaya, 2012; German et al., 2013). Nonetheless, it is equally recognized that large scale investments (foreign or domestic) 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 infusion of capital, new technology and knowledge, such investments can increase agricultural production and improve national food security, while contributing to government tax revenues and water supply cost recovery. Therefore, an appropriate water pricing system that recognizes the economic value of water is crucial to obtain full benefits of these investments, while protecting the livelihood of other users and the environment. This paper elaborates an alternative option to the current system of pricing irrigation water in the study area of the Office du Niger in Mali.

The Office du Niger (ON) covers a large irrigable area of over one million hectares in the inner delta of the Niger River, stretching from Ségou in the south to areas of Mopti in the north. ON is also the name of the semi-autonomous agency in charge of the development of the area. The Malian Government has proactively promoted a policy of opening up land in the ON area to investors with the intention of making the country the "food basket" of the West African Region (PDA, 2013; Kuper and Tonneau, 2002; Brondeau, 2011). Availability of abundant water resources and favourable agro-ecological conditions clearly appear to be some of the major driving forces behind private large scale investment schemes in the area (Woodhouse, 2012). Water use for irrigation is viewed as a way to substantially increase crop yields and boost profits. More than 200, 000 ha of land is currently leased and intended for growing highly water demanding crops such as rice and sugarcane. Consequently, a significant share of the country's water resources may be used in these investments, as suggested by an analysis of similar LSIALs in Ethiopia (Bossio et al, 2012).

Considering growing future demands for water, due to increased rate of urbanization and industrial sector growth, and the implications of reduced rainfall suggested by climate change projections (ODI & CDKN, 2014), the inadequacy and limitations of the water management system currently in place in the ON is likely to quickly surface. The present water management system relies on a flat rate per hectare pricing. Economic theory and empirical analysis suggests that this pricing system is ineffective, in the sense that it does not encourage water conservation because it does not send the right signals to water users to inform them of the relative scarcity of the resource (Johansson, 2000). Therefore, the land investor is unable to properly assess the marginal value of the water used in agricultural production. An alternative approach explored in this paper, based on a volumetric water pricing, should help to efficiently allocate water in the face of scarcity and to recover the costs of water supply while promoting environmental protection (Rogers et al., 2002). Although the flat rate per area pricing implemented in the ON has been largely criticized (Brondeau, 2011; Hertzog et al., 2012), options for implementing a volumetric water pricing system have not been investigated. Our aim in this paper is to address this neglected potential and thereby fill a gap.

The paper analyses different existing and possible future agricultural land investment scenarios in the ON and shows how a volumetric water pricing system lead to a relatively more efficient valuation of agricultural water. A uniform pricing system is considered as it is the simplest volumetric pricing model and may be more adapted for the ON presently using a per are flat rate. A bio-economic model, combining biophysical and economic considerations, is developed to simulate the likely impacts of LSIALs under two alternative water pricing systems: the current flat rate per hectare pricing and a volumetric pricing. A comparative analysis of the effects of the different pricing systems is undertaken in terms of efficiency of water allocation, environmental flow requirements and cost recovery. The paper provides evidence on the merits of volumetric water pricing while addressing some of the possible political economy implications of adopting such a pricing system.

The paper is organized as follows. Section 2 describes the methodological framework used. The subsequent section presents the results and discusses how volumetric water pricing can help to address water management problems in the ON. The final section concludes the paper drawing out the policy implications of adopting a volumetric water pricing system.

Methodological framework

Description of the study area

The analysis focuses on the Office du Niger (ON) area. Created in 1932 by the French colonial administration, the Office du Niger refers to both the area of the inner delta of river Niger River in Mali (about 1, 000, 000 ha)[2] 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). The ON is now limited to the management of land and water and provision of agricultural advisory services. All production activities that it used to undertake have now been privatized. The ON is not directly mandated to handle environmental protection but may intervene if its water management system is affected by environmental problems (especially aquatic weeds). The agency uses a flat rate per area 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 Office du Niger area for this analysis is motivated by its strategic importance for the country’s socioeconomic development (Djiré et al., 2012), its attractiveness to foreign and domestic investors and its rich ecological profile (wetlands, aquatic animals and rich biodiversity). The climate is of Sahelian semi-arid type, annual average rainfall ranging between 600 and 750 mm. Annual mean temperature is 28°C and the annual mean maximum temperature is 35^{o}C (CLIMWAT, 2011). The 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. Most local people are poor subsistence farmers, heavily reliant on natural resources and vulnerable to the vagaries of the climate (Michigan State University, 2011). Figure 1 shows the location of three major schemes in the ON.

Insert Figure 1 here

Model description

A bio-economic model that combines a crop growth model with a farm-level microeconomic model is developed. The crop growth model indicates how much yield is obtained for a given amount of water, while the economic model shows how much profit is obtained for a particular yield level and water price. This modelling approach linking empirical economic model and biophysical models has been used in a number of studies (Stoorvogel et al., 2004; Reynaud, 2009; Sidibe et al., 2012). The advantage of such an integrated assessment approach (compared to a classic econometric approach) is that it creates a tool that is able to simulate behaviours outside the range of the observed domain and account for non-linearities (Antles and Capalbo, 2001). It can be used 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 and Capalbo., 2001). In this study, the bio-economic simulation model is used to conduct a comparative analysis of the impacts of two alternative water pricing systems: a) the current flat rate per hectare pricing, and b) a volumetric pricing in terms of economic efficiency of water allocation, environmental flow requirements and cost recovery.

AquaCrop, an agronomic model developed by FAO (Steduto et al., 2009), was used as the crop growth model. AquaCrop simulates 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.). Aquacrop has been validated under various conditions in sub-Saharan Africa (Khoshravesh et al., 2013). AquaCrop allows the building of a dataset specifying irrigation water quantities and the corresponding yield. The dataset can then be used to estimate production functions. Separate production functions were estimated for wet season rice, dry season rice and sugarcane (see Appendixes A and B). Also in the baseline scenario, the model has been calibrated to reflect the yields obtained by different categories of farmers (small-scale and large-scale).

With respect to the economic model, the objective of the farmer is to maximize profit while the objective of the manager, i.e. the ON, is to maximize agricultural production taking into account water availability and budget constraints. The optimal volumetric price is determined within the model by respecting all the constraints and optimization conditions. The mathematical model was made operational using a solver type algorithm. This formulation is perfectly in line with the objective of the Malian agricultural policy (Loi d'orientation agricole, 2005). 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.). Each investor is assumed to grow only one of two crops, rice or sugarcane. Also, rice is grown twice per year while sugarcane is grown only once. These assumptions are consistent with observations and agricultural production practices of large-scale investors in the ON (see Appendixes A and B). The solution to this problem is characterized as follows. If a flat per area rate is applied, then the price is independent of the amount of water used. Theoretically farmer would tend to choose to use all available water. But in practice, the farmer is limited by his/her water abstraction capacity. Under a uniform volumetric pricing system, the farmer will choose an amount of water that equates the marginal productivity of water to the relative price of water. This means that an increase in water price will lead the farmer to reduce water consumption. Also, because the water price is the same for all crops (rice and sugarcane), optimisation involves that the marginal water productivities for all crops are equal. This is done by reallocating water from the less productive crop to the most productive one. The mathematical details are specified in appendix A.

Data sources

For the crop growth model, agricultural and climatic data from various previous studies in the ON were used to estimate and calibrate the model (Kuper and Tonneau, 2002, Reseau riz, 2004; 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 information on prices and costs were obtained from AMASSA, 2014; Mather and Kelly, 2012 completed and confirmed through recent interviews with ON top managers.

Three scenarios were tested. Scenario 1 mimics the baseline conditions in terms of areas planted to different crops and yields. Scenario 2 assumes that existing land investors implement their production plans. Scenario 3 assumes that new additional land investments are implemented. These assumptions are based on the contractual agreements of current investors with ON and in-depth interviews with senior managers of ON. The assumptions are also consistent with ON Development and Master Plan that was validated in 2008.

Figure 2 shows the production functions for wet season rice, dry season rice and sugarcane. All production functions are increasing and concave which is consistent with microeconomic theory. Rice production in wet season is higher than in dry season because agro-climatic conditions (temperature, humidity etc.) in the wet season are more favourable to rice growth. Sugarcane production considerably increases with more water. But for water allocation purposes what matters is not the overall production per se, but the marginal production as will be shown below.

Insert Figure 2 here

Impacts of different pricing systems on water management

Scenario 1: Baseline

The baseline scenario is constructed based on observed yields in the ON area for smallholder farmers. 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 in the dry season (on approximately 22, 000 ha) and sugarcane yield 74.5T per ha on 9000ha (Tangara, 2011, FAOSTAT, 2010). The associated water demands are 10,900m^3/ha and 10,200m^3/ha, respectively for rice and sugarcane. Water demand is higher in the rainy season than the dry season probably because due to other climatic conditions (evapotranspiration (ET0), temperature, humidity), the marginal crop production per unit of water in the rainy season is higher than in the dry season. Therefore, farmers have more incentive to irrigate in the wet season. When aggregated at the ON level and considering an irrigation efficiency of 0.4 in the ON area (Kuper and Tonneau, 2002), this represents an annual water demand of about 3.52 Billion m^3 according to our model. 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) showing the validity of the model[3].

Insert table 1 here.

Insert table 2 here.

The total amount of water fees that can be potentially collected by ON is US$ 18.8 million per year. 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 gap is met by the State and other technical partners every year.

Scenario 2: Implementation of the plans of LSIALs

In this scenario, we assume that large scale investments like Malibya (100, 000ha) for rice, N-Sukala (15, 000ha) and Sosumar (20, 000ha) for sugarcane are implemented. This will bring the area under rice cultivation to 196, 000ha and the area for sugarcane to 44, 000ha.

With increased irrigated area, it is likely that the budget requirement of ON will also increase as there will be a need to construct more infrastructure (roads, canals etc.) and maintain them. Assuming that the increase in budget is roughly proportional to the developed irrigated area (Perry, 2001; Venot et al., 2011), the ON budget requirement will be about US$ 154 million per year. Tables 3 and 4 below show two different options with the assumption of a flat rate per hectare water pricing and a volumetric linear pricing systems. Rice yields in the area can reach up to 7.5T/ha in the wet season and 5.5T/ha in the dry season[4] (Brondeau, 2011; Tangara, 2011).

Insert table 3 here

Insert table 4 here

With the amount of water abstracted from the river, the volumetric water pricing (US$ 0.045154/m^3) allows an increase in agricultural production value by about US$ 2 million per year. This is because volumetric pricing allows an efficient reallocation of water between rice and sugarcane. In fact, while the rice yield in dry season did not virtually change and there is only a slight decrease of wet season rice yield (about 0.1T/ha), sugarcane yield increases from 75T/ha to 81.8T/ha (an augmentation of 6.8T/ha). This indicates that the marginal value of water is higher in sugarcane compared to rice production.

Considering the ON revenue, the flat rate per area water pricing does not allow the recovery of the budget (3 times less) while with volumetric water pricing, fees collected exceeds by a wide margin the budget requirement due to the tremendous increase in water demand (approximately 15.38 billion m^3). However, the ON could still use a flat rate to cover this budget gap by increasing its level provided ON is willing to considerably raise water fees to around US$ 425/ha for all water users. Taking into account the evaporation of water from the river (0.57 billion m^3), the minimum environmental flow requirement (estimated at 1.5 billion m^3 MCA, 2008; Zwarts et al., 2005) will not be met once every 10 years. But the next scenario is even more alarming.

Scenario 3: More investments

Considering the strong interest of investors in the area and expansion activities planned by the ON, more investments in the ON area can be expected. These investments will translate into more land being developed and inefficient increased water use, if proper water management systems are not put in place. This scenario assumes that 100, 000 ha more land than scenario 2 is put to rice production through various future projects (for example the Millennium Challenge Account project and ON own investment). As for scenario 2, the effect of the business as usual water valuation system (flat rate per ha) is compared to that of a volumetric water pricing.

Insert table 5 here.

Insert table 6 here

This scenario clearly shows the limitations of the current water management and valuation system. Water demand explodes (about 24 billion m^3) and nearly exceeds the average annual available water at the Markala dam (about 25 billion m^3)[5]. This scenario will not meet the environmental requirement and will likely result in conflicts among different categories of users. Large-scale farmers with considerable water abstraction capabilities will likely appropriate the major share of the resource to the detriment of smallholders (Coulibaly et al., 2006). At a volumetric price of US$ 0.055815/m^3, water use will come down to about 20 billion m^3. This will have limited effect on agricultural production, but will help to reduce conflicts among water users and environmental needs will be covered (at least on average). The volumetric water pricing can be designed to conserve more water and even better cover the environmental needs.

Discussion and conclusion

There are two important limitations to the approach used in this paper. First, the bio-economic model used assumes that water pricing has effect only on water use and influences yield mainly through changes in irrigation level. This is a simplification as water pricing may also affect the use of other inputs (Speelman et al., 2009; Frija et al., 2011). The Aquacrop model used balances the trade-off in specifying a complex detailed model against the substantial data requirements to fulfil in order to run such a model. Besides, other studies suggest that the substitution between water and other inputs tend to be limited (Schoengold et al., 2006; Lehmanna and Finger, 2014). Secondly, although a dynamic and adaptive pricing system could have been used to address the environmental flow requirements much more deeply, the use of such a sophisticated model will require information and data on the hydrology of the whole basin and operational rules for water release from the planned Fomi Dam upstream of the ON area which were unavailable to the authors.

Despite these caveats, the analysis presented exposes the economic, social and environmental problems that are unintentionally ignored, but are likely to arise when water availability and utilization by various users, especially rich investors, is not taken into consideration in the approval and/or planning of LSIALs. Water resources appeared to be one of the main drivers of land acquisition in the ON area. As more water demanding crops (e.g. rice and sugarcane) are cultivated on large tracts of land, there will be a pressing need to improve the water management system. Although there is an implicit recognition by the managers of ON of the need to efficiently allocate water, cover the cost of water supply and ensure environmental flows in order to ensure the long-term sustainability of the irrigation and farming systems, yet an efficient water valuation and management system that will allow these objectives to be achieved have not been considered or implemented. Our analysis indicated that the flat rate per hectare pricing system as currently implemented by ON will not allow the managers to achieve efficient water allocation. With the current pricing system and under the second and third scenarios considered, the Markala dam will not even come close to irrigating the 1 million ha area that is generally claimed to be irrigable.

As demonstrated, volumetric water pricing that allows the marginal value of water to be reflected in water allocation decisions is an option to address the inadequacy of the current pricing system. We used in this paper a linear volumetric pricing model as a first alternative to a flat rate per area pricing system. But volumetric pricing models can take many innovative forms to suit the objectives of policy makers, including assessment of trade-offs between efficiency and equity. It can also allow environmental flows to be directly taken into consideration. While environmental management is not in the mandate of the ON, the inner delta of the Niger River has sensitive ecosystems and a unique biodiversity providing several services. Including environmental preservation and management in the mandate of the ON will allow these ecological systems to be taken into consideration and managed in a more integrated way partly through the pricing system used by the agency.

However, problems associated with the practical implementation of volumetric pricing should not be ignored (Cornish et al., 2004; Easter and Liu, 2005). Meters will have to be installed to measure the volume of water delivered and they will have to be transparently and honestly read and reported. As long as the cost of installing measuring devices, monitoring water use and billing system is not a high percentage of the revenue collected or of the value of production, volumetric water pricing can be justified. In the context of large-scale investments considered, the installation and the monitoring of volumetric systems would be easier and less costly because there will be room for economies of scale in metering water use and in collecting water fees. The ON is already planning to install water metering systems at least for some schemes (PIA, 2011). More generally, water pricing is a controversial and politically sensitive subject in many developing countries. Thus, the inclusion of political considerations in economic approaches to water pricing reform is highly desirable as suggested by Dinar (2000). Indeed, ignoring political considerations can hinder the implementation of pricing systems designed only on efficiency basis (Molle et al, 2008; Dinar and Wolf, 1997) because water pricing reforms would necessarily involve changes in institutional arrangement since they are not just about changes in price levels but they imply a change of the pricing rules. Moving from a flat rate area-based pricing to a volumetric water pricing requires institutional reforms to make the change socially and politically acceptable. Approaches that involve farmers, through water user associations, in volumetric pricing are necessary and could prove useful.

Acknowledgement

This paper is drawn out of a project conducted in partnership with the Secretariat of the African Ministers' Council on Water (AMCOW), UNEP, Grid-Arendal and FAO. The authors are grateful for the grant provided by UNEP, Grid-Arendal and FAO for the main project. The authors are also grateful to the Associate Editors of Water International and to an external reviewer for the useful comments provided to improve the paper. The authors are responsible for the contents of the paper, including any error or omission, and absolve the listed organizations of any responsibility in the interpretations and conclusions expressed in the paper.

Endnotes

[1]Out of 177 documented land deals reviewed by the authors in Africa, only 8 explicitly mentioned water management.

[2]This figure varies according to the source considered.

[3]Assuming water use is proportional to area cultivated, we projected water withdrawal for the presently developed area based on data from (Traore, 2008).

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

[5]Based on data from Traore (2008)

[6]Conversions from FCFA to USD was made on the basis of 500 FCFA = 1 USD. USD=$.

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Appendixes

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). The farmer's problem and the manager's problem are formalized as shown below:

Farmer's problem

The objective of the rational farmer is to choose the irrigation water quantity he/she uses so as to 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:

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

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

Description of variables

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:

$$w_i = Y_i'^{-1}\left(\frac{p_w}{p_{y_i}}\right) - \pi \qquad (2)$$

This represents water demand. It is increased with the crop market price (rice or sugarcane) and decreased with water price. Therefore, an increase of water price will lead to water saving that can be quantified for the individual farmer using equation (2). Summing it for all farmers $\sum w_i$, we obtain the total water use.

Water manager problem

The water manager's problem is to choose the water price p_w in order to maximize a social welfare function that takes into account the objectives of all user groups. The social welfare function here is the value of total agricultural production of rice and sugarcane (for all farmers).

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

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.

This problem is mathematically solved using the Lagragian. 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:

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

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:

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

The next step is to estimate *Y(w)* that will feed into the economic model.

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

	Wet Rice	**Dry Rice**	**Sugarcane**
$\boldsymbol{\alpha_1}$	1.11	1.40	11.53
$\boldsymbol{\alpha_2}$	-4000.00	-8450.29	-10599.48
$\boldsymbol{\alpha_3}$	0.200	0.153	0.204
Emp F	11.11	251.72	591.33
Emp χ^2	0.01892394	0.00202189	0.04891976

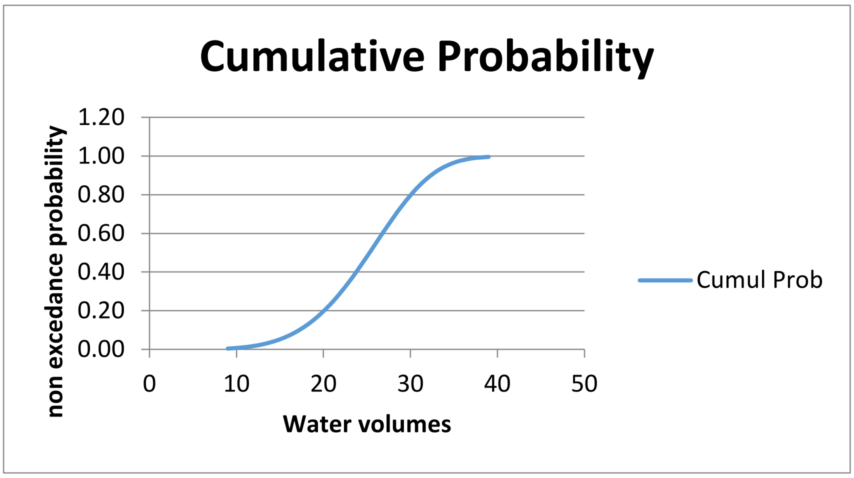
These functions are then used as inputs in the economic model presented in the previous section. An optimization module is then used to simulate the different output variables. The following table (table A.2) summarizes the main economic assumptions used. The assumptions are based mainly on AMASSA, 2014 and Mather and Kelly, 2012.

Table A.2: Prices and costs

	Rice	**Sugarcane**
Market Price ($/T)	400.00	40.00
Other Production costs ($/ha)	568.50	600.00

Based on flow records from 1982 to 2007, we estimate the cumulative probability distribution of available water volumes. This allows to know the probability that a given volume of water will not be obtained. We assume that the data follows a Weibull distribution (as it is often the case for flow data) and validate the assumption with a Student and Fischer tests. This analysis suggests that the flow follows a Weibull distribution with α= 4.893 and β=10559747.318. The distribution function is represented in the figure A.1.

Figure A.1: Cumulative probability of obtaining given water volumes



Appendix B: Parameterization of the crop growth model AquaCrop

Tables B1 and B2 show the soil and crop parameters used.

Table B.1: Soil parameters

Soil	
description	Sandy Loam
thickness (m)	4
PWP (%)	10
FC (%)	22
SAT (%)	41
TAW (mm/m)	120
KSAT (mm/day)	500

Sources: Harmonized World Soil Database and Aquacrop.

Table B.2: Crop parameters

Region	**Crop**	**Planting date**	**Harvest Index (%)**	**Sowing Density (plant/m2)**
Segou	Wet rice[1]	19/06	43	100
Segou	Dry rice[8]	19/10	43	100
Segou	Sugarcane	19/06	82	14
Sources				

Sources: Kuper and Tonneau (2002) used for calibration.

Additional parameterization files are available upon request.

[1] Rice variety considered is ITA 304 (Reseau riz, 2004)

Tables

Table 1: Baseline scenario: economic output per ha without LSIAL

	Yield (T/ha)	Production[6] (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

Table 2: 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 3: Scenario 2: economic output per ha with additional LSIAL

Flat per ha water pricing (138$/ha for rice and 276$/ha for sugar cane)					
	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer Net Profit (US$/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$/ha)	Water demand (m^3/ha)	Farmer Net Profit (US$/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 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 US$/$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	15,381	278

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

Table 5: Scenario 3: economic output per ha with additional LSIAL

Flat per ha water pricing (138$/ha for rice and 276$/ha for sugar cane)					
	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer Net Profit (US$/ha)	ON Revenue (US$/ha)
Rice Wet season	7.5	3000.73	18100	2156.24	138
Rice Dry season	5.5	2199.83	15800	1355.34	138
Sugarcane	75	2999.57	15365	2017.08	276
Volumetric water pricing (0.055815$/$m^3$)					
	Yield (T/ha)	Production (US$/ha)	Water demand (m^3/ha)	Farmer Net Profit (US$/ha)	ON Revenue (US$/ha)
Rice Wet season	7.0	2804.13	14048	1451.56	784.09
Rice Dry season	5.3	2107.28	13926	761.49	777.31
Sugarcane	77.5	3098.04	17023	1441.40	950.15

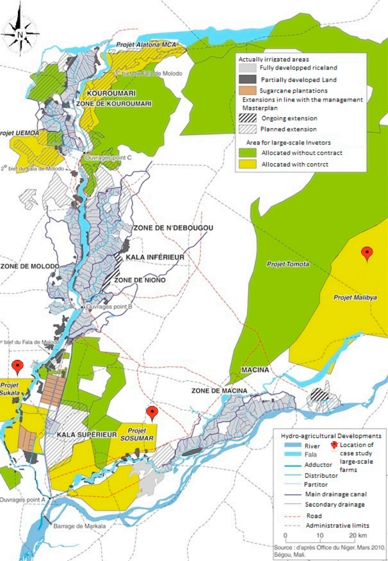
Table 6: Scenario 3: Aggregate economic output for the ON under current LSIALs

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

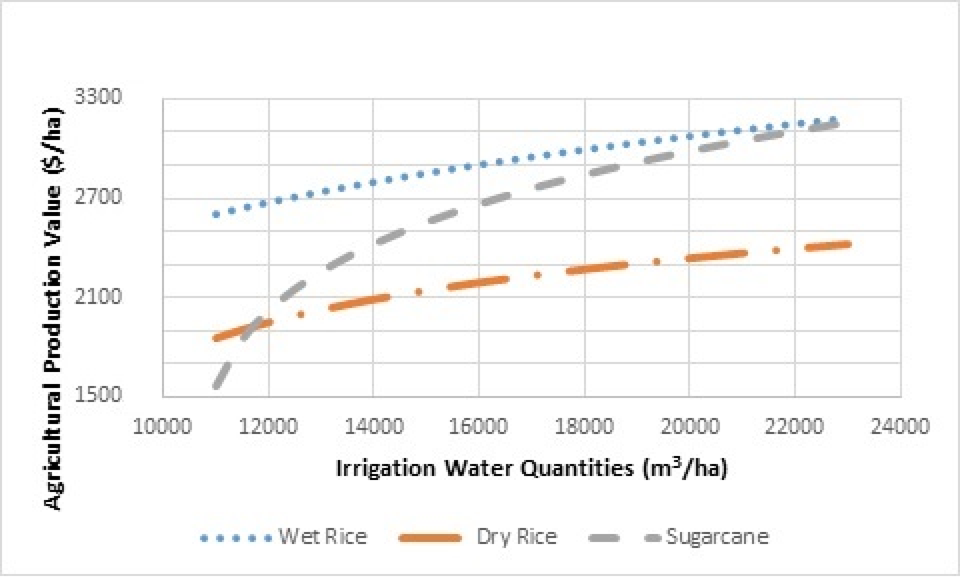
Figures

Figure 1: Map showing the location of three major schemes studied in the ON area.

Figure 2: Estimated rice and sugarcane production functions



N
Projet Alatona MCA
3e bief du Fala de Molodo
KOUROUMARI
ZONE DE KOUROUMARI
Projet UEMOA
Ouvrages point C
2e bief du Fala de Molodo
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
ZONE DE N'DEBOUGOU
KALA INFÉRIEUR
ZONE DE MOLODO
ZONE DE NIONO
Projet Tomota
Projet Malibya
Ouvrages point B
bief du Fala de Molodo
Projet Sukala
MACINA
ZONE DE MACINA
KALA SUPÉRIEUR
Projet SOSUMAR
Ouvrages point A
Barrage de Markala
Hydro-agricultural Developments
River
Fala
Location of case study large-scale farms
Adductor
Distributor
Partitor
Main drainage canal
Secondary drainage
Road
Administrative limits
0
10
20 km
Source : d'après Office du Niger. Mars 2010. Ségou, Mali.



3300
2700
2100
1500
Agricultural Production Value ($/ha)
10000
12000
14000
16000
18000
20000
22000
24000
Irrigation Water Quantities (m3/ha)
Wet Rice
Dry Rice
Sugarcane