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Access to Irrigation and the Escape from Poverty

Evidence from Northern Mali

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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ABSTRACT

Significant changes in the agricultural sector in northern Mali suggest that irrigation has made a large contribution to welfare increases over the past eight years. Using difference-in-differences, propensity score matching, and matched difference in differences with a small panel, this study estimates the impact of access to irrigation on poverty, production, and nutrient intakes. The findings suggest that gains in agricultural production value do not transfer uniquely to household consumption. The paper tests two alternative hypotheses about the distribution of agricultural gains: (1) the gains in agricultural production induced by irrigation yield higher household savings, or (2) intra-village transfers from irrigators to non-irrigators contribute to informal social insurance. The paper provides evidence of both saving and sharing within villages as complimentary strategies for consuming gains in agricultural production. This finding suggests that estimating the effects of a program, relying solely on household consumption, may underestimate the welfare gains of irrigation investment by ignoring the household's savings and informal insurance network.

Keywords: irrigation, Mali, informal insurance

1. INTRODUCTION

Empirical evidence suggests that irrigation projects have positive impacts on agricultural production and the reduction of poverty for farmers (von Braun, Puetz, and Webb 1989; Hussain and Hanjra 2004; Smith 2004; Lipton 2007; and Hussain 2007b). Access to irrigation provides farmers with a reliable water source at critical times in the crop's life cycle, removing the dependence and inherent uncertainty of rainfed and lake-based agricultural systems in arid and semiarid regions of northern Mali. This reduction in risk faced by farmers is likely not only to increase mean agricultural returns but also to reduce their vulnerability to income fluctuations. While farmers are exposed to unforeseen production shocks regardless of the production system, irrigation minimizes these shocks by permitting a wider range of ex-post smoothing mechanisms to be used, which causes fewer distress sales of crop stocks or assets. Lipton (2007) reports that in India, irrigated areas had 2.5 times lower standard deviation of crop output per year during the period 1971—84.

Because irrigation investment is not homogeneous between or within countries, this paper contributes to the literature on the impact of internationally financed irrigation projects on household agricultural production, household consumption, and nutrient intakes in northern Mali, an area that possesses few of the preconditions for agricultural growth, such as good quality soil, frequent and adequate rainfall, moderate temperatures, and sufficient infrastructrure. Most international attention has been paid to the Office du Niger irrigation scheme[1] in the Segou region of Mali. However, small-scale village-level projects (30–40 hectares) and larger-scale projects (500 hectares) dot the inner Niger delta and north of Tombouctou into the Saharan desert, which is one of the poorest regions of Mali and an area hardest hit by the Sahel droughts[2]. These irrigation projects are not investments by farmers in boreholes or wells for irrigating their personal fields; rather they are community-level investments that result from household, village, and international organization partnerships. Borehole or well investment by households is less frequent in northern Mali because of its arid climate, which results in a low water table and increased difficulty in constructing wells. The dominant type of irrigation project considered here are those that use motorized pumps to redistribute water from the Niger River throughout a canal irrigation system.

The analysis in this paper is based on field research, including a multi-topic household survey in northern Mali, conducted in 1997–98[3] and again in 2006. Because these data were not generated as a random experiment, several identification problems exist, which the econometric strategy attempts to control. The first is the endogeneity of access to irrigation due to nonrandom program placement. This bias occurs when intentional or implicit targeting rules are used to allocate projects to villages. These village-level characteristics are more likely to correlate with the explanatory variables if the programs are allocated either to highly productive areas to ensure program success or to less productive areas to target the poor. In either case, estimates of the project impact derived from outcome indicators will contain upward or downward bias, respectively, due to the group's pretreatment characteristics.

A second source of bias in program estimates is the selection bias due to nonmandatory program participation. Access to irrigation is likely to be correlated with household characteristics such as education, which may influence the likelihood of technology adoption or the ability of a farmer to lobby on behalf of his community for the intervention; access to water, which is a necessary condition for motorized irrigation; and whether households live in rural or urban areas, which may increase the facility

[1] The Office du Niger was originally constructed in 1932 as a gravity irrigation scheme during French colonialism. While widely regarded as a failure into the early 1970s, a restructuring of the Office du Niger from 1979 to 1996 has improved the technical efficiency of the institution and increased grain yields for farmers (Couture, Lavigne Delville, and Spinat 2002).

[2] Understanding the effectiveness of these projects is not only of economic importance but also political importance. The Government of Mali has used investment in irrigation and infrastructure in Northern Mali as a strategy to bring peace to an area of social unrest caused, in part, by economic destitution.

[3] These data, originally collected by Luc Christiaensen with support from John Hoddinott, have been made available by the International Food Policy Research Institute (IFPRI) (Christiaensen 1998)

of program implementation. Program placement is not random. Unless the allocation of program interventions was intentionally randomized or can be viewed as a natural experiment, the distribution of observable and unobservable village and household characteristics between treatment (with irrigation) and comparison groups (without irrigation) will not be statistically equivalent.

The econometric strategy employed to address the nonrandomized program placement in villages and adoption decisions by households within these villages is threefold. Difference in differences, propensity score matching, and matched difference-in-differences estimators are estimated, drawing on a growing theoretical and empirical literature on the estimation of program effects from nonexperimental data (Heckman, Ichimura, and Todd 1997; Smith and Todd 2005; Bertrand, Duflo, and Mullainathan 2004; Jalan and Ravallion 2003; and Gilligan and Hoddinott 2007). As a robustness check for the propensity score matching and matched difference-in-differences estimates, four different estimators (nearest-neighbor matching, matching with 10 closest neighbors, kernel Epanechnikov, and local linear matching are employed to produce point estimates. Estimates of the impact of irrigation are robust to both econometric strategy and choice of estimator. Despite these robustness checks, it should be noted that the fundamental role that unobservables may have in driving these relationships is not adequately addressed by difference in differences or propensity score matching. Because irrigation investments were not allocated to villages randomly and participants were not selected into plots randomly,[4] the paper cannot completely rule out the question of whether unobservable characteristics drive the relationship. However, because allocation of village-level projects is predicated on proximity to the Niger River, there are strong observable characteristics that facilitate the construction of legitimate treatment and comparison groups.

Besides measuring the impact of irrigation, this paper attempts to reconcile differences in impact assessments made using agricultural production and household consumption. Because increases in agricultural production do not necessarily transfer one-to-one into gains in household consumption, critics of irrigation suggest that increased input costs erode the benefits of irrigation projects (Kouyate and Haidara 2006). However, empirical evidence from other antipoverty programs suggests that if a participant’s time horizon is sufficiently short, the program may be viewed as a temporary intervention, yielding no changes in a participants’ permanent income (Ravallion and Chen 2005). This paper investigates the hypothesis that households may save surpluses in agricultural production by accumulating livestock. Alternatively, irrigators sharing additional food gained from irrigation with nonirrigators in their village could also explain the discrepancy between average effects of irrigation on production and consumption. Either hypothesis would understate the gains from irrigation if household consumption were used as the sole measure of welfare. As part of a study of potentially offsetting secondary effects of irrigation, the paper examines whether access to irrigation increases the demand for child labor and induces changes in household composition due to increased labor demands.

This paper’s organization is standard. The second chapter presents a household model of agricultural investment and risk. The third chapter describes the data and survey area. Chapter 4 presents the econometric strategy. Chapter 5 presents the estimates of the direct effects of irrigation on household consumption, agricultural production, and nutrient intakes and discusses the secondary effects of irrigation, including livestock accumulation, food sharing within villages, household composition, and child labor. These variables measure potential ex-ante changes to household savings behavior, informal insurance networks, and labor demand induced by access to irrigation. A final chapter concludes the paper.

[4] Although in most villages, after the irrigation scheme is built, participants are allocated an irrigated plot randomly in the village scheme. This controls, at least, for differences in unobserved soil quality among adopters.

2. A MODEL OF IRRIGATION INVESTMENT AND RISK

Rosenzweig and Binswinger (1993) propose a theoretical model to investigate the relationship between risk and agricultural investment. In this paper, the model is applied to irrigation investments made jointly by international organizations and village agricultural producers to install irrigation schemes. Sensitivity to risk is captured in the theoretical framework by modeling farm households whose utility function values not only mean consumption over time but also the variability of this consumption.

Consider a farm household that maximizes utility over mean consumption, $\mu_{c,}$ and wants to minimize the standard deviation of consumption, σ_c. The farm household maximizes a utility function *V* such that

$$U = V(\mu_c, \sigma_c) \tag{1}$$

where $V_\mu > 0$ and $V_\sigma < 0$. The farmer produces output by choosing productive investments I_i, where $i = 1, ..., N$, such as fertilizer, irrigation, or high-yielding seeds. Meyer (1987) and Meyer and Rasche (1992) show that this mean-standard deviation approach is equivalent to expected utility maximization under the location and scale parameters condition. That is, when random variables differ only by location and scale, rankings based on expected utility or moments of the distribution are consistent. The farm household realizes a profit from investment decisions such that

$$\pi = pf(x, I_i) - wx \tag{2}$$

where *p* is the vector of output prices for the production function, $f(x, I_i)$, which produces a vector of outputs. The production technology, $f(.)$, transforms inputs *x*, such as labor, purchased at cost, *w*. $f(.)$ has a positive first derivative and a negative second derivative. Agricultural investments, I_i, are assumed to exhibit constant returns to scale in the production function. Households allocate a fraction of their wealth, *W*, to agricultural technology. This is determined by the function $g(\alpha_i)$, where α_i is a vector of the value share of investment opportunity *i* from total wealth, *W*. This term $g(\alpha_i)W$ does not enter the profit function as a cost because it is a portfolio allocation of wealth.

Agricultural risk is characterized as a mean, μ_r, and a standard deviation, σ_r. Then, following Rosenzweig and Binswanger (1993), the mean and standard deviation of farmers' profits given by (2) is

$$\mu_\pi = g(\alpha_i) W \mu_r \tag{3}$$

$$\sigma_\pi = \Gamma(\alpha_i) W \sigma_r \tag{4}$$

where $\Gamma(\alpha_i)$ measures the riskiness of the investment portfolio. Assume also the second derivatives of $g(\alpha_i)$ and $\Gamma(\alpha_i)$ are less than zero. Then the mean of consumption is

$$\mu_c = \eta(S, N) \mu_\pi \tag{5}$$

where mean agricultural profits, μ_π, are scaled by a function that allocates a fraction of mean profits between household savings, *S*, and intravillage sharing according to social norms, *N*. The standard deviation of consumption is

$$\sigma_c = \kappa(W)\, \sigma_\pi, \tag{6}$$

where κ (*W*) is a function of wealth that interacts with the standard deviation of profits, and it is assumed that κ' (*W*) < 0, or increased wealth, mutes the effects of changes in the standard deviation of profit on the standard deviation of consumption. The standard deviation of agricultural profits scaled by a function of wealth [κ (*W*)] varies with the standard deviation of consumption to permit a wide variety of assumptions concerning financial markets. If $\sigma_c = \sigma_\pi$ (that is, κ (*W*) = 1), the illiquidity of the asset market is implicitly assumed. The alternative assumption would be that $\sigma_c = 0$, which implies that households can fully insure against income uncertainty.

Since *V* is quasi-concave, the first-order conditions are given by

$$V_\mu \eta(S, N) g'(\alpha_i) = -V_\sigma \Gamma' \kappa(W) \sigma_r \tag{7}$$

Profit maximization requires that $g'(\alpha_i) = 0$, since $g'(\alpha_i) = g_i - g_{i+1}$, the marginal contribution to mean profits must be equalized across investments, given the optimality of farmer decisions. Since the right-hand side of the equation is negative, farm households who are risk averse, with a diverse portfolio of investments, have mean profits that will be lower than optimal. That is, farmers pay a premium to reduce risk, which is the difference between optimal mean profits and mean profits that result from the solution to equation (7).

Consider now an irrigation investment that has a high fixed cost but a large mean profit return and a reduction in the standard deviation of profits. Farm households will clearly undertake the investment, given the quasi-concavity of the utility function if *W* > *C*, where *C* is the cost of the irrigation investment. However, if borrowing constraints exist and *C* is larger than *W*, which it will often be for mechanized irrigation projects, then a net social welfare loss is sustained by beneficiaries of the project (*B*) if

$$\sum_{i=1}^{B} \mu_\pi^I - \sum_{i=1}^{B} \mu_\pi^N \geq C \tag{8}$$

and

$$\sum_{i=1}^{B} \frac{\sigma_\pi^I}{B} - \sum_{i=1}^{B} \frac{\sigma_\pi^N}{B} \leq 0 \tag{9}$$

Equations (8) and (9) state, first, that for irrigation investment to be an efficient investment, the difference between mean profits from irrigation, aggregated across all beneficiaries, and the next greatest mean profit from an investment, aggregated across all beneficiaries, ought to be larger than the cost of the irrigation investment. Second, the mean variance of the irrigation investment for beneficiaries should be less than the mean variance from the next most profitable investment opportunity. However, there also may be cases where the difference in mean profits between irrigators and nonirrigators is large enough that, even if the standard deviation of profits is larger than that for nonirrigators, an irrigation investment would still increase social welfare. This case may exist because (1) learning by doing from newer irrigation adopters will create higher variability in profits or (2) the crop choice induced by irrigation, such as rice, has higher variance in yield due to its greater sensitivity to inputs (water, fertilizer, timing of labor inputs) then other rainfed crops like millet.

What this model does not address is how households choose to allocate their additional surplus. Surplus from profitable investments can be consumed, saved, or shared with other villagers, as a form of altruism or quasi-insurance against idiosyncratic shocks. In addition to testing the impact of irrigation investments on agricultural production, consumption, and nutrient intakes, this paper investigates whether households allocate unconsumed agricultural surplus to savings or to intravillage sharing. It also estimates the average treatment effects of irrigation on child labor, a potentially negative secondary effect of irrigation, caused by increased labor demand by irrigators.

3. SURVEY AREA AND DATA DESCRIPTION

The data for this paper were collected as part of the Poverty and Food Security Household Survey in Northern Mali 2006 (*Etude sur la Pauvreté et la Sécurité Alimentaire au Nord Mali 2006*) conducted by the author. This multitopic household survey was implemented to study household behavior related to human capital formation and agricultural production in northern Mali. Of the 2,658 households in the sample, 245 households in the commune of Soboundou, Niafunke, that were originally surveyed in a similar study conducted in 1997–98, were resurveyed twice in 2006. Sample attrition from the 1997–98 round was 12 percent, which is within the bound of attrition commonly found by other surveys (Alderman et al. 2000). Further details related to tracking households from the 1997–98 survey and detailed methodological documentation of the survey design and implementation can be found in Dillon (2005) and in the previous chapter of this paper.

The data set is composed of a village questionnaire and a household questionnaire. The village questionnaire was administered to village leaders in each village or town included in the study. The household questionnaire was divided into men's, women's, and children's sections and was addressed to the head of household and the head of household's wife and children, respectively. Data were collected on a wide range of variables to analyze the household's agricultural production, income-generating activities, livestock, assets, education, health, and demographic composition. Questions concerning the household's composition, education, primary activities, migratory status of household members, and history of positive and negative economic shocks were addressed to the head of household, usually a man. Questions concerning the household's food consumption, meals shared between households, and health and dietary diversity were addressed to women. Sections concerning possessions, nonfood expenditures, agricultural production, herding activities, credit, and time allocation were addressed to both men and women.

Agroecological conditions throughout most areas of Northern Mali would not be favorable for agricultural production without the Niger River, which is the dominant ecological resource in the region. The inner Niger Delta is a potentially productive agricultural area in which flooding from the Niger augments water levels in temporary and permanent lakes and ponds, as well as smaller streams and tributaries. Land quality deteriorates as the distance from the river increases. Farmers harness water resources through motorized pump irrigation and the use of water-recession agriculture around the lakes and streams and in the Niger River itself, as its water levels decrease seasonally. Rainfed agriculture that does not depend on the water levels of the Niger River is also extensively practiced. However, rainfed agriculture is a difficult endeavor. The Saharan zone (a desert or arid region) receives less than 150 millimeters of rainfall per year. This varies starkly with the Sahelien zone (a grassland or semi-arid region), which receives 200–600 millimeters per year, and the south of Mali, which can receive as much as 600—1,200 millimeters per year (Christiaensen 1998).

Despite persistent poverty in northern Mali, it is important to note that the agricultural sector has not remained static over the past eight years. Table 1 illustrates the distribution of water control systems used by farmers in northern Mali. Since 1997, the agricultural sector has shifted toward irrigated agriculture, with a 30 percent increase in access to irrigation in the sample studied. While the utilization of rainfed agriculture has remained somewhat constant, producers using lake-based systems have substantially declined. The increasing number of producers using solely a lake-based system is swamped by the decline in those using lake and rainfed systems in tandem. The increase in use of irrigation correlates with the increase in irrigation investment by international nongovernmental organizations (NGOs), which began making irrigation investments in the late 1990s, as a postconflict development strategy following the Toureg Rebellion.

Production is highly labor-intensive with low levels of agricultural capital available to households. Median agricultural capital is approximately 32,000 CFA francs (FCFA) per household, or 70 US dollars. Other factors that contribute to higher agricultural productivity include labor inputs, crop choice, area cultivated, and input utilization. The median household uses 225 days of labor to cultivate 1.4

hectares. Median expenditures on seed, fertilizer, pesticide, and manure inputs are 26,248 FCFA (US$58) with the majority of input expenditure spent on seed and fertilizer. These low levels of input utilization reflect a multiplicity of farming constraints, including limited access to inputs and technical capacity for appropriate inputs, as well as credit constraints.

Table.1. Utilization of different agricultural production systems
(% of farmers who use the different systems)

	1997–98	2005–06
Irrigation	0.4%	30%
Lake	6.8%	18.50%
Rainfed	35.0%	33%
Irrigation and lake	0.0%	1%
Irrigation and rain	9.4%	10%
Lake and rain	41.9%	6%
Irrigation, lake, and rain	6.4%	2%

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Notes: N = 246. The different agricultural systems are defined by the system that the farmer uses to water his plot. These include a strictly irrigated system, a lake system, rainfed agriculture, and combinations of these three.

In the survey area, access to irrigation is facilitated by international organizations and NGOs who provide motorized pumps to villages at no charge or significantly discounted prices, which are then reimbursed over an extended period of time and with the condition that villages contribute labor for the construction of the irrigation infrastructure, undertake pump maintenance, and provide fuel for the pump's operation. Irrigation is primarily used for rice cultivation, rather than sorghum or millet, two traditionally rainfed crops. Rice production that relies on irrigation is cropped once per agricultural cycle. Internationally, increased agricultural production from a dual cropping system is commonly cited as a benefit of irrigation. However, the arid context in northern Mali does not allow a second cropping season after rice cultivation. This is because temperatures in the dry season are high (in excess of 40º C) and receding river levels make it impossible to provide the minimum water required for rice plants or other cash crops. The benefits of irrigation in northern Mali are accrued through increased water supply and control during the primary agricultural season.

Table 2 investigates the relationship between agricultural production and household consumption descriptively. Mean agricultural production is 2.1 tons, compared with 643 kilograms using a lake-recession system, or 288 kilograms using rainfed agriculture. Mean total annual household consumption (2,085,778 FCFA) is also highest when farmers use irrigation. Farmers who use ng rainfed agriculture have slightly higher household consumption than those who use lake-recession agriculture, but the difference is only 23,000 FCFA (less than US$50) over an entire year. The standard deviations of both agricultural production and consumption are higher under irrigation than under the two other water-control systems. Differences in farmer's skills may also generate greater variation in household production and consumption variables, because rice cultivation requires cultivation of seedlings that then must be replanted with appropriate space between plants in the irrigated plot. Rice seedlings are also highly sensitive to the timing and dosages of fertilizer. Despite the higher standard deviations of consumption and production, the high means of agricultural production with irrigation relative to other water-control systems indicates that rice production is not necessarily a higher risk investment for the farmer. This is because the standard deviation may not be equivalent to "risk," when farmers evaluate both the mean yield and standard deviation of a different agricultural technology before adopting.

Because of the labor intensity of farm production in northern Mali, lack of inputs, high rice prices relative to other cereals, and large differences (more than 1 ton) in production per hectare between rice and other grains, investment in irrigation is likely to have a high return. Table 3 illustrates changes in total agricultural production and nutrient intakes between the 1998 and 2006 surveys by village. The percentage of households with access to irrigation in 2006 by village is reported in column 3 of Table 3.

Villages with access to irrigation had dramatic increases in agricultural production and daily household caloric intake, with the exception of the village of Ouaki. For the entire sample, however, the mean household daily caloric intake increased by only 138 calories over the eight years between the surveys.

Table 2. Total household agricultural production and consumption in 2006, by water control system

Total Household Agricultural Production	Mean	Standard deviation	25th Percentile	50th Percentile	75th Percentile
Irrigation	2,147.4	1,649.9	1,188	1,725.9	2,400
Lake-recession	643	933.5	157.5	270	679.5
Rainfed	288.4	283.3	121.3	196	406.7
Total	1202.1	1473.5	196	620.4	1758.9
Total Household Consumption					
Irrigation	2,085,778	1,490,314	1,180,530	1,938,500	2,615,860
Lake-recession	1,356,355	844,554	698,200	1,141,015	1,758,480
Rainfed	1,586,750	1,027,597	728,150	1,500,581	2,150,700
Total	1,724,158	1,221,531	785,500	1,501,691	2,254,350

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006. Notes: N=246. Total household agricultural production is measured production of male and female household plots during the 2005/06 agricultural season in kilograms. Total household consumption is the annualized household consumption aggregate calculated from men and women's assets, non-food and food expenditures following Deaton and Zaidi (2002).

Table 3. Descriptive statistics: Access to irrigation, agricultural production, and caloric intake by village

Village	Number	Percentage of Households with Access to Irrigation in 2006	Total Agricultural Production, 1997–98	Total Agricultural Production, 2005–06	Total Daily Household Calories, 1998	Total Daily Household Calories, 2006
Aldianabangou	15	0	61.3	156.3	8,354	7,752
Tomba	36	68	61.1	2309.0	4,888	6,309
Mangourou	27	0	154.3	192.4	5,295	5,588
Gouaty	7	0	54.6	359.3	4,682	8,252
N'goro	54	0	417.0	377.6	6,206	5,425
Tomi	12	75	757.9	2,735.4	5,744	8,389
Hamakoira	17	59	309.7	2,006.2	5,716	9,285
Goundam Touskel	12	0	962.4	962.5	8,000	6,293
Ouaki	47	28	1,060.5	1,022.6	6,833	5,639
Anguira	19	0	213.3	674.3	4,141	3,885
Total	246	0.24	447.1	1,028.2	6,048	6,186

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Notes: Agricultural production is calculated as in the previous table. Daily household calories are imputed from food intake data.

Table 4 disaggregates changes in real consumption by initial quartiles to assess whether gains or losses in consumption were equally distributed across the quartiles. Total household consumption is adjusted using a Paasche price index of grain prices.[5] Since budget shares for the households in the sample range from 73 to 88 percent of the household budget, this approximation is an adequate representation of the real prices facing households. In all the villages with access to irrigation, the largest percentage changes in real consumption occurred at the lowest quartile. Changes in consumption for the lowest quartile with irrigation range between 29.8 and 61.4 percent, while the rate of change for the whole sample is only 23.3 percent.

Table 4. Descriptive statistics: Total real consumption by village and expenditure quartile

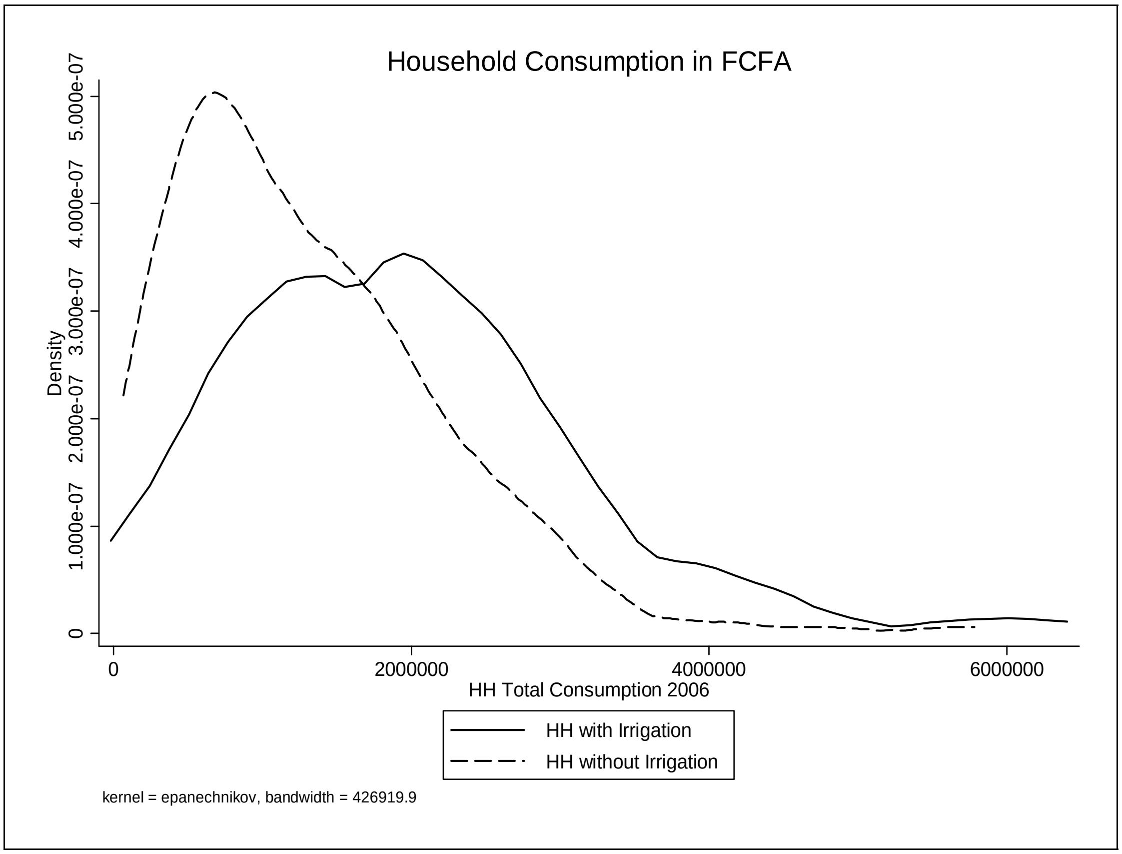
Village	Variable	Consumption 1998	Consumption 2006	% Change	Village	Consumption 1998	Consumption 2006	% Change
Aldianabougou	N		15		Tomi*		12	
	25th Percentile	457,310	414,612	-10.30%		234,075	443,177	47.20%
	50th Percentile	571,500	699,878	18.30%		347,885	672,364	48.30%
	75th Percentile	890,485	1,023,894	13.00%		551,365	849,806	35.10%
Tomba*	N				Hamakoira*	17		
	25th Percentile	236,204	391,448	39.70%		177,560	459,855	61.40%
	50th Percentile	398,780	487,046	18.10%		368,765	654,008	43.60%
	75th Percentile	574,528	727,867	21.10%		478,750	980,372	51.20%
Mangarou	N	27			Goundam Touskel	12		
	25th Percentile	252,360	355,582	29.00%		234,560	380,632	38.40%
	50th Percentile	282,648	516,960	45.30%		362,880	526,776	31.10%
	75th Percentile	376,765	756,938	50.20%		540,273	710,009	23.90%
Gouaty	N	7			Ouaki*	47		
	25th Percentile	70,485	214,187	67.10%		204,490	291,196	29.80%
	50th Percentile	167,278	788,450	78.80%		341,265	430,489	20.70%
	75th Percentile	772,840	1,194,649	35.30%		544,673	660,106	17.50%
N'goro	N	54			Anguira	19		
	25th Percentile	370,373	272,836	-35.70%		110,740	199,824	44.60%
	50th Percentile	603,695	416,862	-44.80%		188,075	285,570	34.10%
	75th Percentile	963,610	563,961	-70.90%		364,305	529,828	31.20%
				Totals	N	246		
					25th Percentile	252,360	329,119	23.30%
					50th Percentile	399,070	482,522	17.30%
					75th Percentile	613,710	714,636	14.10%

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Notes: * denotes villages with access to irrigation. Total household consumption is the annualized household consumption aggregate calculated from men and women's assets, non-food and food expenditures following Deaton and Zaidi (2002). Real consumption aggregates were calculated using a Paasche price index as described in the text.

[5] A Paasche price index is constructed that is composed of rice, sorghum, and millet prices and quantities from the 1998 and 2006 survey rounds, following Deaton and Zaidi (2002).

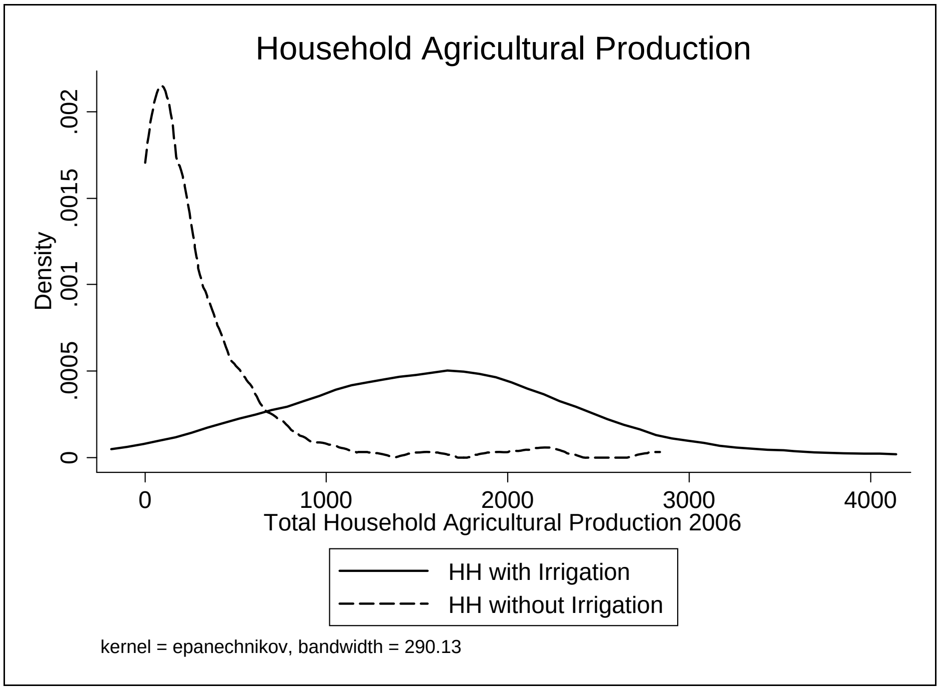
Figures 1 to 3 provide descriptive evidence of the differences in the kernel densities for total household consumption, agricultural production, and total livestock units held by the households, disaggregated by access to irrigation. The dashed lines represents the density of the comparison group of households without irrigation in 2006, while the solid line represents the density of households with access to irrigation in 2006. The shapes of these densities are relatively similar; however the means are clearly higher in the irrigation densities. These density estimates are only descriptive, in the sense that none of the selection bias is accounted for by disaggregating the densities according to irrigation access. In the next chapter, different econometric strategies for estimating the returns to irrigation on production, consumption per capita, and nutrient intakes are discussed, controlling for selection bias and endogenous program placement.

Figure 1. Kernel density estimates of total household consumption (in FCFAs) for households with and without irrigation



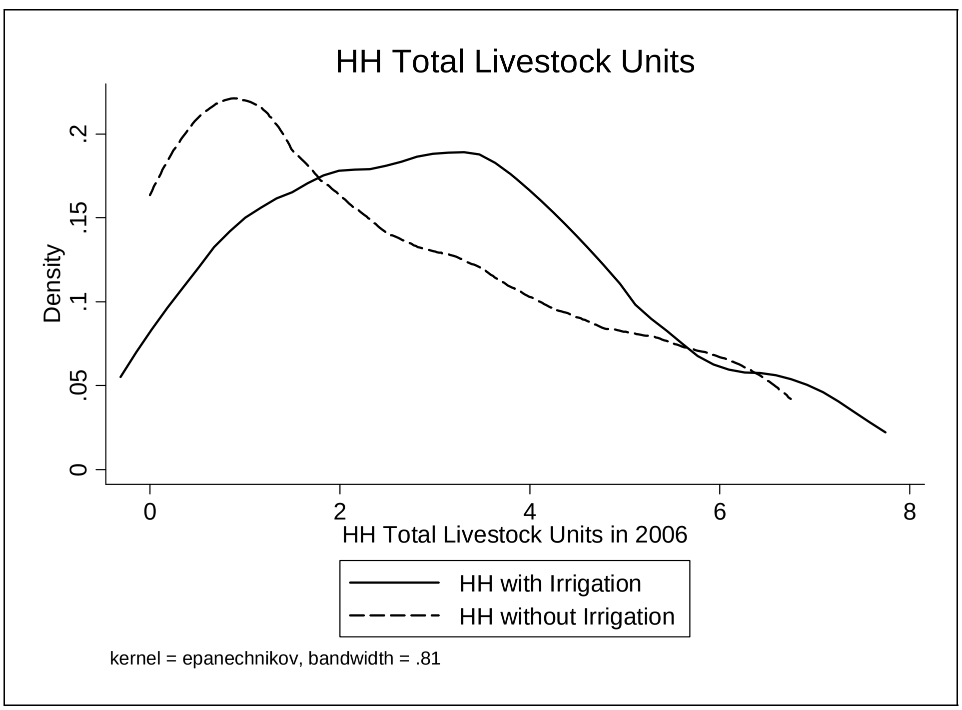
Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.

Figure 2. Kernel density estimates of total household agricultural production for households with and without irrigation



Data Source: Author’s Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.

Figure 3. Kernel density estimates of total household livestock units for households with and without irrigation



Data Source: Author’s Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.

4. ESTIMATING TREATMENT EFFECTS USING NONEXPERIMENTAL DATA

To estimate average treatment effects, recognizing the problem of selection bias between treatment and comparison groups, one ideally wants to estimate $\Delta = Y_t^1 - Y_t^0$, which is the difference of the outcome variable of interest at time *t* between two treatments, denoted by the superscripts 1 and 0. However, the econometrician is unable to estimate Δ in this way because a household cannot receive two treatments simultaneously. The evaluation problem is one of missing data, due to the impossibility of assigning households to both treatment and control groups. The econometrician is forced to measure the average treatment effect (*ATE*) given the observable data:

$$ATE = E(Y_t^1 \mid T = 1) - E(Y_t^0 \mid T = 0) \tag{10}$$

When data are generated through a properly implemented random experimental design, the expectations of the treatment and comparison groups are equal because the groups are composed of randomly allocated members, ensuring that the distribution of observable and unobservable characteristics of the groups are equivalent in a statistical sense. With a randomized design, the selection bias, $E(Y_t^1 \mid T = 1) - E(Y_t^0 \mid T = 0)$, equals zero, which establishes that the estimate of the average treatment effect provides an unbiased estimate of its impact.

Randomized experiments are not always possible or plausibly implemented, so that absence of selection bias is a credible assumption. Hence, applied econometricians are often forced to estimate the average treatment effect on the treated households (*ATT*), given a vector household characteristic, *X* :

$$ATT = E(\Delta \mid X, T = 1) = E(Y_t^1 - Y_t^0 \mid X, T = 1) = E(Y_t^1 \mid X, T = 1) - E(Y_t^0 \mid X, T = 0) \tag{11}$$

where, because $E(Y_t^0 \mid X, T = 1)$ is unobservable, it is assumed that $E(Y_t^0 \mid X, T = 1) = E(Y_t^0 \mid X, T = 0)$.

Difference in differences, propensity score matching, and difference-in-differences matching estimators require identification assumptions with nonexperimental data. An important body of literature has tested these nonexperimental estimators against experimental benchmarks and against each other (see, for example, Heckman, Ichimura, and Todd 1997; Bertrand, Duflo, and Mullainathan 2004; Smith and Todd 2005; and Diaz and Handa 2006. Nonexperimental estimators can perform well if the set of observable characteristics is rich enough to create valid treatment and comparison groups. The advantages and disadvantages of these estimators are described below.

Difference-in-Differences

The difference-in-differences (DID) estimator is estimated by comparing the mean changes between treatment and control groups over two periods. The DID estimator controls for treatment group fixed effects by differencing. However, the DID estimator assumes that rates of change between the two groups would have been the same without the development intervention. The identification of this estimator requires the following three assumptions (Smith and Todd 2005). The first is that there are no differences in unobservables between the treatment and comparison groups $E(\varepsilon_{h1} - \varepsilon_{h0}) = 0$. The second is that there is no interaction between the observables and the treatment $E[(\varepsilon_{h1} - \varepsilon_{h0})T] = 0$. Lastly, identification of the difference-in-differences estimator requires that there is no interaction between the differences in unobservables and the observable characteristics of the treatment and comparison groups $E[(\varepsilon_{h1} - \varepsilon_{h0})(X_{h1} - X_{h0})] = 0$.

Difference in differences estimates control for time-invariant fixed effects by differencing them out of the estimates. However, there are potentially several sources of unaccounted bias. The first source of bias could be the result of the effects of program interventions on the comparison group. Because the original sample is composed of 10 villages within the same district, effects of the irrigation investment may “rub off” on the control group. This would diminish the impact estimate constructed by making comparisons between control and treatment groups. However, due to the relatively large distances between villages and the paucity of public or private transportation, these effects are likely to be small at best. Four out of 10 villages in the original study are located on the opposite sides of the Niger River, so a physical barrier inhibits easy interaction between villages. The second source of bias is due to possible selection bias. If initial conditions that influence village- and household-level welfare are correlated with the selection criteria for program participation, biased impact assessments will result. In our case, access to irrigation is strongly predicated by access to the Niger River. Villages that have access to the Niger may have more commercial activities and lower transportation costs, which would increase their purchasing power. While difference in differences estimates do not completely control for this selection bias, using propensity score matching or propensity score matching along with the difference in differences estimates can control for the correlation between observable factors influencing household welfare and program participation.

Propensity Score Matching

To estimate the effects of irrigation, propensity scores are used to match households with similar observable characteristics, varying only the treatment, which is access to irrigation. Households are matched to each other conditional on a set of observable household and village characteristics, Z and V, respectively. Propensity scores are estimated to match households with similar observable characteristics, varying only the treatment—access to irrigation. The following probit model is estimated using a vector of household characteristics, Z and village characteristics, V, to obtain predictions of household propensity scores, where

$$P^*_{v,h} = \beta Z_{v,h} + \gamma V_{v,h} + \varepsilon_{v,h} \tag{12}$$

where

$$P_{v,h} = 1 , \quad \text{if } P^*_{v,h} > 0 \tag{13}$$

$$= 0 \quad \text{otherwise.}$$

Then the distribution of $P_{v\,h,,}$ given $Z_{v\,h}$, $V_{v,h,,}$ yields the familiar result:

$$\begin{aligned} P(P_{v,h} = 1 \mid Z_{v,h}, V_{v,h}) &= P(P^*_{v,h} > 0 \mid Z_{v,h}, V_{v,h}) \\ &= P(\varepsilon_{v,h} > -\beta Z_{v,h} - \gamma V_{v,h} \mid Z_{v,h}, V_{v,h}) \\ &= 1 - \Phi(-\beta Z_{v,h} - \gamma V_{v,h}) = \Phi(\beta Z_{v,h} + \gamma V_{v,h}) \\ &= 1 - \Phi(-\beta\, Z_{v,h} - \gamma\, V_{v,h}), \end{aligned} \tag{14}$$

where $\Phi(.)$ is the standard normal cumulative distribution function.

To estimate equation (14), household variables are used as controls, including household size, household assets such as household durables and total livestock units, the age of the household head, an education indicator for the household head and his or her spouse, an ethnicity indicator variable, and landholdings. Village characteristics include indicators for distance to the nearest road, distance to the Niger River, and the log price for transporting a sack of rice to Mopti, a regional center. These characteristics control for village development; access to water, which is a necessary precondition for pump agriculture, given the dearth of rainfall; and market integration. When the propensity score matching estimates are generated, the sample is also restricted to matches within villages, so that intervillage fixed effects do not bias the estimates. Table 5 displays the descriptive statistics for the household and village characteristics.

These variables are used in the specification to generate the propensity scores that should satisfy the balancing property. That is, the treatment and comparison observations are tested to ensure equality of observables across different propensity score groupings, so that there is an appropriate distribution of characteristics in each grouping of propensity scores. The assumption that $0 < P(T=1 \mid Z) < 1$ is satisfied in our sample and the top and bottom 5 percent of the sample have been trimmed, following Smith and Todd (2005). Figure 4 illustrates the region of common support from the density estimates of the propensity scores by treatment status.

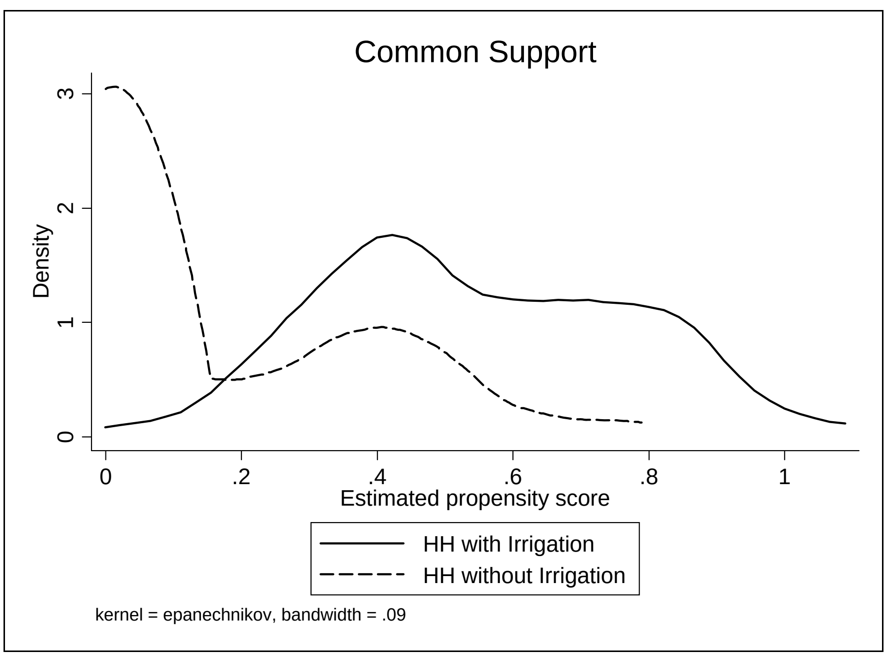
Table 5. Household descriptive statistics for propensity matching

Household Characteristics		Education of Head (1 if yes)	0.11
Access to Irrigation	0.23		(0.31)
	(0.42)	Education of Spouse (1 if yes)	0.07
Age of Household head*	3.86		(0.26)
	(0.69)	*Ethnicity*	
Household Durables*	11.1	Peulh (1 if yes)	0.18
	(1)		(0.38)
Total Livestock Units	3.05	*Village Characteristics*	
	(5.69)	Road through Village	0.26
Land (Hectares)	2.18		(0.44)
	(2.80)	Road between 1-10kms	0.45
Land Squared (Hectares)	9.23		(0.50)
	(22.81)	River Access	0.31
Household size*	1.40		(0.46)
	(0.50)	Rice Transport Price to Mopti	2152.66
			(568.37)

N=242

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Notes: Numbers in parentheses are standard deviations. Mopti is the nearest urban area. * denotes the natural logarithm of a variable was taken and used for analysis.

Figure 4. Distribution of propensity scores for households with irrigation and without irrigation



Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.

Four matching estimators are employed as robustness checks. These estimators include a single nearest-neighbor matching estimator with replacement, a nearest-neighbor estimator using the 10 nearest neighbors with replacement, an Epanechnikov kernel-matching estimator, and a local linear matching estimator. Both nearest-neighbor matching estimators are constructed with replacement of observations after they are matched. Replacement increases the quality of the matches by using more information to construct the counterfactual, but it increases the variance of the estimator by reducing the number of nonparticipant observations used in the comparison group. A nearest-neighbor estimator using 10 nearest neighbors with replacement increases the quality of matches but with the tradeoff that the variance of the estimator is increased.

The third estimator employed is the Epanechnikov kernel-matching estimator for the average treatment effect on the treated, which is constructed such that

$$ATT = \frac{1}{n}\sum_{i \in T}[Y_t^1 - \frac{\sum_{j \in C} Y_j^0 K(\frac{P_j(Z) - P_i(Z)}{a_n})}{\sum_{k \in C} K(\frac{P_k(Z) - P_i(Z)}{a_n})}] \tag{15}$$

where T is the treatment group, K is the kernel function, C is the comparison group, and a_n is the band-width parameter proposed in Heckman, Ichimura, and Todd (1997) and Heckman et al. (1998).

The last estimator is the local linear matching estimator, which is a generalized version of the kernel estimator. The advantage of the local linear matching estimator is that it is generally more robust to data design densities and has a faster rate of convergence at the boundary points (Smith and Todd 2005). These four estimators are used here to generate propensity score estimators, but they will also be used in the next section as a robustness check with the difference-in-differences matching estimator.

Difference-in-Differences Matching Estimator

The last econometric strategy to evaluate the impact of irrigation is a difference-in-differences matching estimator. Let the outcome variable of interest (agricultural production, consumption, nutrient intake, or dietary diversity) be represented by Y_{ht} for household $h=1,\ldots, N$ at time $t=1, 2$. Then variation in Y_{ht} is explained by covariates X_{ht} for household h at time t. The treatment variable, T indicates the household's access to irrigation. P is the propensity score estimated as in the above section using the probit model. In a pooled cross section,

$$Y_{ht} = \beta X_{ht} + \lambda T + \gamma P + \varepsilon_{ht} \tag{16}$$

where the error term represents an idiosyncratic (ε_{ht}) error term. Because selection bias due to the correlation of program placement with household characteristics (assets, education, location, etc.) is probable, the inclusion of the propensity score controls for the selection bias of the observable characteristics when the impact of irrigation is estimated on the outcome variables. Using the predicted propensity scores and taking first differences with the panel subsample yields the difference-in-differences matching estimator, γ^m.

$$Y_{h2} - Y_{h1} = \beta(X_{h2} - X_{h1}) + \gamma^m T + \gamma P + (\varepsilon_{h2} - \varepsilon_{h1}) \tag{17}$$

To provide estimates of irrigation's impact that do not necessarily depend on the estimator chosen, the results of nearest-neighbor estimates with the closest neighbor, nearest-neighbor estimates with the 10 closest neighbors, the Epanechnikov kernel estimator, and the local linear matching estimator are all reported as robustness checks. These estimators were described above. All standard errors of the estimator are bootstrapped with 1,000 repetitions. In the next section, the results of these three different econometric techniques to account for selection bias and endogenous program placement are presented.

5. EMPIRICAL RESULTS

Impact Estimates using Difference-in-Differences and Propensity Score Matching

In the difference-in-differences results (Table 6), the consumption aggregates for the control group are higher than those of the irrigation group were before most of them actually had access to the irrigation intervention. This may be because irrigation interventions were targeted initially to relatively poor villages. The difference-in-differences estimate between groups is 148,529 FCFA or almost US$300. Increases in the consumption aggregate of the irrigation group are significant at the 1 percent level. Agricultural production by households with access to irrigation has increased more than threefold over the past eight years, compared with farmers who do not have irrigation. Agricultural production for the control group declines slightly. Increases in the irrigation group are significant at the 1 percent level. The difference-in-differences estimate suggests a 1.9-ton increase for households who have access to irrigation.

Table 6. Difference-in-Differences Results

		1998		N	2006		Differences 1998-2006	
Variable	N	Mean	SD	N	Mean	SD		
Consumption Aggregate (Real)(FCFAs)	227	482,729	346558	246	541,155	294,436	65,225	*
With irrigation	81	427,961	343826	82	589,107	299,357	160,755	
Without Irrigation	146	513,114	345494	164	517,178	289,891	12,226	
Difference with and without irrigation		-85,152			71,929		148,529	**
Agricultural Production (kg)	246	447.1	879.1	246	1,028.2	1,554.6	581.0	
With Irrigation	82	589.9	958.5	82	2,472.5	1,845.2	1,882.6	
Without Irrigation	164	375.7	830.5	164	306.0	605.2	-69.7	
Difference with and without irrigation		214.3			2,166.5		1,952.3	**
Daily Household Calories	228	5,307.4	301.0	228	5,096.9	208.4	-210.5	
With irrigation	59	4,398.1	387.0	59	6,234.8	474.8	1,836.8	
Without irrigation		5,624.9	380.5	169	4,699.7	220.0	-925.2	
Difference with and without irrigation		-1,226.8			1,535.1		2,762	*
Daily Household Protein (grams)	228	160.5	8.9	228	139.3	5.7	-21.1	
With irrigation	59	136.0	11.4	59	172.4	13.1	36.4	
Without irrigation	169	169.0	11.3	169	127.8	6.0	-41.2	
Difference in protein with and without irrigation		-33.1			44.6		77.6	**

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
*significant at 10% level. ** significant at 5% level. *** significant at 1% level.

Calorie and protein intakes per day between households with and without access to irrigation are also displayed in Table 6. These results can be compared with the recommended dietary allowances of the Food and Nutrition Board of the National Academies, which recommends a daily caloric intake of 2,500 calories and protein intake of 392 grams per day for active adult males (Otten et al. 2006). Households with access to irrigation have increased their daily caloric intake by 1,836 calories, whereas households without irrigation have decreased their daily caloric intake by 925 calories. Statistically significant increases in protein intakes are also found in households who have access to irrigation. The difference-in-differences estimate is 77.6 grams of additional daily protein intake per household. Despite statistically significant increases in both calories and protein, households with irrigation still fall 18,000 calories below what would be required for the mean household of six in the sample, according to the recommended dietary allowances.

Table 7 presents the results of the probit model used to estimate the propensity scores given village and household characteristics. Significant characteristics that predict access to irrigation include infrastructure such as roads and access to the Niger River. However, this is not a causal model. The specification chosen satisfies the balancing property and does not include all observable household characteristics from the data set that could possibly influence irrigation access. The use of the balancing property to include variables as part of the propensity score specification ensures that a comparison group is constructed with observable characteristics distributed equivalently across quintiles in both the treatment and comparison groups, as described by Smith and Todd (2005).

Table 7. Probit model results

	Irrigation
HH Characteristics	
Ln Age of Household head	-0.026
	(0.130)
Ln Household Durables	0.012
	(0.145)
Total Livestock Units	-0.047
	(0.035)
Land (Hectares)	-0.343
	(0.318)
Land Squared (Hectares)	0.078
	(0.071)
Ln Household size	-0.17
	(0.282)
Education of Head (1 if yes)	0.114
	(0.437)
Education of Spouse (1 if yes)	0.08
	(0.486)
Ethnicity	
Peulh (1 if yes)	-0.551
	(0.504)
Village Characteristics	
Road through Village	14.168
	(2.334)***
Road within 10kms	0.648
	(0.679)
River Access	14.6
	(1.964)***
Rice Transport Price to Mopti	0
	(0.001)

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Notes: N=212. Constant is included. Mopti is the nearest urban area.
*** Significant at the 1 percent level.

Table 8. Average treatment effects on the treated estimates using four different propensity score matching estimators

Estimator *Outcome Variables*	N	Nearest-Neighbor Matching (1)	Nearest-Neighbor Matching (10)	Kernel Epanechnikov	Local Linear Matching Estimator
Household Consumption (FCFA)	98	775,674	734,908	776,748	775,673
		(339,480)**	(270,311)***	(278,568)***	(320,187)**
Agricultural Production (kg)	98	1,254	1,647	1,361	1,835
		(351)***	(276)***	(341)***	(292)***
Daily Total Household Calories	98	8,428	9,205	9,796	8,429
		(3,596)**	(2,916)***	(3,194)***	(3,697)**
Daily Total Household Protein	98	228	281	299	228
		(114)**	(89)***	(99)***	(108)**
Household Composition					
Men	98	.78	.906	.862	.776
		(.530)	(.420)**	(.424)**	(0.517)
Women	98	.286	-.178	.041	.286
		(0.578)	(0.434)	(0.475)	(0.562)
Boys	98	-.510	-.361	-.405	-.510
		(0.491)	(0.340)	(0.375)	(0.497)
Girls	98	0	-.337	-.082	0
		(0.536)	(0.436)	(0.469)	(0.560)
Informal Food Sharing					
Meals Given to other HH	98	.367	.690	.756	.367
		(.475)	(0.363)*	(.390)*	(.487)
Meals Received from other HH	98	-1.449	-.527	-.443	-1.449
		(1.611)	(1.291)	(1.086)	(1.545)
Net Sharing Indicator	98	.224	.204	.213	.224
(1 if HH gives more meals than received)		(.087)**	(.076)***	(.079)***	(.085)***
Livestock (in Total Livestock Units)	98	6.4	6.3	5.8	6.4
		(2.19)***	(2.323)***	(2.05)***	(2.321)***
Children's Weekly School Hours	137	-12.4	-2.33	-1.014	-10.73
	(children)	(6.68)*	(4.003)	(5.22)	(6.443)*
Children's Weekly Farm Work Hours	137	7.15	4.42	6.82	3.36
	(children)	(5.26)	(4.657)	(4.207)	(4.86)

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Note: All standard errors are bootstrapped with 1,000 repetitions.
* Significant at the 10% level
** Significant at the 5% level.
*** Significant at the 1% level.

Table 8 reports the estimates of the four matching estimators specified for consumption, agricultural production, and nutrient intakes.[6] The results indicate significant effects when either propensity score matching or the difference-in-differences estimator are calculated. However, the magnitudes of the effects estimated with propensity score matching are larger than the difference-in-

[6] The Stata command psmatch2 developed by Leuven and Sianesi (2003) is used to estimate the treatment effects in the empirical section.

differences estimates. Consumption is significant at the 1 and 5 percent levels across the different matching estimators. The effect of irrigation on the household total consumption aggregate varies from 734,908 to 776,748 FCFA, depending on the estimator used. Total agricultural production, total daily caloric intakes, and total daily protein intakes are significant at the 1 and 5 percent levels. The effect of irrigation on total agricultural production ranges from 1.25 to 1.83 tons per household. Increases in calories and protein per week are also statistically significant.

Lastly, the matched difference-in-differences estimator, using propensity scores to control for the endogeneity of access to irrigation, is estimated in Table 9, which presents the average treatment effects on the treated. The difference-in-differences matching estimates indicate that the impact of irrigation on consumption ranges from 694,921 to 739,050 FCFA. Estimates of the impact of irrigation on agricultural production range from 1.17 to 1.89 tons per household. The impact of total household calories and protein intakes per week are also statistically significant across the matching estimators, although the matched difference-in-differences estimates are greater across all estimators. The propensity score matching estimates and matched difference in differences are similar, despite variations in the estimators and evaluation techniques.

Table 9. Difference-in-differences matching

Estimator *Differences in the Outcome Variables* *(1998-2006)*	N	Nearest Neighbor Matching (1)	Nearest Neighbor Matching (10)	Kernel Epanechnikov	Local Linear Matching Estimator
Household Consumption (FCFA)	98	738,148	694,921	739,050	738,148
		(310093)**	(274,938)**	(292275)**	(318,645)**
Agricultural Production (kg)	98	1,170	1,591	1,284	1,888
		(367)***	(288)***	(341)***	(295)***
Daily Total Household Calories	98	11,371	10,494	10,618	11,371
		(4862)**	(3,742)***	(4,230)**	(4,611)**
Daily Total Household Protein	98	360	326	328	361
		(141)**	(115)***	(126)**	(144)**
Livestock (in Total Livestock Units)	98	6.6	6.4	6.2	6.6
		(2.13)***	(2.07)***	(2.03)***	(2.19)***
Household Composition					
Men	98	.429	.733	.625	.429
		(.483)	(.364)**	(.370)*	(.444)**
Women	98	.265	-.139	.106	.265
		(.585)	(.449)	(.514)	(.601)
Boys	98	-.326	-.237	-.073	-.327
		(.548)	(.411)	(.439)	(.550)
Girls	98	-.061	-.112	.187	-.061
		(.587)	(.438)	(.471)	(.605)

Data Source: Author's Calculations from the Poverty and Food Security Household Survey in Northern Mali, 2006.
Note: All standard errors are bootstrapped with 1,000 repetitions.
* Significant at the 10% level;
** Significant at the 5% level.
*** Significant at the 1% level.

Differences in the Impact of Irrigation on Household Agricultural Production and Consumption

Despite the robust response of the estimates to different estimators on the impact of irrigation on household agricultural production and total consumption, the benefits of agricultural production induced by irrigation technology do not transfer one-to-one into gains in household consumption. The lack of unity between production and consumption potentially presents a problem in establishing irrigation's impact on poverty reduction, because gains in agricultural production could be offset by higher input costs, which erode the benefits of irrigation technology and are reflected in lower household consumption.

There are two hypotheses that could explain this pattern in the data. Consuming the gains from increased agricultural production from irrigation may not be the only household strategy for increasing welfare. Households could also save these gains or share some of them with others in their village, either for purely altruistic reasons or as an informal kind of intravillage insurance against future shocks. Empirical evidence for the saving hypothesis is found in other studies. Ravallion and Chen (2005) found that antipoverty programs in southwest China had little impact on consumption but a large impact on household saving, because the community expected that the program's duration would be short.

To test the hypotheses of increased savings or increased intravillage sharing, the estimates of a standardized asset, livestock, reported in total livestock units (TLUs) and the number of meals shared and received are estimated using propensity score matching. The evaluation estimators support both hypotheses: saving via livestock accumulation and sharing of meals both increased. Irrigation significantly increases livestock holdings by 5.8 to 6.4 TLUs using propensity score matching and 6.2 to 6.6 TLUs with matched difference in differences (Table 8). Meals given to other households significantly increase by 0.69 to 0.76 meals per week, while the number of meals received did not change with any statistical significance (Table 9). According to a net sharing indicator that represents 1 if the household is a net sharer, or 0 if the household receives more meals than it gives, households were 20.0–22.4 percent more likely to be net sharers if they had access to irrigation.

In addition to these variables, the number of hours children spend in school and on farm work and changes in household composition are evaluated as outcome variables, using propensity score matching in Table 8. Child labor could plausibly increase with the introduction of irrigation technology because the demand for household labor will increase as the household responds to more lucrative income opportunities, which increase the opportunity costs of children's time. While there was no effect on the hours children spent on farming, hours spent on schooling did decrease in households with access to irrigation by 10.7 to 12.4 hours per week in two of the estimators used. Decreased hours of schooling have potentially serious long-term implications for human capital accumulation. Another outcome variable that may erode the effects of increased agricultural production on household consumption is household composition changes that increase household size in response to the increased labor demands that irrigated agriculture necessitates. In Table 8, the propensity score matching estimates illustrate that in households with access to irrigation, the number of men in the household increased by almost one additional member, while there was no effect on the number of women, boys, or girls.

6. CONCLUSION

Regardless of the estimation method used to evaluate irrigation investments in northern Mali, significant positive increases in total household consumption, agricultural production, and caloric and protein intakes are estimated for households who have access to irrigation. These results reinforce previous studies on smallholder irrigation investments by showing that, in an area with low agricultural potential, welfare gains can be realized with targeted investment (Lipton, Litchfield, and Faurès 2003; Hussain 2007b). Irrigation investment also induces households to save more and share more within their villages, which is a type of investment in informal social insurance. Both of these responses to irrigation are effects not captured by estimating program effects using consumption aggregates.

In future work, a major interest will be to investigate the role that village-level investments in irrigation have in reducing inequality within villages and households. Because irrigation interventions are primarily targeted at the village level in northern Mali, this may promote greater reductions in poverty and inequality than larger-scale projects that are primarily targeted to larger urban population centers. Because male and female expenditure data were collected, investigating the impact of irrigation on intrahousehold inequality may also yield important insights into household behavior. Differences in welfare gains between genders may be of particular concern because most irrigation projects are targeted to men. If irrigated plots require more labor, then women may be drawn away from their plots to work on irrigated plots, for which they do not control the output.

This paper provides direct evidence about the returns to irrigation by tracking households from 10 villages over an eight-year period. Small-scale irrigation projects can have significant impacts on household consumption, agricultural production, and nutrition. In an environment such as northern Mali, where the Sahelian droughts have been severe and agroecological conditions are not favorable to rainfed agriculture, a green revolution is possible if villages harness the water provided by the Niger River. Not only do irrigation projects increase village food supply, but they also reinforce informal sharing within villages and help households build assets that may serve to buffer consumption against transitory income fluctuations, particularly during the lean season. These secondary effects of irrigation projects can be overlooked if the net benefits of irrigation projects are only evaluated with respect to household consumption.

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