THE EFFECT OF FARM SIZE ON EFFICIENCY IN IRRIGATED AGRICULTURE: The Case of the Zimbabwe Communal Areas

discussion of planned research

Peter C. Bloch

One of the principal socioeconomic issues in irrigation design is the size of holdings to be allocated to individual farm households. The arguments for larger versus smaller plot sizes are summarized in Bloch et al.[1]; the major ones concern equity -- allocating a given amount of irrigable land to larger or smaller numbers of poor farmers -- and efficiency -- obtaining the maximum economic returns from a given resource outlay.

The equity arguments can be made without reference to the data, because they are generally expressed in such a way that their point is obvious: a given area divided among a larger number of farmers is a more even distribution of land. This is not true of the efficiency arguments, however, which are by their very nature empirically based. In the principal published work that has addressed this issue, Berry and Cline[2] summarize a large number of studies in many parts of the world, finding evidence of a negative correlation between farm size and productivity. They do not, however, focus on or distinguish irrigation from dryland farming, or on systems with the complicated patterns of interdependence among farmers that irrigation necessitates. Many of the studies about India and Pakistan include irrigated and unirrigated land in the same samples, frequently without distinguishing them from one another.[3]

---

1. Peter C. Bloch; Lucie Colvin Phillips; James C. Riddell; Jayne L. Stanning; Thomas K. Park. Land Tenure Issues in River Basin Development in Sub-Saharan Africa. LTC Paper No. __, University of Wisconsin Land Tenure Center, April 1986, esp. pp. 9-12.

2. R. Albert Berry and William R. Cline. Agrarian Structure and Productivity in Developing Countries. Baltimore: Johns Hopkins University Press, 1979.

3. see, e.g. Lawrence J. Lau, and Pan A. Yotopoulos. "A Test for Relative Efficiency and Application to Indian Agriculture." American Economic Review, 61(1), 1971, pp. 94-109, and Mahmood H. Khan and Dennis R. Maki. "Effects of Farm Size on Economic Efficiency: the Case of Pakistan." American Journal of Agricultural Economics. 61(1), February 1979, pp. 64-69. Khan and Maki, incidentally, find that larger farms are more economically efficient than small farms.

If Berry's and Cline's results about the relation between farm size and efficiency are correct, there is no tradeoff between efficiency and equity, and therefore the appropriate land policy is to distribute the available land among as many people as wish to have access to it. If their generalization is not true, then there is a tradeoff, and policymakers must balance equity and efficiency goals in designing land policies. In any event, there is a risk of serious error if policy is based on preconceptions rather than facts.

Africa has contributed little to the comparative international experience because little economic research has been done on African irrigation. The principal summary of agricultural research on Africa[4] suggests that the sparse literature supports the idea that small-scale irrigation may be more efficient than large-scale irrigation in Africa. But the size of the scheme is not necessarily correlated with the size of the individual farmer's holdings, and it is the latter which is relevant for equity considerations.

The holdings size issue can be addressed by standard econometric techniques. One can estimate production functions with an added variable representing farm size by ordinary least squares; the farm size parameter will provide a test of relative technical efficiency of larger versus smaller farms. The problem is that while the parameter estimates from such models will be unbiased, they will not be consistent. Also, they only test for technical, and not for economic, efficiency. One can overcome these difficulties by using models such as those developed by Lau and Yotopoulos (1971). They estimate a profit function, which is the dual of a production function, to assess the relative economic efficiency of large versus small farms. The estimates of production relationships which come out of this model have the desirable econometric properties of consistency and efficiency, but the data requirements are somewhat severe, as the comments in Attachment 1, below, make clear.

Another technique which could be used is that of the multicrop production function.[5] This very recently developed technique recognizes that in complex farming systems, many of the needed data, especially on the input side, will be available only as aggregates rather than attributed to individual crops. On the plus side, the technique is more forgiving of data

---

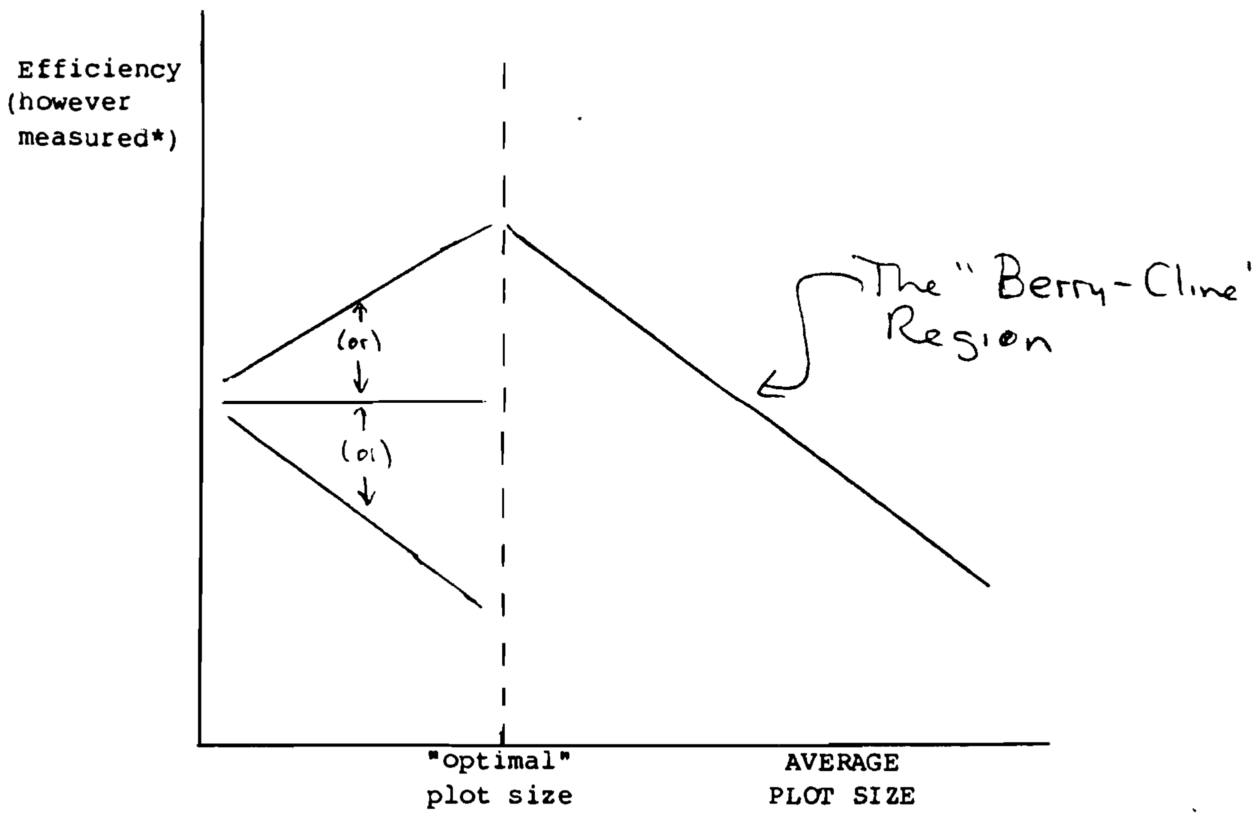
4. Carl K. Eicher and Doyle C. Baker. Research on Agricultural Development in Sub-Saharan Africa: A Critical Survey. MSU International Development Paper No. 1. East Lansing: Michigan State University Department of Agricultural Economics. 1982). One of the few interesting pieces of work on this issue is Hasan Tuluy's article on Senegal River irrigated rice farming in Scott R. Pearson; J. Dirck Stryker; Charles P. Humphreys; et al. Rice in West Africa: Policy and Economics. Stanford, CA: Stanford University Press, 1981.

5. The standard reference is R. E. Just; D. Zilberman; and E. Hochman. "Estimation of Multicrop Production Functions." American Journal of Agricultural Economics. 65 (1983), pp. 770-780. Useful extensions are contained in C. Richard Shumway; Rulon D. Pope; and Elizabeth K. Nash. "Allocatable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling." American Journal of Agricultural Economics. 66 (1984), pp. 72-78.

gaps. On the minus side, it is more econometrically ambitious, therefore more likely to be perceived by non-econometricians as the use of a sledgehammer to crack a very thin-shelled nut. Both the Lau-Yotopoulos and the Just methods merit consideration in spite of their weaknesses, however, because they overcome some of the greatest problems of simple OLS estimation of production functions.

The basic hypothesis to test is that there is an optimal holdings size, below which plots are too small either to benefit from appropriate intensification technologies or to maintain the active interest of the farmer, and above which the Berry-Cline scale diseconomies set in. The best way to visualize this hypothesis is to consider that the relationship between holdings size and efficiency is not linear, and may be discontinuous. In other words, the Berry-Cline results apply only above a certain minimum plot size (perhaps one-half to one hectare, but we have no firm evidence yet to support this), but below that size efficiency is lower. One possible way to depict this graphically is shown below.

Figure 1
Hypothesized Relationship Between Plot Size and Efficiency



* Most correctly as total economic resource cost per unit of output. It is likely that it will have to be measured imperfectly given our lack of information on shadow prices of inputs and outputs in Zimbabwe, but efficiency should definitely not be measured simply as yield per hectare.

The first data set on which I expect to employ the above techniques to assess the holdings size issue is from Zimbabwe. It is a series of annual reports on Agricultural Production in Communal Land Irrigation Schemes and ARDA Estates put out by the Department of Rural Development of the Ministry of Agriculture. I became aware of its existence while visiting Zimbabwe for the Land Tenure in River Basins study in 1984. Production, marketing and input data for twenty-five to thirty smallholder irrigation schemes are available for a period of seven to ten years (see attachment 2 for the data reported for one scheme for one year). These schemes range in size from about 10 to over 200 hectares, with average plot sizes varying from less that 0.05 ha. to over 1.00 ha. per plotholder. Some of the schemes are over 50 years old (the Sabi River schemes -- see the Zimbabwe Chapter of the River Basins paper), and some were established in the last few years. A variety of crops is produced; most of the farmers produce several cash crops as well as basic foodgrains. Most of the schemes suffer periodically from water shortages, especially during the drought of the early 1980's, but many are able to double-crop anyway. Most schemes use fertilizer, draft oxen, and contract plowing. The labor information is the least satisfactory, because it refers to "persons on the plot" by age and sex, rather than giving their activities. The "other persons" listed may or may not be hired laborers. But in order to use "persons on the plot" as a proxy for labor input we only have to assume that there is a roughly similar percentage of effort devoted to irrigation by households on the different schemes, or alternatively that labor input per "person on the plot" varies systematically with other information (such as livestock ownership) that we possess.

This is a rich source of data, which to my knowledge (and that of a couple of faculty members in the Department of Land Management at the University of Zimbabwe) has never been used as a base for the economic analysis of irrigation. With more than one hundred observations, the data set is certainly large enough to yield robust results. The single-year cross-section analysis which I have already done (to explore whether the behavior of the data makes sense, i.e. whether one can reasonably assume that the data are reliable) give very tight-fitting production and supply functions; this is a very good sign given the doubts expressed above about the labor input information. The addition of a time series can only help to give the hypothesis tests even higher power. The econometric problem of bias due to grouped data is present, but can be lived with as long as its existence is recognized from the start.

If this study bears fruit it will be only the first in a series of studies of the economics of land tenure in African irrigation. The next data set, which may permit the study of the impact on efficiency of tenure security as well as holdings size, could very well come from Senegal, where my work in Bakel should give me access to SAED and OMVS data on a wide variety of irrigation projects. Beyond those, data coming out of the Michigan and GARD projects in the Gambia and ARD's work in Somalia might be appropriate as followup sources (I expect to do a short study of the economics of irrigation in Somalia next year).

ATTACHMENT 1

Notes on the Lau-Yotopoulos Methodology

Lau and Yotopoulos (1971, 1972) and Yotopoulos and Lau (1973), together with the people who adopt their methodology such as Khan and Maki (1979), make certain assumptions about the factors of production that may not be borne out in LDC agriculture. In order to define a profit function, it is necessary to define profits . All the papers define it as value of output less the value of variable inputs. The three factors that all these studies identify are labor, land and capital, which is hardly an astonishing list, but their definition in the studies leaves a lot to be desired. All of the studies assume that labor is the variable input, and capital and land the fixed inputs. This is hardly unusual given that inputs are generally assumed to behave this way, but it may not be correct in many LDCs.

There is no reason why land should not be treated as a fixed factor, but the assumptions about the other two inputs may not be made cavalierly. Capital is -- for data availability reasons -- rarely defined in the stock formulation in which it appears in the theory. Khan and Maki, for example, define capital as the "sum of costs of seed, fertilizer, tubewell water, and animal and mechanical power," (1979, p. 64) most of which are clearly variable inputs which do not have zero opportunity cost once the cultivation season has begun. For example, it is clearly possible for farmers to vary the amount of fertilizer they apply to a given area of land, even if the package directions suggest that they shouldn't. Rational farmers will apply fertilizer -- or most of the other items in Khan & Maki's list -- according to marginal productivity considerations at least as surely as they will labor. Lau and Yotopoulos in fact recognize this:

> Total other costs (i.e. costs other than labor costs, interest on fixed capital and land rent) should also be treated as a variable input of production. This is impossible in our profit function formulation due to the fact that we lack the "price" of other costs ... To the extent that the price of other costs varies only across states, its effect is captured by the state dummies. An alternative rationalization is that the other costs are employed in fixed proportions to output. (1971, p. 103, footnote 25)

Regardless of what one might think about the authors' justification for omitting other costs as a variable input, it is clearly not acceptable for Khan and Maki to treat them as fixed without any explanation.

The assumption that labor is a variable input is probably justified in most cases, because farmers and farm family members have almost instantaneous ability to stop or start working, i.e. to vary the intensity of farming on a given size piece of land. In the case of very low levels of nonlabor and nonland input use, however, in regions where land scarcity makes it difficult for people to survive without devoting every last bit of potential effort to food production on the little land they have, labor and land may, in fact, be applied in fixed proportions, with labor being used up to some point such as zero marginal productivity. Hired labor, of course, would not have much of an element of fixity about it.

To define profits as the value of output less total labor costs is, therefore, open to question. It would be much better to define variable inputs as those which are truly variable, which in low-technology LDC agriculture are likely to include everything except land. The measurement problems are severe, of course, but that should not stop people from trying.

Implications for the profit function

The Lau-Yotopoulos profit function derived from the Cobb-Douglas production function to compare the relative efficiency of two groups of farms is written as:

(1) $$\ln P = \ln A + a_1 D_L + b_1 \ln W + c_1 \ln K + c_2 \ln T \quad ,$$

where: P is profits (value of output minus total labor costs);
D_L is a dummy variable differentiating the two groups -- sizes of farms or gender of household head or whatever -- to be distinguished in the analysis;
W is the wage rate, defined as a weighted average of rates for family and hired labor;
K is capital, defined as interest charges paid or imputed on the quantity of fixed capital per farm by Yotopoulos and Lau (1971), and as previously cited by Khan and Maki (1979);
T is land, in units of square measure;
A, a_1, b_1, and the c_i are parameters to be estimated.

W enters rather than L (labor) because of the definition of profit. K is not really measured as the stock of capital, but as flows of capital costs (by Lau & Yotopoulos, interest paid on capital, real or imputed; by Khan & Maki, as input costs); L&Y argue that if interest rates are essentially constant interest costs will be essentially proportional to the value of the capital stock (1971, p. 103). K&M have no excuse. Only land is measured as one would "expect."

The mathematics of the derivation of the profit function imply that profits are measured as the difference between the value of output and the total cost of variable inputs. On the right-hand side, variable inputs are expressed by their prices, and fixed inputs by their quantities. In a typical LDC farm sector, land and (perhaps) machinery are the only obviously fixed factors. Therefore, labor and purchased inputs should be represented by prices rather than quantities. In most data sets, some or all of these data are lacking. This means that it will not be possible to estimate profit functions any better than K&M do. One wonders if it is worth doing at all.

The econometric arguments about using profit functions instead of production functions to make direct estimates of relative efficiency have to do with consistency and efficiency. The only evident bias in estimates is that due to grouped data; see Maddala (1977, pp. 69, 273). For our purposes, though, it is unlikely that asymptotic problems will be cared much about. Therefore, perhaps production function estimates will be sufficient. If so, estimate the Cobb-Douglas form:*

---

* One could test for the assumption of unitary elasticity of substitution in the standard manner if one desired; if the hypothesis were rejected one would have to estimate a CES function.

(2) $$Q = A\ K^a\ L^b\ T^c\ M^d \quad ,$$

where Q is the volume of output, M is the volume of purchased inputs, and K, L and T are as defined before.

Any difference in technical efficiency between two groups of farms should show up as a difference in the constant A, so that a dummy variable would be as satisfactory here as in the profit function. The specification of the function for estimation purposes should be:

(3) $$\ln Q = \ln A + a_1 D + b_1 \ln K + b_2 \ln L + b_3 \ln T + b_4 \ln M \ ,$$

where D is the dummy designed to capture differences in efficiency and the other variables are as defined above.

M, L and K can be disaggregated if need be to reflect internal diversity: fertilizer versus pesticides, hired versus family labor, tractors versus draft animals. The estimates of the elasticities obtained from ordinary least squares regressions will be unbiased, but not consistent.

ATTACHMENT 2

BEST AVAILABLE DOCUMENT

TABLE 3.- CROP PRODUCTION (CONTD.)

MANICALAND PROVINCE

1981/82 SEASON

CROP	NO. OF PLOT-HOLDERS	AREA PLANTED	PRO-DUCTION	YIELD PER HECTARE	SALES: No. of Plot-holders	SALES: Quantity Sold	CROP RETAINED	FERTI-LIZER USED
		hectares	tonnes	kg		tonnes	tonnes	tonnes
1202-04 MUTEMA								
MUTEMA IRRIGATION SCHEME :								
OTHER CROPS :								
Sunflowers (threshed)	*	*	*	*	*	*	*	*
Edible beans	191	105	127	1 204	190	96	31	29
Sugar cane	*	*	...	...	*	*	...	*
Other crops n.e.s.	-	-	...	...	-	-	...	-
TOTAL :	315	461	...	...	314	...	...	153
1202-05								
TAWONA IRRIGATION SCHEME :								
CONTROLLED CROPS :								
Maize	211	126	775	6 171	86	111	664	33
Wheat	24	6	12	2 067	10	7	6	3
Cotton	81	20	33	1 618	81	33	-	8
Groundnuts (unshelled)	*	*	*	*	*	*	*	*
OTHER GRAIN CROPS :								
Barley	-	-	-	-	-	-	-	-
VEGETABLES AND FRUIT :								
Onions	*	*	...	...	*	*	...	*
Sweet potatoes	*	*	...	...	*	*	...	*
Tomatoes	143	42	...	...	142	40 268[a]	...	15
Other vegetables	4	1	...	...	4	116[a]	...	-
OTHER CROPS :								
Nyimo	-	-	-	-	-	-	-	-
Edible beans	191	102	104	1 020	187	77	27	24
TOTAL :	213	298	...	...	212	...	...	93
1501-09								
MUTAMBARA IRRIGATION SCHEME :								
CONTROLLED CROPS :								
Maize grain	167	133	521	3 916	151	290	231	21
Wheat	144	54	83	1 544	114	49	34	13
Cotton	-	-	-	-	-	-	-	-
Burley tobacco	-	-	-	-	-	-	-	-
OTHER GRAIN CROPS :								
Bar[illegible]								

TABLE 4.- LAND USAGE, NUMBER OF PERSONS AND LIVESTOCK (CONTD.)

1202-04

MUTERA IRRIGATION SCHEME [illegible] PROVINCE

1981/82 SEASON

	NO. OF PLOT-HOLDERS	HECTARES		NO. OF PLOT-HOLDERS	NUMBER
LAND USAGE :			**PERSONS ON THE PLOT :**		
Total area of occupied plots	316	232	Total persons on the plot	316	2 295
Total area planted to crops	315	461	Family members :		
Area irrigated during winter	314	230	Males 16 years and over	276	350
Area irrigated during summer	315	232	Females 16 years and over	314	511
Total area manured	101	56	Children :		
Area ploughed :			7-15 years at home all year	239	520
By the D.D.F.	*	*	7-15 years but not at home all the year	120	191
By other contractors	171	206	Under 7 years	217	405
By the plotholder	151	252	TOTAL FAMILY MEMBERS :	316	1 977
			Other persons	178	318

BEST AVAILABLE DOCUMENT

	NO. OF PLOT-HOLDERS	NUMBER		NO. OF PLOT-HOLDERS	NUMBER
Owned by plotholder :			**Cattle sales :**		
Trained draft oxen	151	419	Direct to C.S.C.	14	31
Other cattle	148	1 006	At Home Affairs Auctions	*	*
TOTAL CATTLE :	158	1 425	Other sales	88	257
No. of cattle stall fed	-	-	TOTAL SALES :	98	294
No. of cattle held at the Scheme	155	1 261			

ALL OTHER LIVESTOCK AND POULTRY

	OWNED BY PLOTHOLDERS		HELD AT THE SCHEME BY PLOTHOLDERS	
	No. of plotholders	No. of animals	No. of plotholders	No. of animals
Sheep	5	30	5	30
Goats	130	695	124	659
Pigs	*	*	*	*
Horses, donkeys and mules	*	*	*	*
Poultry	269	4 622	269	4 602