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A Game Theoretic Approach to Analyse Cooperation between Rural Households in Northern Nigeria

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Abstract

To improve the livelihood of the poor in Sub-Saharan Africa (SSA) much attention has been paid to the development of new agricultural technologies. We hypothesize that farmers can also improve their livelihood through cooperation. Partial cooperation, in which knowledge is shared or bargaining power improved, is relatively common in SSA, while cooperation where all resources are fully shared, which we address, has rarely been investigated. An important pre-requisite to establish such cooperation, is the need for a fair division rule for the gains of the cooperation. This paper combines linear programming and cooperative game theory to model the effects of cooperation of (individual) households on income and farm plans. Linear programming establishes insight in the optimal farm plans in cooperation, and cooperative game theory is used to generate fair division rules. The model is applied to a village in Northern Nigeria. Households are clustered based on socio-economic parameters, and we explore cooperation between clusters. Cooperation leads to increased income and results in changes in farm plans, because more efficient use of resources leads to more intensified agriculture (labour intensive – high value crops).

Keywords: Cooperations, Linear Programming, Nigeria, Livelihood

Introduction

In this paper we consider cooperation of farmers in a village in which physical resources are fully shared. In practice, this means that all land, labour and capital are shared and decisions are made based on the aggregated resources. Individual farmer decisions are frequently analysed with the use of linear programming (LP) models, firstly introduced by King (1953) and Heady (1954). The basic LP model describes the most important decisions of the farm households, namely production, market and consumption decisions. The constraints are based on the major input-factors used in farming: land, labour, and capital. The solution of the LP model leads to an optimal farm plan corresponding with the optimal objective function. The LP approach can also be used for modelling the decisions of a cooperation, with the only difference that the resources are aggregated for several farmers. As resources do differ among farmers, resources of different farmers may complement each other, and cooperation possibly leads to more efficient use of the resources and to different farm plans with extra gains. Indeed, if cooperation yields extra gains, another problem arises: in which way should these extra gains be divided among the involved farmers.

The innovation of this paper is that LP and cooperative game theory are combined to model the effects of cooperation of (individual) households on income and farm plans. Owen (1975) developed LP games, a special class of cooperative games in which LP and cooperative game theory are combined. By constructing a suitable LP model for farm planning and developing an associated LP game we are able to analyse the attractiveness of cooperation and the changes in farm plan decisions. Moreover, a game theoretical division rule is considered. Our LP model is based on the basic farm household model as described in Schweigman (1985).

A case study from Northern Nigeria is used to illustrate the model. This paper is organised as follows. After the introduction, we describe the model and data in Section 2. Thereafter, in Section 3, we discuss the results of the applied model, and a conclusion appears in Section 4.

Materials and Methods

First, we developed an LP model based on a basic farm household model as described in Schweigman (1985). The decision variables reflect the production, consumption and market decisions of a farmer.

Production decisions are twofold. The farmer needs to decide which crops to be cultivated and needs to make a choice of a cropping system to cultivate the crop. Other decisions include decisions on hiring (out) labour and taking or paying off a loan.

As objective function we use the maximisation of gross margin of crop production. From the basic farm household model (Schweigman (1985)) we incorporated the monthly constraints for labour supply, storage balances, capital and loan balances and production levels of crops.

Furthermore, the basic constraint for the total area used by the farmer is included. To make the model specific for the region, we include restrictions for both land use of common farm area and use of fadama area (low lands) for growing crops with high demand on water such as rice, sugarcane, etc. Furthermore, a subsistence constraint is included about the nutritional needs on energy and protein of households. Moreover, a constraint is included for the maximum loan which can be taken during the year. Finally, a constraint is incorporated to set a maximum to the total amount of time the farmer is able to work on other farms to earn additional income against the local wage rate

Second, we used the LP model to explore the changes in farm plans by comparing the optimal farm plan of the grand coalition with the (sum of the) farm plans of the individuals. Third, we introduced the linear production (LP) game (see Owen (1985), by using the above described LP model. We assume that the production matrix is the same for everybody in the village, in line with the assumption of local homogeneity in production technologies. This assumption is justified as prices, yields and required inputs do not differ among farmers in the same village while available resources can be different for each farmer. After construction of the LP game, the gain of the cooperation should be divided among the farmers. We opted to use the Owen-value (Owen (1985)), which is a division rule especially developed for LP games.

The model is applied to farmers in Ikuzeh village, Kajuru Local Government Area, Kaduna State, Nigeria. This village is located in the Northern Guinea Savannah (NGS). This agroecological zone is defined by a length of growing period of 151-180 days and unimodal rainfall pattern. Hausa is the major ethnic group. Main crops include sorghum, maize, and cowpea for the upland fields. In the lowlands, sugarcane and rice are cultivated in the village. Crop yields and fertilizer inputs in the model were estimated

Table 1. Characteristics of the five clusters

Cluster	A	*B*	*C*	*D*	*E*
Number of farmers	23	8	4	2	2
Farmsize (hectare) [a b]	4,72	6,45	18,07	13,70	6,05
Fadama (hectare) [a b]	0,45	0,72	1,96	2,23	0,52
Household size (# persons) [a]	6.2	14.6	11.5	11.0	6.0
Ownership Livestock (TLU) [a]	0.5	1.7	0.9	5.7	3.2
Value of stated Assets (Naira) [a]	2900	5700	3000	2600	53700
Labour (Man hours month)[b]	570	980	885	1104	561
Outgoing Labour (Manhours /month)[b*]	57	98	88.5	110.4	56.1
Energy required (MJ) [b]	1484	2402	2778	2957	1560
Protein required (g) [b]	5664	9189	10428	11235	5898
Maximum Loan (Naira) [b*]	0	2850	2850	5700	5700

[a] cluster variable, [b] resource parameter in the LP model; *(rough) estimations of the researchers

from a baseline survey carried out in 2002 on a sample of 39 farmers (De Haan (2002). Prices are estimated based on data from the Kaduna State Agricultural Development Program (KADP (2002) and Kaduna State Fertilizer Company (KSFC (2002).

Wage rates and detailed labour input requirements are based on biweekly surveys in the region in 2005 (Berkhout (2005)). From FAO (2007) we obtained the food energy and protein contained in each crop. For the estimation of the resource parameters, which are different for each farm household, we use the data on the 39 different farmers from the same 2002 baseline survey. We used cluster analysis to classify farmers into five homogeneous groups (Hazell and Norton, 1986). The 39 households were clustered using data on farm size, area for fadama, household size, livestock ownership, and household stated assets such as radio, bicycle, tools etc. Based on the results of the hierarchical cluster analysis the 39 farmers are grouped into five clusters.

We calculate the average resources in each cluster, such that five average farmers can be constructed. We will analyse the attractiveness of cooperation between the five average farmers. In Table I the average characteristics of the five clusters are presented. We show cluster variables, as well as the farm specific resource parameters which are used in the model, i.e., farm and fadama size, labour availability, energy and protein requirements and loan availabilities.

Results and Discussion

In Figure I we present the optimal farm plans of the individuals, the sum of the individuals and the cooperation, by solving the corresponding LP models.

The results show that farmers C and D do not cultivate their complete farms, which is probably due to their large available farms (see Table I) and the lack of resources to cultivate all available land. For all individual farmers together, there is cultivation of 24 % fallow land, while in cooperation the fallow land will reduce to 17 % and fields with sorghum-cowpea relay and sugarcane are expanded.

In cooperation, one expects to find an improvement in gross margin; therefore we compared the results of the individuals and those of the cooperation. In Table II we show the resources and corresponding gross margin for the individual average farmers and the cooperation.

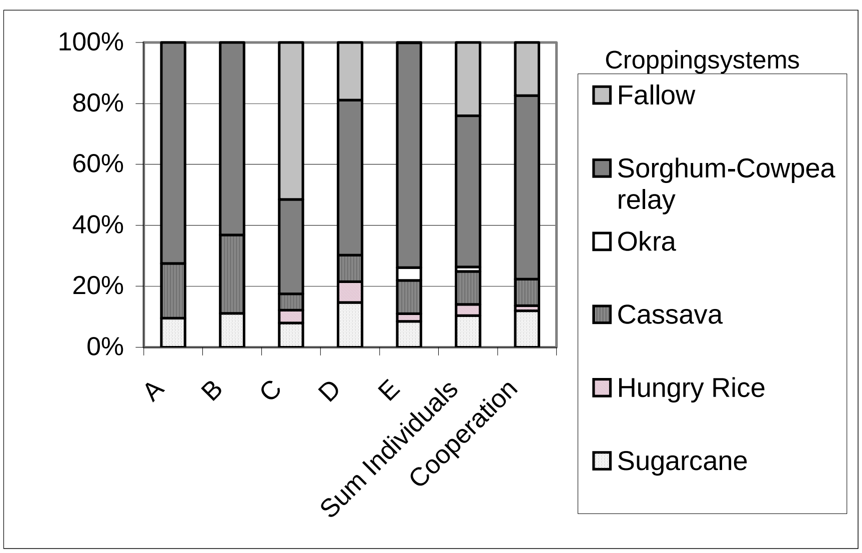

Figure: 1. Optimal relative farm plans for individuals and cooperation

The gross margin of all individuals (A+B+C+D+E) is equal to 2.394.258 Naira, which is lower than the gross margin of the cooperation, which is 2.685.004 Naira. Hence cooperation leads to a substantial improvement in benefits.

Now the corresponding LP game (Owen (1985)) can be introduced in this setting. We considered N={A,B,C,D,E} as the set of players and using the LP model and the data of Section 2. In Table III the complete LP-game (N,v) is presented. For each coalition S (defined as a cooperation between certain farmers), the resources of the coalition are calculated and based on this we solve the LP model for the coalition. The resulting gross margin is reflected by v(S) in the game. Consecutively, in Table IV we compare for each farmer the individual gross margin and its Owen value. The Owen value is a fair division of the grand coalition, N, that arises in a natural way from the LP game (cf. Owen (1975)). To calculate the Owen value, the shadow prices of the LP model of the grand coalition are used, to valuate the resources of each individual.

Table 2. Gross margin for individuals, the sum of individuals and the grand coalition

		A	*B*	*C*	*D*	*E*	*A+...+E*	*Coop.*
Resources	Farm	4,72	6,45	18,07	13,70	6,05	48,99	48,99
	Fadama	0,45	0,72	1,96	2,23	0,52	5,88	5,88
	Labour	570	980	885	1104	561	4100	4100
	Outgoing Labour	57	98	88,5	110,4	56,1	410	410
	Energy	1484	2402	2778	2957	1560	11181	11181
	Protein	5664	9189	10428	11235	5898	42414	42414
	Loan (Naira)	0	2850	2850	5700	5700	17100	17100
	Gross Margin (Naira)*	271099	396074	604609	800591	321885	2394258	2685004

* Exchange rate: 1 USD= 133 Naira (at December 2006)

Table 3. Game for gross margin maximization

S	*V(S)*	*S*	*V(S)*	*S*	*v(S)*	*S*	*v(S)*	*S*	*V(S)*
A	271099	AB	667173	ABC	1507522	ABCD	2351735	N	2685004
B	396074	AC	954334	ABD	1625392	ABCE	1835246		
C	604609	AD	1137887	ABE	999496	ABDE	1955472		
D	800591	AE	600965	ACD	1754925	ACDE	2166980		
E	321885	BC	1212479	ACE	1328126	BCDE	2388637		
		BD	1349520	ADE	1471518				
		BE	728397	BCD	2050770				
		CD	1405200	BCE	1541344				
		CE	1029093	BDE	1679716				
		DE	1173810	CDE	1866015				

Table 4. Owen value (Naira) compared with individual gross margin

	Individual	Owen Value	Increase	Increase %
A	271099	294064	22965	8%
B	396074	507686	111613	28%
C	604609	705772	101163	17%
D	800591	849192	48601	6%
E	321885	328290	6406	2%

The results show that especially farmers B and C gain a lot with cooperation, as we expected from the patterns of the cropping systems (Fig. 1). Those improvements can be explained with the shadow prices (not shown). Farmer B has 150 man hours per hectare (= 980/6.45) on labour available, which is the highest among all farmers. For his individual farm plan the labour shadow price is zero, and not all of this resource is used, while in the grand coalition the labour has a high value. The improvement of farmer C is mainly due to the high shadow price of fadama fields and the fact that C owns relatively many fadama fields. Furthermore, farmer E has a small increase in the gross margin of 2% only, which means that in his individual plan, the resources are (almost fully) and efficiently used.

Conclusion

Findings from this paper clearly gave evidence that cooperation of farmers should be stimulated, because extra gains can be obtained. Moreover, cooperation has more potentials to develop and to be stable if fair division rules can be provided. The Owen value shows to have this property, because it divides exactly the gain that is obtained when all farmers cooperate and each individual farmer receives more than the case in which he is not cooperating.

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