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Econometric analysis of farmers' decision making patterns as a prerequisite for sustainable technology development: The case of yield variability and risk in small-holder systems of southwestern Niger

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1 Problem statement

Risk is commonly defined as the known probability of losses or failure of an activity and quantified as the variance of returns of a certain activity. According to the portfolio-theory of *Markowitz*, activities with both high returns and high risks are hedged by activities that diminish risk when having a negative covariance of returns with the other activities. Here, returns are decreasing automatically, as a negative covariance between activities implies lower total returns of the portfolio than a risk indifferent and simply profit oriented portfolio would have (Leupold 1996). In farming systems, risk in production is assumed to be mainly dependent on temporal yield variability induced by rainfall variability, linked with the assumption that other agronomic parameters are kept stable over time.

Risk has proven to be an important factor for the decision making in smallholder farming systems in development countries, especially in semi-arid tropics, where risk is determined by temporal rainfall variability. The attitude towards risk – risk aversion or risk indifference – can be defined as the degree of deviation of a profit maximizing behavior. The higher the degree of risk aversion, the more are farming activities aiming at hedging potential risks, and the smaller will be the profit maximizing component within their goals. In literature, cases can be found where farmers are risk averse (Hedden-Dunkhorst 1993, Munyemana 1995), but also where farmers seem to be risk neutral or even preferring (Hedden-Dunkhorst 1993). Factors influencing risk attitudes seem to be food sufficiency and off-farm income opportunities (Hedden-Dunkhorst 1993), assets (Binswanger 1981) or resource endowment (Munyemana 1995). Although the impact of risk on production and the potential for innovations is stressed for many cases as e.g. for the millet production in Niger (Adesina and Brorsen 1987), it can also be shown that institutional constraints like marketing and credit are more important for the improvement of production (Binswanger 1981) and that the influence of risk can be minimized by introducing low-risk technologies (Sanders et al. 1996). However, precise and objective assessment of risk and risk attitudes seems to be an important prerequisite for the participatory development of innovations, even more as farmers seem too have difficulties to perceive the risk of innovations and tend to consider them in a pessimistic way (Sanders et al. 1996). As a consequence, although attitude towards risk can be assessed both experimentally (Binswanger 1981) and by means of mathematic models, risk determination and quantification has to be done basically by econometric models in order to avoid biased estimations of farmers or scientists.

Agricultural production systems in southwestern Niger are considered to be mainly subsistence-oriented and based on millet, with "intercrops" (defined as crops that are simultaneously planted together on a specific plot) like sorghum, cowpea, groundnut and others (Baidu-Forson and Williams 1996). In these systems, input intensity is of a high variability. Further, it can be said that not only a temporal variability, but also a high spatial variability of climatic factors and resources can be observed. Finally, synergetic or competitive effects between intercrops have to be assumed. This implies the violation of the "ceteris paribus"-condition that is the base for most scientific on-station experiments. In these experiments, only the one yield-influencing parameter that is subject to research, is varied, while all the others are kept stable. This facilitates the precise determination of the relationship between the dependent and the independent variable.

In existing agronomic or economic models, data on the above mentioned yield variability – and therefore on risk - caused by temporal rainfall variability is mainly taken from on-station experiments. For the case of intercropping systems in southwestern Niger, such data is not available, as research on the agronomic level focuses mainly on single crops, partially analyzing their yield response to fertilizer and rotation (Bationo and Vlek 1998, Muehlig-Versen et al. 1998) or focusing only on cowpea-millet intercropping effects while neglecting other intercrops like e.g. sorghum or sorrel (Bielders 1998). On the economic level, analysis is thoroughly limited to millet and millet byproducts (McIntire et al. 1989, Lamers 1995). For intercropping systems in northern Benin, correlation in intercropping systems with respect to intercropping aspects and management practices has been calculated, yet without determining functional relationships of in- and outputs in production (Brüntrup 1997a and 1997b).

In order to generate the lacking information on the determinants of yield variability in intercropping systems, it had been decided to estimate production functions of an intercropping system for the nine main crops and crop byproducts. The hypothesis to be tested are the following:

(1) Crop yields are determined by seed input, fertilizer input, temporal rainfall variability and soil parameters.

(2) The relation of yields of different intercrops is determined by their synergetic and competitive effects in the intercropping system.

(3) The relation of yields of different intercrops is also determined by the different responses of intercrops to spatial variability of climatic and phytosanitary factors.

The testing of hypothesis (1) implies that the "ceteris paribus" condition cannot be kept and that, as a consequence, a multiple regression analysis has to be applied. Hypothesis (2) has to be tested by extending the multiple regression to estimating a simultaneous equation system where the dependent variables (here: crop yields) can also become independent variables in the function of their intercrops. Hypothesis (3) can also be tested by assuming a relationship between intercrop outputs that can be seen as an indicator for spatial variability of factors that might influence yields but were not included in the data-set. One of them might be spatial rainfall variability, that was not measured, as measuring rainfall on each plot would be too costly. Another factor that have different impact on different crops would be pests and diseases. These were also not included in the data set.

Under the assumption of heteroskedasticity, i.e. that disturbance terms are dependent on the observation or the sample respectively (Henze 1994), the equation system has to be estimated with the three-stage-least-squares regression method (3SLS) (Kennedy 1992). 3SLS is based on the two-stage-least-squares technique, where some independent variables of a system are estimated as dependent ones and then subsequently fed into the other equations of the system.

For the case of heteroskedasticity, this method has to be combined with the application of generalized least squares. Every system of equations has to be identified in order to provide feasible results. In a system with the number of G equations, any equation is identified when of all the variables in the system G-1 are excluded from the equation. For reasons of practicability, identification is only checked by the necessary but insufficient order condition (Common 1980).

2 The econometric model

2.1 Database and study area

The database used for the analysis covers data on production in millet-based intercropping systems. The sample used are about 1,800 plots of farms in four villages in Western Niger. They were taken from an ICRISAT/IFPRI research program in the eighties that focused on improving the millet production system in Niger. The sites represent two regions in Niger with different rainfall conditions, 200 – 400 mm in the North and 400 – 600 mm in the South. The main crop is pearl millet, both sole and intercropped with cowpea, sorghum, groundnut as well as bambara groundnut, okra and sorrel. Different intensification levels of phosphorous fertilizer, applied as SSP and rock phosphate and other fertilizers can be observed. The database represents a time series from 1983 to 1987, with daily rainfall data over these years and additionally for the year 1982 (McIntire et al. 1989). The number of observations is 1800 plots.

2.2 Variable description

The variables included in the model were inputs of seed and mineral fertilizer per hectare, outputs and byproducts per hectare as well as monthly rainfall and some soil parameters. The crops and byproducts are millet, cowpea and cowpea hay, groundnut and groundnut hay, sorrel, okra as well as red and white sorghum. Most of the variables were included in their linear form, some, like phosphorous fertilizer and rainfall where additionally included as quadratic variables to determine their decreasing rate of return. A description of the variables in the model is given in Table 2.1.

Table 2.1: Variable description

Variable name	Description	Unit
Mout	Millet yield	Kg/ha
Nout	Cowpea yield	Kg/ha
Nfaout	Cowpea hay yield	Kg/ha
Aout	Groundnut yield	Kg/ha
Afaout	Groundnut hay yield	Kg/ha
Sbout	White Sorghum yield	Kg/ha
Srout	Red Sorghum yield	Kg/ha
Oout	Sorrel yield	Kg/ha
Gout	Okra yield	Kg/ha
Mseed	Millet seed	Kg/ha
Nseed	Cowpea seed	Kg/ha
Aseed	Groundnut seed	Kg/ha
Sbseed	White sorghum seed	Kg/ha
Srseed	Red sorghum seed	Kg/ha
Oseed	Sorrel seed	Kg/ha

Gseed	Okra seed	Kg/ha
P	Phosphorus content of fertilizer applied	Kg/ha
P^2	Squared phosphorus content of fertilizer applied	Kg/ha^2
Rain5	Rain in May	mm
Rain6	Rain in June	mm
$Rain6^2$	Squared Rain in June	mm^2
Rain7	Rain in July	mm
Rain8	Rain in August	mm
Rain9	Rain in September	mm
Rain10	Rain in October	mm

2.3 Functional form

Crop yields can be formulated either as a linear and quadratic function of independent variables with no interaction of the independent variables, or as a multiplicative functional form assuming the interaction of independent variables (e.g. a Cobb-Douglas-function) (Hedden-Dunkhorst 1993). To facilitate the analysis, the first variant was chosen, so that the functional form of each equation in the system is

Eq (2.1) $$O = \sum_i a_i x_i + b_i x_i^2$$

with:
O the crop yield
x_i the independent variable i (input, rainfall or intercrop)
a_i, b_i the coefficients to be estimated

2.4 Regression results

The estimation of the simultaneous equation system shows the expected results. As shown in Table 2.2, every crop yield is basically a function of seed and the amount of rainfall in different months. Considering rainfall, response differs across crops: Some respond more to the rain in June and July, some more on the later rain. Further factors influencing certain crops are phosphorus fertilizer application, e.g. millet or sorghum and, for some crops, the amount of intercrop seeds applied on the same plot. Also, effects of intercrops can be seen, as the output of e.g. millet, cowpea and red sorghum is related to the output of intercrops.

Table 2.2 Estimated coefficients (t-ratios)

DEP	Mout	Nout	Nfaout	Aout	Afaout	Sbout	Srout	Oout	Gout
Nout	-8.9 (-1.8)		-6.8 (-3.1)				-0.05 (-2)		
Aout					-5.0 (-19.6)				
Sbout	-0.5 (-1.7)								
Oout	19.8 (5.5)								
Mseed	1.8 (13.5)		0.2 (2.7)						
Nseed	100.1 (12.5)	0.7 (3.2)	56.7 (15.6)						
Aseed				2.4 (59.8)	15.4 (25.1)				
Sbseed						7.7 (19.8)			
Srseed							27 (53)		
Oseed								2.0 (15.4)	
Gseed									19.7 (11.1)
P	16.8 (4.3)					0.7 (1.2)	0.03 (1.9)		
P^2	-0.1 (-4.2)					-0.04 (-1)			
Rain5	-3.3 (-3.7)					-0.3 (-3.0)			
Rain6	23.4 (7.2)		6.2 (3.5)			0.7 (1.7)			0.2 (1.3)
$Rain6^2$	-0.1 (-5.3)		-0.04 (-2.9)			-0.005 (-1.5)			
Rain7		0.1 (5.5)							0.1 (1.5)
Rain8							0.003 (1.4)		-0.08 (-1.4)
Rain9	3.2 (4.5)		1.2 (3.3)	0.4 (3.4)	2.1 (6.5)	0.2 (1.8)	0.01 (2.4)	0.03 (3.3)	
Rain10		-0.2 (-3.4)							
Const.	-750.2 (-6.5)	-5.6 (-2.9)	-258 (-4.3)	-13.6 (-1.7)	-88.7 (-2.9)	-17 (-1.1)	-0.9 (-1.9)	-1.3 (-1.8)	-8.5 (-0.7)

System $R^2 = 0.97$

Focusing on certain output functions, the above mentioned factors can be illustrated more clearly. For example, millet yield per hectare is a function of millet seed, but also of the rain in May, which affects millet yield negatively. This could be due to a management error of farmers: Seeding might be done to early when having high rainfall in May. When this early rain is not followed by high amounts of rain in June, cropping might fail. Rain in June and September show a positive effect on millet yield. The rain in June has a decreasing rate of return, expressed by the negative coefficient of its squared value. This implies that rainfall above a certain limit can cause damage to the young plants. Also with a positive linear and negative quadratic impact is the amount of phosphorus applied related with the millet yield, which implies a decreasing rate of return on the input of this type of fertilizer. Concerning intercropping effects, it can be seen that the amount of cowpea seed put in has a positive impact on millet yield. This could be due to the nitrogen-fixing or to the soil covering effects of cowpea. Cowpea and white sorghum yields have a negative impact of the millet output, which either implies a certain competition or a different response on climatic conditions of the crops. Looking at the equations of the two crops reveals that in the case of sorghum, it might rather be the effect of competition, as sorghum depends mainly on the rainfall of the same months and the optimum rainfall in June is about 90 mm and 75 mm for millet and white sorghum respectively. Cowpea seems to respond differently to climatic conditions: The most important rainfall for cowpea is in July (as cowpea is seeded later than the cereals) and there is a significantly negative impact of late rain on cowpea. Considering the cowpea and cowpea hay relationship, it can be seen that the output of cowpea hay is negatively related with the output of cowpea but positively with the amount of millet seed on the same plot, which implies the same synergetic effects as mentioned above.
Looking at the other functions, the groundnut equation is of some interest, as it detects some important relationships of management. First, groundnut yields are not related to yields or seed of any other crop. This can be interpreted by the fact that groundnut is in common planted independently by women on small plot sectors that have been given to the women by the household head. Groundnut output has a negative impact on the output of groundnut hay, but it has to be emphasized that this also might be due to management patterns: It can be observed that the hay is only harvested when groundnut grains cannot be harvested. In years of good grain yield, harvesting of the hay decreases although there must be some in the field.

3 Simulation of yield

Having detected the output functions of the intercropping system, the next step would be to simulate a yield series that describes the response of the crops to rainfall variability and therefore finally the risk induced by rainfall variability. At this state, it is possible to create a "ceteris paribus" situation when keeping the independent variables, except rainfall, constant. Feeding the rainfall data of the four sites over 5 years and additionally two sites' rainfall of one year into the model leads to a simulated series with a length of 22 yields for each crop. The simulated yield series is shown in Table 3.1. Here, yields of different crops within different production systems have been simulated according to the model. The different systems are e.g. for millet sole and intercropping with and without the application of P. The rainfall scenarios consist of observed rainfall combinations during the cropping season. Out of the simulated yield series, the corresponding variance-covariance matrix can be calculated. This matrix is shown in Table 3.2. Here, it can be seen that mainly the leguminous crops (cowpea and groundnut) have a negative covariance with the cereals, and some cereals have negative covariance with other cereals (e.g. red sorghum and millet). It has to be emphasized that this is just a variance-covariance matrix of yields per hectare. It has to be extended by two factors:

a) with prices for the outputs. The hereby derived matrix could be different from the one of yields, as prices might tend to vary in the opposite direction of yields
b) with input costs: Intensive production systems bare a higher risk of losses, as the sunk costs are higher than in less intensive systems

Table 3.1 Simulated yield series (average input of seed and fertilizer under 22 rainfall scenarios)

Rainfall scenario	Millet inter-cropped	Millet sole	Millet inter-cropped with P	Millet sole with P	Cowpea hay	Ground-nut hay	Ground-nut	W. Sorgh-um	W. Sorgh-um with P	R. Sorgh-um with P	R. Sorgh-um	Sorrel	Okra	Cowpea
1	394	270	498	374	480	94	67	16	21	27	27	0	49	5
2	382	258	486	362	321	97	71	15	20	27	27	1	38	6
3	336	213	441	317	153	94	67	25	30	27	27	0	38	0
4	0	0	0	0	0	93	66	2	7	27	27	0	34	0
5	372	248	476	353	199	110	86	20	25	27	26	2	60	13
6	389	265	493	369	132	124	102	28	32	27	27	4	58	11
7	568	444	672	548	437	103	78	28	32	27	27	1	58	7
8	541	417	645	521	285	105	80	28	33	27	27	2	44	1
9	65	0	169	45	97	112	88	1	6	27	27	2	43	13
10	359	235	463	339	215	128	108	12	16	27	27	4	49	17
11	219	95	323	199	119	108	83	15	20	27	27	2	47	1
12	0	0	0	0	0	94	67	3	7	27	26	0	43	0
13	600	476	704	580	285	107	82	34	39	27	27	2	43	3
14	581	457	685	561	298	103	78	33	37	27	27	1	41	3
15	415	292	520	396	174	101	75	29	34	27	27	1	46	0
16	555	431	659	535	397	97	70	27	32	27	27	1	47	1
17	369	245	473	349	108	135	116	30	35	28	28	5	28	5
18	217	93	321	197	53	134	115	26	31	28	28	5	30	5
19	0	0	28	0	0	113	89	19	24	27	27	2	37	10
20	361	237	465	341	108	123	101	31	35	28	28	4	37	1
21	470	346	574	450	218	100	73	30	34	27	27	1	41	2
22	438	314	542	418	194	101	75	29	33	27	27	1	45	1

Table3.2: Variance-Covariance-Matrix of yields for different crops

	Millet inter cropped	Millet sole	Millet inter-cropped with P	Millet sole with P	Cowpea hay	Ground-nut hay	Ground-nut	W. Sorghum	W. Sorghum with P	R. Sorghum with P.	R. Sorghum	Sorrel	Okra	Cowpea
Millet inter-cropped	34082	-	-	-	-	-	-	-	-	-	-	-	-	-
Millet sole	29484	27165	-	-	-	-	-	-	-	-	-	-	-	-
Millet inter-cropped with P	39383	33248	46033	-	-	-	-	-	-	-	-	-	-	-
Millet sole with P	34755	30895	39866	35972	-	-	-	-	-	-	-	-	-	-
Cowpea hay	5811	4633	6803	5617	1383	-	-	-	-	-	-	-	-	-
Ground-nut hay	-93	-348	21	-235	95	164	-	-	-	-	-	-	-	-
Ground-nut	-98	-408	42	-269	119	199	243	-	-	-	-	-	-	-
W. Sorghum	1336	1135	1549	1346	295	28	34	103	-	-	-	-	-	-
W. Sorghum with P.	1327	1124	1538	1333	294	28	33	103	104	-	-	-	-	-
R. Sorghum with P.	0	-9	3	-6	3	4	4	0	0	0	-	-	-	-
R.	-8	-14	-5	-12	2	3	4	1	1	0	0	-	-	-

Sorghum													
Sorrel	10	-26	28	-8	18	20	24	5	4	0	0	3	-	-
Okra	603	627	685	708	27	-20	-23	3	1	-2	-2	-2	69	-
Cowpea	-50	-15	-60	-26	-20	30	36	7	6	0	0	3	6	15

4 Conclusions

Out of the above mentioned procedure, the following conclusions can be drawn:

(1) The information that was not available from on-station research could be gained by the application of statistical tools out of the data-set of a common farm and household survey. The data that were representing a "non-ceteris paribus" situation have been used to set up a model that allows to simulate scenarios with the variation of one variable (here: rain) keeping the others stable, "ceteris paribus". This will help to better assess risk in subsistence-oriented systems where intercropping is frequent if not dominant.

(2) The information gained can be used for several purposes in a participatory research and development process: The attitude towards risk can be assessed in various procedures: First, within an experimental, participatory framework, where farmers value the risk that is related with existing and innovative technological options. The hereby gained information on farmers' attitude towards risk can again be fed into quantitative models with the purpose of impact assessment, like the above mentioned Markovitz-Portfolio-Models. The second option of using the information is to evaluate farmers' attitude towards risk by feeding the variance-covariance-matrix into an above mentioned Portfolio-Model and confronting it the farmer's observed production program. The Portfolio-Model is now adjusted to the observed program by setting the risk aversion parameter by which the variance-covariance-matrix is weighted against the gross margins of activities so that the results of the Portfolio-Model correspond to the observed ones. With this model, innovations can be assessed with respect to farmer's attitude towards risk. A better differentiation of risk in intercropping systems will again help to evaluate the significance of risk-borne constraints versus agronomic or institutional constraints. This is especially important for subsistence systems that are forced to change like in the Sahel.

(3) It has to be pointed out that the model presented above is a meta-model between agronomic and management subjects, as described in the interpretation of the estimation results. It should not be interpreted without knowledge of agronomic and management facts on-site. It certainly has to be extended and differentiated for agronomic purposes, as some coefficients are only valid within the observed range, so that drastic changes in assumed input amounts of e.g. seed and fertilizer would probably yield an unrealistic output of the model.

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