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Risk analysis of new maize technology in Zaire: a portfolio approach

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ABSTRACT

Risk associated with the adoption of new maize technology and the impact of mandatory cotton production on traditional farmers in the Kasai Oriental Region of Zaire are evaluated within a portfolio context using a quadratic programming model. Seasonal net returns for farm plans including four levels of maize technology in combination with staple food crops are evaluated, with and without mandatory cotton production. The results indicate that cropping systems that include new maize technology are risk-efficient relative to local maize varieties while mandatory cotton production is not risk-efficient at the prevalent price and yield levels in the farming system.

INTRODUCTION

In the 1980s much of the debate on agricultural development in sub-Saharan Africa has focused on structural adjustment policies and the need to stabilize and reverse the declining trends in major macroeconomic equilibria, including balance of payments, debt burden, deficits, and foreign exchange revenues. Tshibaka (1990, p. 8) has criticized these policies for their lack of attention to the problems of achieving long-term agricultural productivity growth.

In African countries, price ceilings and other policies often are imposed by marketing boards or governments both to keep prices low and to control supplies of basic food and export crops. As a result, cross-commodity inverse acreage responses may occur in reaction to those regulated commodities. Mandatory production policies may lower producers' returns and

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increase their risk, thereby bringing about a risk reducing response. Thus, it is important to analyze the risk associated with the adoption of currently available technology and evaluate the impact of agricultural policy constraints upon the adoption process within the context of sub-Saharan Africa.

This study focuses on the adoption of new maize technology, as promoted by the Projet du Maïs au Kasai Oriental (PMKO), in the Kasai Oriental Region of South-Central Zaire, and the impact of agricultural policy constraints on traditional farmers. The objectives include (1) a review of the cropping systems and agricultural policies in the Kasai Oriental Region of Zaire, (2) analysis of risks and returns resulting from the introduction of new maize technology into the cropping system, and (3) evaluation of the impact of agricultural policies upon net farm income, risk-efficient crop plans, and their interaction in the adoption of new maize technology.

FARMING SYSTEMS IN KASAI ORIENTAL REGION

Peasant farmers in the study area, which covers 26 300 km^2, plant in either forest or savannah environments. Heavy subtropical rains, averaging between 1200 mm and 1600 mm annually, begin in late August and last until late January, followed by a short dry season of 10–15 days. A second, light rainy season lasts from February to early May, followed by a longer dry season (Dép. Agric., 1986, pp. 9–11). Consequently, there are two seasonal maize crops; one is grown in Season A from August to January, another in Season B from February to May.

Shifting cultivation is commonly practiced in the study area. Successive plantings of one or more crops take place until unacceptably low yields are reached, usually after six years, then the site is abandoned to fallow. Staple crops include maize, cassava, beans, groundnuts and cotton. Common rotational sequences include maize–maize, maize–cassava and cotton–maize–cotton. Cotton generally comes at the beginning of the crop rotational sequence (Dép. Agric., 1986, pp. 151–157). Through the mid-1980s, this sequence was partially dictated by la Cotonniere, a cotton ginning company, supervising the production of cotton under a government mandate. Government regulations, applicable to Kasai Oriental, mandated that farmers plant a minimum acreage of cotton (0.5 ha) each farming season. Penalties and fines were imposed for non-compliance (Dép. Agric., 1977). Generally, unstable yields, high cash outlay and intertemporally declining profitability characterize cotton production.

The political economy of food and fiber policy in Zaire is a legacy of both the colonial period and economic development policies implemented since independence. During the colonial period, production and marketing were tightly controlled by companies who provided farm inputs, organized marketing campaigns to aggregate commodities at harvest time and paid producers fixed prices. Elements of the colonial policies were carried over by the new government and combined with import–export taxation and exchange rate controls. Agriculture's role has been to provide cheap food supplies and to earn foreign exchange for Zaire's economic development program (Tshibaka, 1986, p. 15).

Since 1961 Zairian policy has been a classic example of the double development squeeze on agriculture (Owen, 1966, p. 44). The farm production squeeze consisted of controlled marketing outlets through official or licensed buyers while the expenditure squeeze has been maintained through fixed prices, set at both the national and regional level, combined with exchange rate controls. The government's rationale for controlling farm prices has been to "...protect both farmers and consumers against unscrupulous middlemen" (Tshibaka, 1986, p. 17). As a result of these policies, food production has lagged behind domestic needs while export earnings have declined.

In the early 1970s, three important projects were started for the purpose of conducting agricultural research on maize, the staple food in the Kasai-Oriental Region. These projects were: National Institute for Agronomic Study and Research (INERA), National Maize Program (PNM), and the FAO's National Fertilizer Program. Later, in 1980, another project – the Maize Program for Kasai-Oriental (PMKO) – was implemented in the rural areas to assure expanded use of fertilizer and high yielding varieties of maize. The project also encouraged INERA and PNM to continue research on alternative rotations of maize, leguminous crops, cassava and cotton.

In 1980 PMKO began to promote the extensive use of a package of inputs consisting of both fertilizer and high-yielding, open-pollinated varieties (HYVs) of maize in the rural areas of Kasai Oriental. Both local and new high-yielding varieties of maize were planted in subregions of Kasai Oriental. These improved maize varieties, 'SALONGO II' and 'KASAI I', were originally developed by CIMMYT in Mexico and shipped to Zaire for on-farm testing. The selection criteria in Zaire included an acceptable flowering period, disease resistance, and yield stability (Programme National Maïs, 1980, pp. 1–9). In general, local maize is considered as a crop of low but stable yield in Season A, but with lower and more variable yield in Season B.

In project areas, farmers were administratively compelled to sell their output at official prices, then in the parallel market only if the project lacked funds to purchase commodities from participating producers. The benefits of these development projects and the level of farmer participation were quite sensitive to output pricing. In the early 1980s, farm-gate prices, at the official rate, for maize and rice were less than one-half the parallel market rate (ne Nskau, 1981, pp. 52–57; Tshibaka, 1986, p. 18).

In 1983 another drastic structural adjustment program was enacted to deal with Zaire's balance of payments deficit. It instituted an immediate devaluation of the currency, a transition period leading to floating exchange rates, and reforms in customs duties. It also decontrolled most prices, including agricultural producer prices except prices of seed cotton, whose producers continue to bear the impact of in-kind taxation, price controls, and mandated resource allocation (Tshibaka, 1986, p. 21).

ANALYSIS OF MAIZE TECHNOLOGY ADOPTION AND COTTON POLICY

Risk efficient farm plans for traditional farmers were derived within a mean-variance portfolio context (Markowitz) in order to assess the impact of new maize technology and the effect of the mandated cotton production policy on farmers' risk and returns and the desirability of their adopting the new technology. The mean-variance approach is a well-known technique for approximating efficient sets in the context of expected utility maximization. Recent work by Meyer shows that conditions are not very restrictive for the mean-variance rule in efficiently ordering risky prospects, and work by Reid and Tew, and Hanson and Ladd show a high degree of consistency between mean-variance and maximum expected utility portfolios. The model specification and data are discussed in the following section.

Data base

Time-series yield data, taken from PMKO's annual reports, were available by technology type, local and improved maize, and by fertilizer treatment for ten growing seasons, A and B, between 1981 and 1985. Also, field surveys were conducted in eight zones of the Kasai Oriental Region in July 1986; 140 randomly selected farmers were interviewed. Data reported by farmers in the survey for Season B comprised the eleventh season in the analysis and they were consistent with those in PMKO's reports for previous years. [1]

Farmer participation in the National Maize Program for Kasai Oriental ranged from a low of 40% in Kamiji to 70% in Gandajika (Lukusa, 1988, p.

[1] For a complete description of the data, see Tshidinda M. Lukusa, M.S. thesis, University of Georgia, Athens (1988).

TABLE 1

Maize and other food crops yields (kg/ha) in the Kasai-Oriental region of Zaire, 1981–86

Crop	Season A			Season B		
	Mean	Standard deviation	Coefficient of variation (%)	Mean	Standard deviation	Coefficient of variation (%)
Local Maize	970	30.82	3.18	866	37.84	4.36
Local Maize plus Fertilizer	1432	229.71	16.04	1140	136.40	11.96
New Maize	1158	86.71	7.49	947	56.04	5.91
New Maize plus Fertilizer	2252	256.65	11.40	1866	402.95	21.59
Cassava	8746	725.62	8.30	9257	759.64	8.21
Beans	588	59.32	10.09	500	42.89	8.58
Groundnuts	754	60.66	8.05	663	35.59	5.37
Cotton	359	73.52	18.60	362	74.66	20.60

There were only 5 years of data for Season A, 1981–85, while data were available for 6 years for Season B. Season A generally refers to the primary rainy season from September to January while Season B refers to the secondary rainy season from February to May. The heaviest rainfall occurs in November and December (Lukusa, 1988, p. 35).
Sources: National Maize Program (Annual Reports) and Lukusa (1988, p. 35).

37). In 1986, 58% of the farmers reported that they were growing HYVs of maize while 42% were growing local varieties of maize. On the average, 72% of the farmers were using fertilizer; only 14% of the farmers were able to purchase fertilizer with cash, while the remainder received it as an in-kind loan from PMKO.

The National Maize Program recommended split fertilizer applications of 1/3 at planting time and 2/3 as side dressing 40–45 days after planting at the actual nutrient rate of 180 kg/ha N and 120 kg/ha P_20_5 (Programme National Maïs, 1980, p. 24). The introduction of new maize alone increased yields 19% in Season A when compared to local maize without fertilizer (Table 1), but yield variability also increased from 3.2% to 7.5%. As expected, new maize with fertilizer exhibited greater yields (94%) than new maize without fertilizer, but also greater relative yield variability (11%).

The critical importance of yield variability is its impact on farm income and food supplies. Traditional, small-scale farmers follow a variety of cultural practices such as intercropping, spatial diversification, and sequential planting dates to reduce income risks and increase food security (Adesina and Sanders, 1990). Risk reducing practices may be jeopardized if government policies impose crops or cultivation practices upon farmers that force reallocation of scare family labor, land or other inputs, upon the farming system. These policies create conditions for greater yield variability in basic food crops under the misguided assumption that other crops or practices may have higher value to society. Mandated cotton cultivation in the Kasai-Oriental Region is a prime example of one of these detrimental policies.

RISK AND EXPECTED RETURNS IN THE KASAI ORIENTAL REGION OF ZAIRE

The impacts of technological and cropping pattern risks on net income were evaluated by comparing real net returns from observed cropping systems, comprising local or improved varieties of maize, with or without fertilizer, in some combination with cassava, beans, groundnuts or cotton. A quadratic programming model was specified to analyze various farm plans in order to evaluate the risk efficiency of new maize technology and the impact of cotton production on traditional farmers. In the study area, cotton was produced in four of the eight zones which allowed for comparisons of farm plans in a homogeneous area with and without the mandated cotton cultivation system. Net returns per crop and cropping system were calculated from data published in PMKO's annual reports and collected during the farm survey.

Model specification

The mean-variance efficient farm plan portfolios were derived using quadratic programming models. The general model specification is:

$$\max \text{EV} = \text{NR} \cdot X - \tfrac{1}{2}\lambda X' \,\Sigma\, X \tag{1}$$

$$\text{s.t.} \qquad X \geq 0 \tag{2}$$

$$\text{C}\,X \geq D \tag{3}$$

where EV is expected value; NR the vector of net returns per crop per hectare; X the vector of crop activity levels; Σ variance–covariance matrix; λ absolute risk aversion coefficient; C is the constraint matrix and D is a vector of resource availabilities and requirements (see INEAC, 1958). For a discussion of the applicability of the EV model as an analytical tool, see Robison and Barry (1987, pp. 72–75) and Meyer (1987, pp. 421–422).

Constraints consisted of labor availability and minimum food requirements for the typical family in the Kasai Oriental Region of Zaire. The labor availability constraint was assumed to be 300 man-days per 6-month season, where the composition of family labor was adjusted for age and gender roles. A second set of constraints specified a minimum amount of food required by a typical farm family, adjusted for regional food preferences, consisting of 994 kg of maize, 173 kg of cassava, and 80 kg of beans and groundnuts in each season as determined by nutritional studies in Zaire (Dép. Agric., 1982, p. 307). The quadratic programming model was solved by using the General Algebraic Modeling System (GAMS/MINOS) non-linear maximization option (Brooke et al., 1988).

EMPIRICAL RESULTS AND IMPLICATIONS

The impacts of the introduction of improved maize varieties on the risk-efficient Kasai Oriental farm production plans were analyzed for both the primary and secondary rainy seasons at various levels of risk aversion. First, analyses including all crops and maize technologies were performed with and without a mandatory cotton production policy. The mandated cotton requirement was set at 0.30 ha, which was the average area devoted to fiber production by farmers in the survey area, but less than officially desired area of 0.50 ha. Then, similar analyses were performed assuming that the improved maize technologies were unavailable.

All maize technologies

When all maize technologies are considered in the analysis, new maize technologies are preferred over the local technologies for every risk aversion level in both Season A and Season B, with or without cotton production restrictions (Table 2). For the risk-neutral solution in Season A, all maize production is new maize with fertilizer. As risk aversion levels increase, the production mix changes by decreasing the level of new maize with fertilizer, increasing new maize without fertilizer, decreasing cassava, and increasing beans. This pattern of change occurs regardless of the cotton policy. The interesting aspect of this pattern is that the 'technology package of new seed and fertilizer' may not be an appropriate recommendation for the more risk-averse farmer because it may be perceived as too risky, ceteris paribus.

In Season B, the level of new maize with fertilizer is higher in the production mix than in Season A and remains constant for every level of risk aversion, with or without mandated cotton production. These results reflect the importance of fertilizer in stabilizing net returns in this type of agronomic environment. Responses to risk in the production mix occurs in cassava and beans.

Local maize technologies

When maize is limited to local maize only, the crop mix looks similar to the one found with the new maize technology, except local maize replaced

TABLE 2

Summary of optimal solutions for selected levels of risk aversion, improved maize varieties, with and without mandated cotton cultivation, Kasai Oriental region, Zaire, 1981–86

Risk aversion constant, α *	With policy constraint			Without policy constraint		
	I	II	III	I	II	III
	0	3	5	0	3	5
OPTIMAL PLANTING AREA						
Season A	hectares					
HYV Maize	0.0	0.149	0.325	0.0	0.110	0.355
HYV + Fertilizer	0.544	0.458	0.357	0.544	0.481	0.340
Cassava	1.425	1.023	0.815	1.894	1.431	1.141
Groundnuts	0.142	0.142	0.142	0.142	0.142	0.142
Beans	0.110	0.233	0.253	0.110	0.279	0.307
Cotton	0.300	0.300	0.300	0.0	0.0	0.0
Season B						
HYV Maize	0.0	0.0	0.0	0.0	0.0	0.0
HYV + Fertilizer	0.631	0.631	0.631	0.631	0.631	0.631
Cassava	1.118	0.462	0.281	1.588	0.788	0.653
Groundnuts	0.167	0.167	0.167	0.167	0.167	0.167
Beans	0.122	0.430	0.516	0.122	0.498	0.561
Cotton	0.300	0.300	0.300	0.0	0.0	0.0
EXPECTED NET FARM RETURNS						
Season A						
Mean of total net return (Zaires)	787.374	700.027	655.246	914.450	822.873	739.657
SD of total net return (Zaires)	44.676	37.156	34.277	44.647	34.824	28.60
Season B						
Mean of total net return (Zaires)	428.122	358.535	339.250	510.108	425.321	410.959
SD of total net return (Zaires)	33.967	21.677	19.540	34.383	18.003	16.219

* The absolute risk aversion coefficients (λ) were converted to relative risk aversion (α) by dividing the absolute risk coefficient by the maximum average expected return.

the HYV variety (Table 3). As before, *given risk neutrality*, maize with fertilizer prevails in Seasons A or B, with or without mandated cotton production. As risk aversion increases, more maize without fertilizer is produced while maize with fertilizer decreases. As farmers become risk-averse, local maize without fertilizer prevails in Season B. Also, as expected, the mandated cotton production has the same type of effect on local maize producers as in the situation with new maize production, decreased returns and increased variance of returns.

TABLE 3

Summary of optimal solutions for selected levels of risk aversion, local maize technologies only, with and without mandated cotton cultivation, Kasai Oriental region, Zaire, 1981–86

Risk aversion constant, α	With policy constraint			Without policy constraint		
	I	II	III	I	II	III
	0	3	5	0	3	5
OPTIMAL PLANTING AREA						
Season A	hectares					
L Maize	0.0	0.778	0.922	0.0	0.810	0.948
L Maize + Fertilizer	0.799	0.226	0.120	0.799	0.220	0.100
Cassava	0.785	0.277	0.020	1.254	0.567	0.315
Groundnuts	0.142	0.142	0.142	0.142	0.142	0.142
Beans	0.110	0.153	0.238	0.110	0.229	0.313
Cotton	0.300	0.300	0.300	0.0	0.0	0.0
Season B						
L Maize	0.0	0.717 [a]	0.717	0.0	0.647	0.864
L Maize + Fertilizer	0.962	0.388	0.388	0.962	0.444	0.270
Cassava	0.287	0.020	0.020	0.756	0.515	0.434
Groundnuts	0.167	0.167	0.167	0.167	0.167	0.167
Beans	0.122	0.122	0.122	0.122	0.122	0.122
Cotton	0.300	0.300	0.300	0.0	0.0	0.0
EXPECTED NET FARM RETURNS						
Season A						
Mean of total net return (Zaires)	563.749	433.387	382.766	690.853	529.307	479.888
SD of total net return (Zaires)	62.048	46.181	43.454	57.008	37.490	34.226
Season B						
Mean of total net return (Zaires)	244.288	202.150 [a]	202.150	326.275	288.231	275.495
SD of total net return (Zaires)	52.379	47.814	47.814	46.081	41.109	40.342

[a] Enterprise adjustment occurred between the first and second stages of risk aversion. At progressively higher levels of risk aversion $\alpha > 3$, there were no subsequent enterprise adjustments.

What is not readily apparent from the crop portfolios is the impact on the levels of return and risk resulting from the lack of new maize technology. Comparing returns and standard deviation of returns between different maize technologies in the same seasons clearly indicates that returns for production mixes with the new maize variety are much higher and standard deviations are much lower than enterprise combinations when maize is limited to the local variety (Tables 2 and 3). The disparity in these two technology situations are vividly demonstrated in the gap between the net returns for both Seasons A and B, with and without the mandated cotton production.

Impact of cotton policies

The mandated cotton production reduced expected farm income and increased standard deviations at all levels of risk aversion. [2] At risk neutrality the amount of maize production was the same with and without the mandated cotton production; the biggest difference occurred in cassava production. However, as risk aversion increased, more maize without fertilizer is grown with the cotton production mandate. This reflects the risk management response from imposing a risk-increasing policy upon small farmers and it is also an example of how the rate of technology adoption can suffer because of cross-commodity effects.

Sacrifices in expected net farm income due to the mandated cotton cultivation were 13.8% for risk-neutral ($\alpha = 0$) farmers using the new maize technology in Season A and 16.1% in Season B (Table 2). The sacrifice in expected net income was 18.4% in Season A and 25.1% in Season B (Table 3) if farmers were limited to local maize technology. Comparable sacrifices in expected net income would be expected among more risk-averse producers. Thus, the non-inclusion of cotton in the enterprise mix without the policy constraint is attributable to both low expected returns and high variability of returns; a finding which is consistent with other studies of risk aversion in African agriculture (Elamin and Rogers, 1992, p. 165). The mandated policy constraint taxed farmers in the Kasai Oriental Region both in terms of foregone income and misallocation of resources.

CONCLUSIONS AND IMPLICATIONS

The results illustrate that the optimal crop combinations are sensitive to variations in farmers risk preferences. Risk aversion can influence the relative advantages of improved maize varieties versus local maize in combination with other food crops. Farmers willing to follow a risky strategy would plant improved maize in combination with other crops. As risk aversion increased, maize both with and without fertilizer would be

[2] Fourteen different levels of relative risk aversion were specified in the model. Generally, the crop portfolio adjustment occurred between the first and second stages of risk aversion. At progressively higher levels of risk aversion, there were only minor adjustments in the crop portfolio. Only three enterprise portfolios are presented here. While expected net returns for higher levels of relative risk aversion were calculated, there were few changes in the enterprise mix.

planted. These results are consistent with Nanseki and Morooka's study of risk preferences and optimal crop combinations in upland Java. They concluded that as risk aversion increases, the optimal cropping system shifts from monocropping to an intercropping system which was close to the actual cropping system in the study area (1991, pp. 52–54).

The policy implications of this analysis are quite clear. As Wolgin (1975) concluded "... risk aversion plays a very important role in farmer behavior; farmers are willing to grow high-risk crops only if they get a higher payoff in expected return" (p. 629). The converse is also true. A policy of mandatory cotton production not only lowers the level of profitability but also increases the variability of returns for a given level of expected returns. Farmers have been obliged to bear the cost of the higher risk and lower returns of the mandated cotton production policy, a policy that has never resulted in self-sufficient national fiber output.

Zaire and other African countries must continue to analyze policy constraints to agricultural growth and evaluate new on-farm technology. If farmers have access to and adopt improved technology, there may be an upward shift in aggregate agricultural production, thereby increasing per capita food supply. However, to stimulate the adoption process, the 'technology package' needs to be evaluated from a risk efficiency perspective. Inadequate technology and policy appraisal may create disincentives or adverse situations that deter farmers from operating efficiently and achieving sustainable agricultural development.

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