

Impacts of New Agricultural Technologies on Rural Malian Households

written by:

Jeffrey D. Vitale¹

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John H. Sanders²

¹ Ph.D. Candidate and Research Assistant at Purdue University.

² Professor of Agricultural Economics at Purdue University.

Contacts: vitale@agecon.purdue.edu

ph. (765) 494-4305

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Abstract

A need in Sahelian agriculture is to transform from traditional farming to more modern systems. This paper presents a safety-first type of risk programming model, using complementary programming, to assess the impacts of new agricultural technology. Model results indicate that some new technologies are economically attractive to Malian households.

Introduction

Raising agricultural output remains an important challenge for agricultural policy makers in the Sahel (Sanders et al., 1996). As land supply dwindles, the focus of agricultural policy has shifted from land extensification to transforming farming from traditional, low input technologies to modern systems based on improved cultivars and increased fertilization (Day, 1990). Rural households are at the center of this agricultural transformation. Sound agricultural policies are needed to facilitate and encourage households in moving to the new farming methods.

Supporters of the transformation to more intensive farming argue their position on two points. The first is that there already exists a suite of new agricultural technologies that have demonstrated their ability to improve performance over existing technologies (Ohm and Nagy, 1985; Pieri, 1985; Adesina, 1988). The technologies are backed by an in-country agricultural research system that is equipped, through its extension activities, to adapt the technologies to local growing conditions. The second point is that structural adjustment has removed many of the policies that had previously discriminated against domestic cereal production, providing an environment more conducive to new technology adoption (Coulibaly et al., 1998). The economic environment should continue to grow more lucrative for domestic agriculture as the Malian economy is expected to expand in the post-structural adjustment era.

Experience in smallholder farming suggests that raising yields is not sufficient for households to adopt new technologies. Despite the call for cautious optimism, farmers will still encounter impediments on their path to more intensive farming. The risk associated with the use of new technologies has been shown to explain why many farmers are hesitant to adopt (Binswanger, 1980). In Mali, the effects of production risk are aggravated by the relatively weak structure of the cereal economy. In the below-normal years of rainfall, production in many areas is insufficient to meet household subsistence. The limited availability of intra-year storage results in substantial price increases, prompting households to hold onto a subsistence-oriented viewpoint of farming. In the good years, benefits from yield increases

are attenuated by the collapse in cereal prices. The collapse is due to the rather inelastic demand for the cereals, which is too weak to maintain strong cereal prices when surplus grain enters the market place.

Another concern is improving access to the inputs required by the new technologies. The seed industry in Mali is still in its infancy, and many farmers have stated the difficulties with obtaining new seeds on an annual basis. In their absence, new varieties get cross-pollinated with local varieties and their yield effect vanishes after one or two seasons (Kergna, 1998). There is no formalized extension or credit scheme to assist farmers in purchasing inputs such as fertilizers and pesticides. In their place, households must generate their own source of liquidity to purchase fertilizers from private sources. Agricultural investments compete within the larger umbrella of household activities for financial resources, making the need for increased profitability in domestic cereal production all the more critical (Coulibaly, 1995).

It follows, then, that an important input to agricultural policy is to determine adoption potential of the new technologies from the economic perspective of the rural household. A variety of farm programming models have been used in the literature to assess the economic viability of new technologies. As mentioned above, studies have concluded that production risk is an important factor influencing technology adoption. Among the risk programming techniques, safety-first methods most directly address the risk confronting Sahelian farmers: the hardships that must be endured when production outcomes are poor. Households are aware that if not properly planned for, their welfare may be severely jeopardized.

The purpose of this paper is to investigate the potential for the adoption of new agricultural technologies in southern Mali. A whole-farm risk model, using a modified safety-first approach, is used to determine the economic impacts and the adoption potential of the new technologies. In addition to finding the economic benefits of the new technologies, constraints that hinder adoption are identified. The risk model will be run under two policy scenarios. The first is the expected strengthening of cereal demand in the post structural adjustment era. This should minimize the effect of the price collapse in the good years. The second scenario considers improvements to the rural cereal market infrastructure. An

improved rural infrastructure should lessen the concerns for food security and allow households to be more aggressive in their adoption of new technologies.

The paper begins with a conceptual discussion of the rural household decision making process. The approach presented in this paper is compared to E-V types of models. The empirical model is then laid out in mathematical terms and discussed. The model is calibrated to observed farming patterns, and results of the policy scenarios are presented and discussed. The paper finishes with a brief conclusion.

Conceptual Discussion

As mentioned above, safety-first methods most directly address the risk confronting Sahelian farmers: the hardships that must be endured when production outcomes are poor. This leads households to place the largest emphasis on achieving the most important household needs when production outcomes are below normal. Our field research indicates that the two most important needs are: (1) generating sufficient agricultural income for recurrent and unexpected expenses; and (2) producing adequate quantities of food crops for annual home consumption. Following the structure of safety-first approaches, households move to the objective of maximizing expected profits only when these two needs have been satisfactorily achieved.

Safety-first methods define disaster levels of income, and then choose decision alternatives to minimize the probability that income may actually fall below the disaster level (Roy 1952). The rural household definition of risk, and the farm programming model presented in this paper, is a modification of the safety-first risk approach. One modification is already apparent, the addition of a second dimension of risk. This added dimension maintains household food security above a level deemed critical by the household. A second modification is that the income and food security are forced, via constraints, to always be held above their disaster levels.

For the purposes of this paper, food security is a strategy that provides for household food subsistence needs, using an acceptable combination of on-farm cereal production and grains purchased in external markets. The use of outside cereal markets is considered, to some extent, to be risky. The

prospect of having to purchase grains in outside markets discounts the level of food security associated with a particular strategy. Financial security can be defined in a similar manner: agricultural income must be maintained above some critical level to assure financial solvency of the household. The weak financial infrastructure in rural areas provides little in the way of safety-nets, leaving households vulnerable to financial crises.

The disaster (or critical) level of household food security is defined as follows. Rural households will place the highest priority on consuming, at the very least, a subsistence level of cereal. This preference corresponds to an inelastic (vertical) demand curve rising at Q_{sub} . Here, it is assumed that perfect substitutability exists among the cereal crops. This permits the subsistence quantity to be achieved with any cereal combination (Figure 1). In addition to the total household demand for cereals, there is a second variable of interest: the amount of cereal that is produced on the farm. When the food target is combined with the cereal supply curve the internal cereal price, P^* , is obtained. This is the cereal price realized by households in meeting food security entirely with their own production, and is given by the shadow value of the subsistence target.

The amount of cereals that are produced on-farm depends upon the amount of subjective risk associated with cereal market participation. Often it is the case that household production will fall short of the target. Gaps between the cereal demand curve and household production can be made up with market purchases and gifts-in-kind. Food security strategies that rely on external markets for household subsistence are associated with some amount of risk. Grain produced on the farm is a certain outcome, whereas market participation involves taking on additional uncertainty. This comes in the form of price variability, and the need for generating cash (which has a high opportunity cost, particularly in the poor years of production). The cost of meeting food security internally is equivalent to being risk averse to market participation. The cost of this aspect of risk grows as the gap widens between P^* and market price.

Households that are very risk averse to market participation will choose to produce all the way to Q_{sub} . In this single commodity case, this will entail a surplus loss of A. This can be viewed as the risk premium associated with food production autonomy. Households with a large degree of confidence in

cereal markets (and less risk averse to market participation) will choose to stop production at Q_1 , and will purchase the difference in the cereal markets. They will incur no surplus loss. Between these two extremes are a wide variety of food security strategies, dependent to varying degrees upon cereal market purchases.

The household decision structure implies that production and consumption are jointly determined. The risk of market participation creates a split between cereal market prices and the price realized by the household. The household price can only be determined using the shadow value from the food consumption target. This means that the combination of cereal production and market purchases that comprises the food security strategy cannot be determined through independent production and consumption decision processes.

The income target is the second dimension to the safety-first risk program. Households are able to determine how much income they demand based upon total household needs (education, health, consumption). This demand is met by household's income that comes from several sources in addition to agricultural production, and from liquid assets. This is a complicated decision that requires an extensive amount of attention. The focus in this paper is on the food demand targets. For the purposes here it is sufficient to use an income target judged as reasonable given field observations.

The use of a two dimensional safety-first model necessitates the need for households to set their relative preference between setting income goals and subsistence goals. The two compete since the subsistence goal trades-off higher production costs to increase food security (avoiding market participation). This will decrease expected income, and will aggravate the chances of falling below disaster income levels.

The use of fixed food and income targets has limitations. Safety-first approaches are open to criticism for the inherent rigidity in the targets, and for the fact that the targets are "just constraints" and not economic variables. Fixed targets by their very nature lack elasticity, and are incapable of responding to the changes from new technologies and other stimuli in the production environment. Overly ambitious target values will have large opportunity costs, or shadow values, associated with them. Households may

be willing to adjust target values downward once they perceive that the cost of meeting the target is too high.

The food target shown above is rigid in the sense that the consumption level will remain at Q_{sub} irrespective of the shadow value's magnitude (Figure 1). This is a Hicksian demand, since utility is fixed at Q_{sub} . With rising shadow values, the expenditure required to maintain utility at Q_{sub} will increase. At some point, households will consider the expenditure to be too large and will choose to move to a lower level of utility. The opposite is true when the cost of a target falls. For instance, in good production years falling may persuade households to be more ambitious in their target selection. They would then increase the food consumption and agricultural income targets in step with the decline in the costs of the targets.

Households desire to trade-off between utility and expenditures, but neither the Hicksian, or Marshallian demand functions can adequately represent the adjustments to the food target. In the expenditure-utility plane, the Hicksian demand curve is a vertical line and the Marshallian demand is horizontal (Figure 2). The Hicksian demand maintains constant utility, but allows expenditures to range freely. For large expenditures, households would most likely reduce demand, taking a cut in utility. The Marshallian demand has the opposite problem. Food expenditures are held constant, but utility ranges freely. In this case, utility could fall far below the subsistence region, and households would be willing to expend additional amounts to raise utility. To allow for more realistic preferences, the food target needs to be a hybrid-mixture of the Marshallian and Hicksian demand structures. It needs to maintain utility near the subsistence level as in the Hicksian approach, but it must also keep total expenditures in check as in the Marshallian approach.

The use of complementary programming (CP) permits setting the food and income targets in a more realistic manner than with conventional programming methods. Complementary programming is a methodology that endogenizes the target values, transforming them from exogenous parameters into demand functions for the consumption and revenue targets. This is made possible by an important feature of CP: the ability to use dual (shadow) variables in the objective and resource constraint equations. Thus, each target is defined as a demand variable, with its value changing depending upon its opportunity cost.

As costs rise, target values are reduced in magnitude, a much truer reflection of the manner in which households set target values. The resulting curve has more realistic properties than either the Marshallian or Hicksian curves, since it allows utility to change with expenditures in a more flexible manner than either a vertical or horizontal line.

Comparison to the E-V Methods

The safety-first approach to risk is more consistent with rural household decision making than the E-V genre of risk models. The particular form of the E-V method renders it inconsistent with the preferences of rural households in one important way. This inconsistency is the manner in which household food security issues are treated. Variance is translated into an additional cost of production, driving a wedge between marginal costs and marginal revenue. The net effect is a decrease in cereal production, and a shift towards lower cost technologies. If the risk neutral case provides only a marginal degree of food self-reliance, the effect of risk aversion is to decrease food production, moving the household further away from its subsistence needs. It is unlikely that households would retreat from subsistence production, since a retreat would increase their dependence on purchased.

An additional point often made is that E-V methods penalize deviations from expected income in a counter-intuitive manner. Equal deviations above and below the mean are weighted identically in calculating income variance. However, incomes that fall above the mean are obviously considered more beneficial to households and possess less of a concern than incomes below the mean. In short, the fundamental definition of risk used in the expected utility framework does not correspond well to the definition used by rural households. For these reasons, the modified safety-first risk programming model presented above is used to determine the adoption potential of the new agricultural technologies.

Empirical Model

The modified safety-first risk programming model has the following form:

$$\text{Max. } \sum_i \sum_k \phi_k (M_{ik} P_{ik} (1 - \epsilon_{s,i}) - B_{ik} P_{ik} (1 + \epsilon_{b,i})) - \sum_i \sum_j X_{ij} C_{ij}$$

subject to

$$\sum_i \sum_k Y_{i,j,k} X_{ij} \geq HCS_{i,k} + M_{i,k}$$

$$HCS_{i,k} + B_{i,k} \geq HCD_{i,k}$$

$$U_F = f(HCD_{i,k}) \geq U_0(\lambda_F)$$

$$[A_{lij} X_{ij}]_{lm} \leq b_l$$

where

X_{ij} = quantity planted of crop i using technology j

$Y_{i,j,k}$ = yield of crop i using technology j in state k

C_{ij} = unit cost of X_{ij}

M_{ik} = quantity sold in market

B_{ik} = quantity bought in market

$HCS_{i,k}$ = quantity of home production in state k earmarked to home consumption

$HCD_{i,k}$ = quantity demanded for home consumption

P_{ik} = price of crop i in state k

$\epsilon_{s,i}$ = transaction cost in selling crop i

$\epsilon_{b,i}$ = transaction cost in buying crop i

U_F = utility of the F^{th} food group (cereal and legume)

U_0 = demand for utility of the F^{th} food group (cereal and legume)

λ_F = shadow value of the food consumption utility function constraint

A_{lij} = resource demand of X_{ij} for the l^{th} resource.

The objective function maximizes expected profits over the discrete states-of-nature. The first constraint is a production accounting identity that limits the amount supplied for internal consumption and sold in markets to be less than or equal to the quantity produced on the farm. The second constraint is an accounting identity that balances home production and quantity purchased in the market with total home consumption. The third equation is the food consumption target for each food group in F . This equation requires the utility to be greater than or equal to a nominal value, which through the use of mixed-

complementary programming can be defined to a function of the equation's shadow value. This allows the nominal utility level to be adjusted in response to changes in the opportunity cost of the food consumption target. The last equation is a set of resource equations that limits the availability of land, labor and capital. The program is placed into the mixed-complementary form through first taking the first-order conditions, and then defining shadow values for each equation (Paris 1979).

Data

The models were constructed to represent a typical household located around Segou. This is an important cereal producing region in Mali, accounting for about one-fourth and one-third of Mali's sorghum and millet production (RSSRM 1997). In addition to the cereals, groundnuts and cowpeas are also grown. The average annual rainfall is 600 mm, and the presence of early and late season drought is the primary limiting factor to production in this region. Poor soil fertility is becoming an increasing problem to farmers, as fallow periods have been reduced due to increased pressure on the land from high population growth (Vierich and Stoop, 1990).

The three main components of agricultural technology in this region are: (1) Improved cultivars, (2) Inorganic fertilizers, and (3) Improved water retention techniques. Breeding has focused on shortening the growing season to minimize the exposure to late season drought and to shorten the time to harvest to lessen the effects of the hungry season. Inorganic fertilizers are used to replenish depleted soils, and to increase soil nutrient levels to the heights required of the new varieties. The improved water retention techniques are used to minimize soil stress during periods of early and late season drought. Animal traction has opened the doors to improved water retention, and is widely adopted in this region. Roughly 90 percent of the households owning at least one oxen draft team (Coulibaly 1995).

Existing Technologies

The use of improved sorghum and millet cultivars in this region is limited to about 15 percent of the households. The private sorghum and millet seed industry is still in its infancy, leaving the

agricultural research stations as the main supplier of improved seeds. Low to moderate levels of inorganic fertilizers (cereal compound and urea) are used along with the improved varieties. The remaining households use local sorghum and millet varieties with only small quantities of inorganic fertilizers. As for water retention, both the improved and local varieties are cultivated with ridging, a moderately intensive soil preparation technique that reduces soil moisture stress in the key early stages of seed germination.

Improved, early maturing varieties for groundnuts and cowpeas are used at about the same rate as the improved cereal varieties, 15 percent. The legumes have a shorter growing cycle than the cereals, and are used by households to meet shortfalls in household food requirements during the hungry season prior to cereal harvest. The new varieties are combined with moderate levels of cereal compound. Traditional groundnut and cowpea varieties are grown with only small amounts of cereal compound. As with the cereals, ridging is used on both the local and traditional varieties.

New technologies

The new technologies are characterized by the exclusive use of improved cultivars, a marked increase in the use of inorganic fertilizers, and an improved water retention technique. The recommended dose of inorganic fertilizers is 100 kg/ha for complex cereal compound, and 50 kg/ha for urea. Tied ridges (a.k.a. furrow dikes) is a soil preparation technique that increases water retention through the use of a large number of small dikes laid perpendicular to adjacent rows. This has proven to result in large yield gains, but its adoption has been limited to about 5 percent. This technique requires a special piece of equipment, and demands a considerable amount of labor.

Yield and Price Data

With the strong dependence of yields and prices upon rainfall, it was necessary to categorize the yields and prices into discrete states-of-nature. Yield, price, and rainfall data from 1986 through 1992 were used to develop a set of three states-of-nature (IER). The yield gains using the new technologies can

be dramatic (Table 1). Tied ridging provides nearly a three-fold increase in yields over traditional technologies.

Household Data

There are 14 persons in the representative household (4 men, 4 women, and 6 children), and labor is supplied entirely by the household. Additional family members enter the labor force during critical periods (planting and harvest). The household has 16 ha of land to farm on. The food consumption utility functions were chosen to be of the Cobb-Douglas form, with exponents equal to .5 for each of the arguments. The reference utility level was determined using an annual consumption rate for men, woman, and children. The input and output price data were from the 1997 growing season. To account for transportation costs and other market transaction costs, buying prices were adjusted by 20 percent upwards, and selling prices were adjusted downwardly by the same amount.

Results

In this model, the income and food subsistence targets function as risk aversion parameters. The food consumption targets were held at fixed utility values (Hicksian demand), allowing the income targets to be varied. Larger income targets correspond to increased risk aversion (Tables 2 and 3). In addition, two different cases regarding market purchases are presented. The first case has a very strong risk aversion to market purchases in meeting food security (large values of ϵ_b), whereas in the second case market purchases are allowed.

In the calibration to existing farm practices, the model was most accurate with the legumes, choosing acreage very similar to those of the observed farm. The model had more difficulty with the cereals primarily because it did not distinguish among soil types. Millet is grown on the poorer quality lands, whereas sorghum is grown on the heavier soils with a stronger affinity towards water retention. With returns and consumption preferences nearly equal between the two crops, the model was biased towards sorghum.

Consider first the case of households that are strongly averse to market participation. Results show that expected profit in the poor production years is never positive. This is consistent with field observations that show poor performance with existing technologies in the poor years. This forces households to have to withstand large changes in welfare among the various states. Without any income target, the profit in the poor production year is -31,000 fcfa. Households that are more risk averse regarding income would choose to increase profits in the poor years. The largest possible return in the poor production years is -22,500 fcfa. In this case, the cost of income risk aversion is 2,200 fcfa (Table 1). This is the difference in expected profits between income risk neutral case and the most income risk averse case with an income target of -22,500 fcfa.

An important part of the calibration process is to compare the shadow values of the food subsistence target with the market price. It was argued in the conceptual section that households are willing to put up with production costs, P^* , that rise above market price to obtain the security and convenience of having cereal stocks on their farm. Increasing risk aversion in the income dimension, by demanding larger income returns, raises the home production costs P^* . Without any income target present in the model, the shadow value of the food consumption target is 170 fcfa. This is a bit higher than the buying price, but some will accept this level of added costs in exchange for increased security.

For households that are more risk averse with respect to income and demand a return of at least -25,000 fcfa, the cost of home cereal production rises sharply to 705 fcfa/kg. In the most risk averse case, the cereal cost rises to 1,560 fcfa/kg. Food expenditures, calculated using the shadow value, are as high as 8 million fcfa. Even though the shadow value and expenditures can be quite large, the actual cost in terms of lost expected profits is relatively small (4,000 fcfa). This is because it is possible to switch to a crop mixture that increases cereal and legume production in the poor years, with only modest revenue losses in the average and good production years.

This points out that using the target's shadow value as an indicator of food expenditures is not always a sound approach to adjusting food target values. With the model's first-order optimality conditions, it is possible to show that the food target's shadow value is able to grow much higher than

market prices. This happens since increases in the food consumption's shadow value can be balanced by the sum of the resource costs from the other constraints in the model. The preferred method, then, is to adjust the food target values using the actual change in expected profit brought on by the food target.

Now consider the case of households that are willing to use external markets. Without any income target present in the model, the shadow value of the food consumption target is 132 fcfa. This is the buying price, and there is no added cost to producing on farm. For households that are more risk averse with respect to income and demand a return of at least -40,000 fcfa, the cost of home cereal production rises sharply to 221 fcfa/kg. In the most risk averse case, the cereal cost rises to 875 fcfa/kg.

The fact that the food target's shadow value has risen above the market price merits attention. The explanation begins by pointing out that the income target's shadow value is included in the first-order condition of the buying variable. This can be seen by noting the contribution that market purchases has in reducing income. Once the income target becomes enforced, the net effect is to allow the food consumption target's shadow value to increase above the market buying price.

The move towards increased income risk aversion results in households relying less on external markets for meeting food subsistence needs. This is consistent with field observations, which show that many households are unwilling to participate in cereal markets. So, in this model, the increasing income risk aversion also increases the level of food security by reducing dependence on markets.

Flexible Food Consumption Target

If the costs of production or output prices change, the food security risk premium will be affected. In situations when it does grow too large (or too small), households may look to adjust their food consumption targets. To see the workings of the flexible targets, it is necessary to perturb the model slightly to see how the household will adjust consumption. Consider a 10 percent rise in output prices, for the case of households that do not actively participate in markets to meet food security. With the use of flexible food consumption targets, utility of cereal consumption increases from 2,612 to 2,664 when compared to the fixed target case (Table 4). The slope of flexible target curve was chosen to be nearly

flat. This moves the food target moving from a vertical, Hicksian curve to a horizontal curve closer to that of a Marshallian demand (Figure 2). As a result, expenditures remained nearly unchanged and the shadow value was higher than the fixed target case. Again, the high shadow value does not indicate a large loss in expected profit. The gain in cereal utility was at the loss of only 4,800 fcfa.

The Adoption of New Technologies

With new technologies available, under current economic conditions households, households choose to adopt tied ridges in sorghum (0.3 ha), groundnuts (0.8 ha), and cowpeas (0.7 ha; Table 5). With the new technologies, profit in the poor production years is nearly brought to the break-even point, falling short by only 284 fcfa. Expected profit rises from 78,000 fcfa to 91,000 fcfa (Tables 2 and 5). The cost of home cereal production in the poor years, P^* , falls significantly. It changes from over 700 fcfa with existing technologies, to 185 fcfa with new technologies. The model demonstrates that the new technologies have beneficial impacts on the poor years, a property that many in the development field claim are missing in the new technologies.

In the post-structural adjustment era, domestic agricultural prices are expected to rise. This scenario has a 20 percent rise in prices in prices in the poor and average years. The price collapse in the good years is assumed eliminated, leaving prices equal between the average and good years. This improved economic environment, combined with the adoption of tied ridges (sorghum, groundnuts, and cowpea), has substantial beneficial impacts. For the first time, profit in the poor production years is positive (14,000 fcfa). The higher prices increases the opportunity cost of home produced cereals, increasing P^* from 185 fcfa/kg to 215 fcfa/kg. Cereal expenditures in the poor years rises by about 15 percent.

If households are made to be less risk averse to cereal market participation with improvements to the market infrastructure, it is expected that market purchases will increase. In this scenario, market buying is allowed with a 20 percent markup on purchases to cover transaction costs. The use of tied ridges on the groundnuts and the cowpeas pushes up the profit in the poor production years to a level (–

10,000 fcfa) well beyond the income target. With the income target not enforced, the cost of home production returns (as it must) to the buying price of 132 fcfa/kg. The participation in the cereal markets allows households to reduce their resource allocation towards the cereals, and to increase the production of the higher valued legumes.

Conclusions

This paper has presented a risk programming model that incorporates two dimensions of risk: income and food security. The results of this modeling exercise revealed that the new agricultural technologies raise household farm income. More importantly, the new technologies increase household welfare in the poor production years, reducing the concerns for household food security. With the potential to reduce problems with food security, households will over time gain an entrepreneurial attitude towards agriculture. The process of intensification should then proceed at a faster pace. The use of flexible food consumption targets was shown to provide a tool to better replicate the food preferences of rural households.

It was found that the existing form of the model relies too heavily on the food subsistence shadow values in adjusting food consumption targets. The shadow values may grow very large, even though the actual decline in expected profit is small. The next generation of this model will add the ability to incorporate target adjustments using changes in expected profits.

Other refinements include adding more agricultural technologies, trying different forms of utility functions, and adding more states-of-nature to the model. An appendix of the first-order conditions will be written. This will explain the interaction among the shadow value's of income target, the food subsistence target, and the other resource constraints.

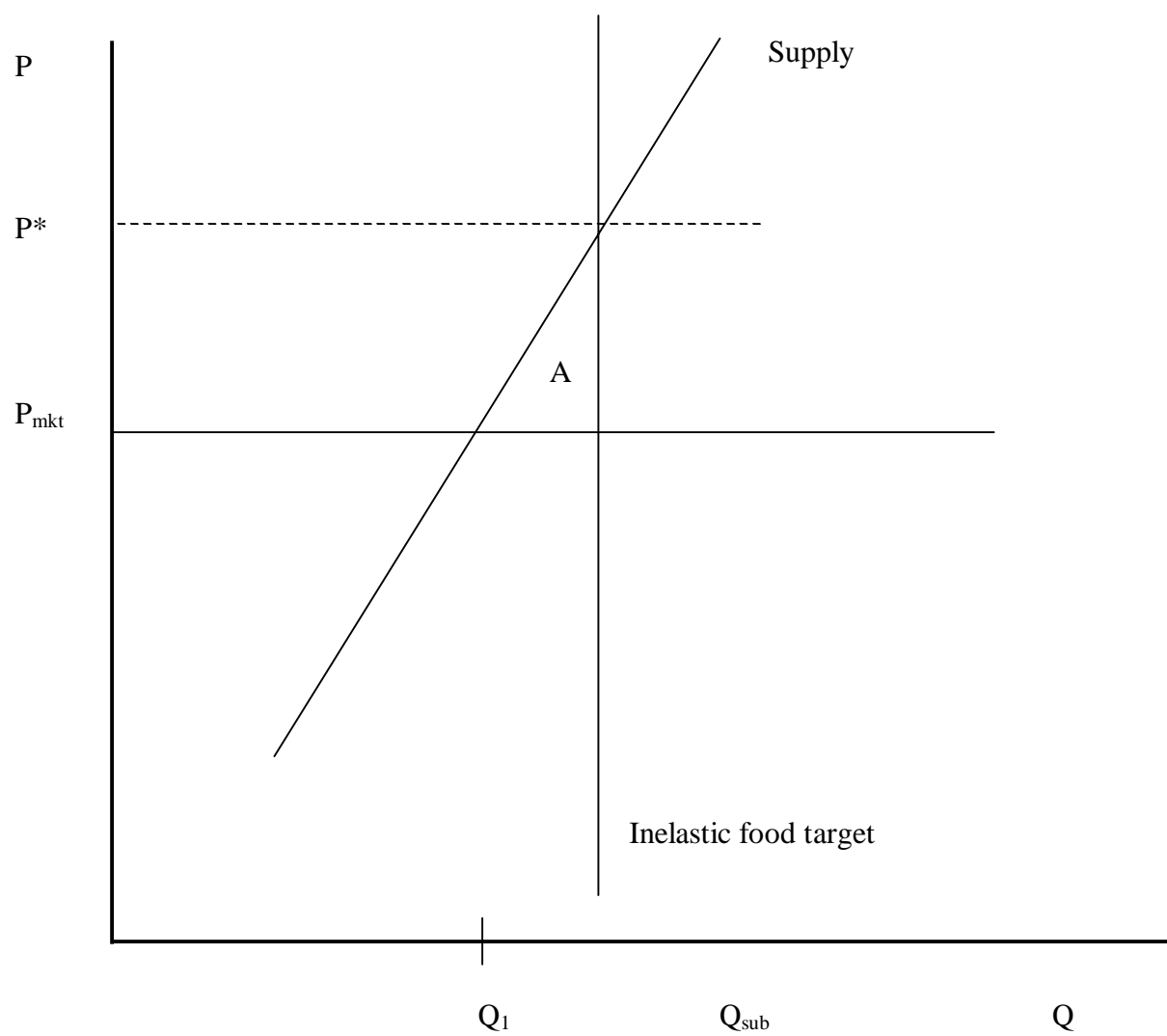


Figure 1 Description of the food subsistence target.

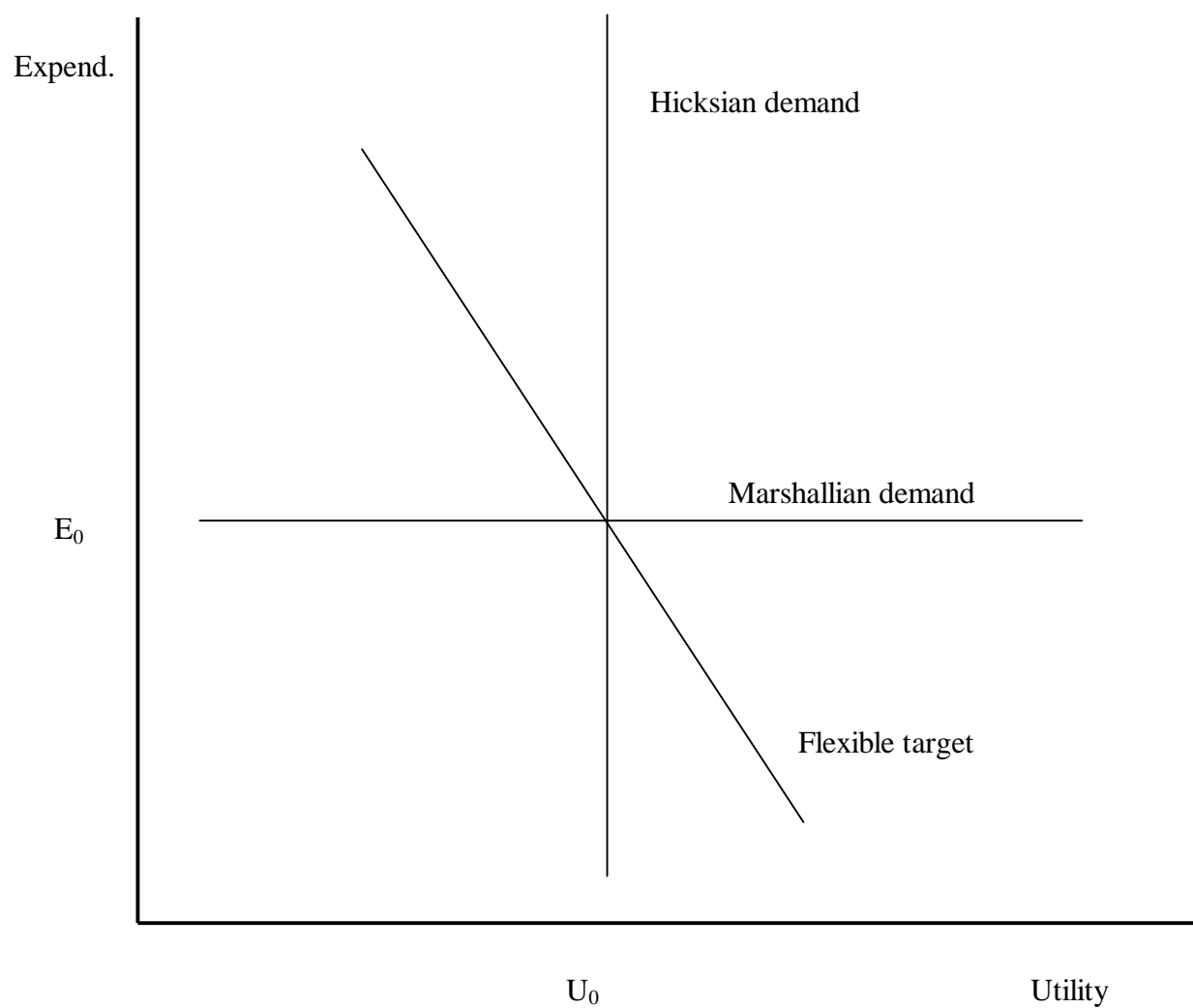


Figure 2 Description of the flexible food consumption target.

Table 1 Yields and prices used in the risk programming model.

Crop	Technology ¹⁻³	State-of-nature ⁶		
		Poor	Average	Good
Sorghum	L-0-0-R	470	570	620
	L-100-50-R	719	820	899
	I-50-50-R	869	1430	1457
	I-100-50-R	1001	1499	1227
	I-100-50-TR	1156	1658	1804
Millet	L-0-0-R	450	569	670
	L-100-50-R	720	762	871
	I-50-50-R	868	1098	1199
	I-100-50-R	868	1206	1266
	I-100-50-TR	1120	1496	1762
Groundnut	L-0-0-R	500	640	700
	I-0-100-R	970	1401	1428
	I-0-100-TR	1000	1427	1561
Cowpea	I-0-100-R	832	1310	1400
	I-0-100-TR	1089	1310	1400
Prices ⁴⁻⁵				
Sorghum		110	93	68
Millet		112	88	71
Groundnut		149	126	102
Cowpea		157	141	119

¹ This notation depicts: variety type-complex cereal compound (kg/ha)-urea (kg/ha)-soil preparation.

² Variety types: I = improved variety, L = local variety.

³ Soil preparation types: R = ridging, TR = tied ridges.

⁴ Currency conversion is given by: 584 fcfa = 1 \$ (International Financial Statistics Yearbook, 1997)

⁵ Input prices are given by: Complex cereal compound: 215 fcfa/kg; urea: 200 fcfa/kg.

⁶ Probabilities for the states are: poor (.2), average (.55), and good (.25).

Table 2 Effect of the income target in the modified safety-first risk programming model with existing technologies (strong aversion to legume market participation).

			Safety-first risk model		
Crop	Technology ¹⁻³	Ave. farm	Income risk neutral (no income target)	Moderate risk aversion ⁵	Strong risk aversion ⁵
Sorghum	L-0-0-R	3	4.7	4.6	4.6
Sorghum	I-50-50-R	0	0.5	0.6	0.6
Millet	L-0-0-R	7	5.7	5.7	5.7
Groundnut	I-100-0-R	1	0.8	0.9	0.9
Cowpea	I-100-0-R	1	0.6	0.4	0.4
Profit in poor year (fcfa) ⁴			-31,000	-25,000	-22,500
Expected profit (fcfa)			80,000	78,600	77,800
Profit variance (million fcfa ²)			1080.7	969.7	911.8
Cereals bought in poor year (kg)			0	0	0
Legumes bought in poor year (kg)			0	0	0
P* cereals (fcfa/kg) ⁶			170	705	1,560
P* legumes (fcfa/kg) ⁶			239	950	1,990
Cereal cost in poor year (fcfa)			893,000	3,688,000	8,321,000
Legume cost in poor year (fcfa)			384,000	2,446,000	5,691,000

¹ This notation depicts: variety type-complex cereal compound (kg/ha)-urea (kg/ha)-soil preparation. Compound cereal fertilizer is N:P:K(15:15:15).

² Variety types: I = improved variety, L = local variety.

³ Soil preparation types: R = ridging, TR = tied ridges.

⁴ Currency conversion is given by: 584 fcfa = 1 \$ (International Financial Statistics Yearbook, 1997)

⁵ Moderate risk aversion used a -25,000 fcfa income target, strong risk aversion used -22,500 fcfa income target.

⁶ Values are from the food consumption target's shadow value, averaged for each of the crop.

Table 3 Effect of the income target in the modified safety-first risk programming model with existing technologies (moderate aversion to market participation).

Crop	Technology ¹⁻³	Ave. farm	Safety-first risk model		
			Income risk neutral (no income target)	Moderate risk aversion ⁵	Strong risk aversion ⁵
Sorghum	L-0-0-R	3	5.0	5.7	4.7
Sorghum	I-50-50-R	0			.5
Millet	L-0-0-R	7	5.2	5.2	5.7
Groundnut	I-100-0-R	1	.8	.4	.8
Cowpea	I-100-0-R	1	1.2	1.6	.6
Profit in poor year (fcfa) ⁴			-51,000	-40,000	-25,000
Expected profit (fcfa)			85,000	84,000	81,000
Profit variance (million fcfa ²)			1,646	1,407	1,011
Cereals bought in poor year (kg)			546	198	0
Legumes bought in poor year (kg)			168	588	111
P* cereals (fcfa/kg) ⁶			132	221	875
P* legumes (fcfa/kg) ⁶			178	301	1,225
Cereal cost in poor year (fcfa)			695,000	1,154,00	4,588,000
Legume cost in poor year (fcfa)			332,000	559,000	2,969,000

¹ This notation depicts: variety type-complex cereal compound (kg/ha)-urea (kg/ha)-soil preparation. Compound cereal fertilizer is N:P:K(15:15:15).

² Variety types: I = improved variety, L = local variety.

³ Soil preparation types: R = ridging, TR = tied ridges.

⁴ Currency conversion is given by: 584 fcfa = 1 \$ (International Financial Statistics Yearbook, 1997)

⁵ Moderate risk aversion used a -40,000 fcfa income target, strong risk aversion used -25,000 fcfa income target.

⁶ Values are from the food consumption target's shadow value, averaged for each of the crop.

Table 4 Flexible food consumption targets in the modified safety-first risk programming model with existing technologies (strong aversion to legume market participation).

Safety-first risk model				
Crop	Technology ¹⁻³	Ave. farm	Fixed food consumption target ⁵	Flexible cereal consumption target ⁵
Sorghum	L-0-0-R	3	4.7	4.6
Sorghum	I-50-50-R	0	0.5	0.7
Millet	L-0-0-R	7	5.7	5.8
Groundnut	I-100-0-R	1	0.	0.9
Cowpea	I-100-0-R	1	0.6	0.4
Profit in poor year (fcfa) ⁴			-25,000	-25,000
Expected profit (fcfa)			110,800	106,000
Profit variance (million fcfa ²)			969.7	1,533
Cereal utility in poor year			2,612	2,664
P* cereals (fcfa/kg) ⁶			205	687
P* legumes (fcfa/kg) ⁶			950	1,222
Cereal cost in poor year (fcfa)			1,071,000	3,682,000
Legume cost in poor year (fcfa)			461,000	2,338,000

¹ This notation depicts: variety type-complex cereal compound (kg/ha)-urea (kg/ha)-soil preparation. Compound cereal fertilizer is N:P:K(15:15:15).

² Variety types: I = improved variety, L = local variety.

³ Soil preparation types: R = ridging, TR = tied ridges.

⁴ Currency conversion is given by: 584 fcfa = 1 \$ (International Financial Statistics Yearbook, 1997)

⁵ Income target was -25,000 fcfa for all of the cases and output prices are 10 percent higher than in Table 1.

⁶ Values are from the food consumption target's shadow value, averaged for each of the crop.

Table 5 Adoption of the new agricultural technologies under two policy scenarios.

		Safety-first risk model		
Crop	Technology ¹⁻³	Existing economic conditions ⁵	Improved economic conditions ⁵	Improved market infrastructure ⁵
Sorghum	L-0-0-R	4.9	5.0	5.0
Sorghum	I-100-100-TR	0.3	0.3	0.0
Millet	L-0-0-R	5.7	5.5	5.2
Groundnut	I-100-0-TR	0.8	0.8	0.8
Cowpea	I-100-0-TR	0.7	0.7	1.2
Profit in poor year (fcfa) ⁴		-284	14,000	-10,000
Expected profit (fcfa)		91,000	139,000	97,600
Profit variance (million fcfa ²)		838	2,127	
Cereals bought in poor year (kg)		0	0	534
Legumes bought in poor year (kg)		0	0	160
P* cereals (fcfa/kg) ⁶		185	215	132
P* legumes (fcfa/kg) ⁶		243	293	
Cereal cost in poor year (fcfa)		975,000	1,123,000	
Legume cost in poor year (fcfa)		387,000	465,000	

¹ This notation depicts: variety type-complex cereal compound (kg/ha)-urea (kg/ha)-soil preparation. Compound cereal fertilizer is N:P:K(15:15:15).

² Variety types: I = improved variety, L = local variety.

³ Soil preparation types: R = ridging, TR = tied ridges.

⁴ Currency conversion is given by: 584 fcfa = 1 \$ (International Financial Statistics Yearbook, 1997)

⁵ All three cases used a -25,000 fcfa income target, and fixed food subsistence targets.

⁶ Values are from the food consumption target's shadow value, averaged for each of the crop.

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