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Modelling embedded risk in peasant agriculture: methodological insights from northern Malawi

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Abstract

Using a linear-programming model of farming systems in northern Malawi, the conditions under which peasant farm-household models may need to allow for embedded risk are investigated. Tactical, sequential responses to uncertainty are found to be more important to labour-scarce households with limited access to capital and to credit markets. Compared with semi-sequential programming, discrete stochastic programming (DSP) provided more efficient solutions for problems involving embedded risk. There may be intuitive advantages in presenting results from DSP models in terms of a semi-sequential strategy. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The extent and nature of risk in agriculture is one of the features of agricultural economics that gives it its special characteristics. This is reflected in a long-standing interest in different means of describing risk in agriculture (see, e.g. summaries by Hazell and Norton, 1986; Hardaker et al., 1991; Rae, 1994; Hardaker et al., 1997); in the relative merits of subjective expected utility approaches and models as compared with more heuristic safety-first approaches (e.g. Roumasset, 1976; Anderson et al., 1977); in the extent of farmers' risk aversion (e.g. Hazell, 1982; Binswanger, 1980); and in the effect of risk on farmers' resource-allocation decisions (e.g. Herath et al., 1982). The majority of studies examining risk have, however, focused on non-embedded risk, where activities are assumed to have known resource requirements but to yield uncertain returns, as a result of physical yield or output price uncertainty.

In many situations, however, farmers face 'embedded risk' (Hardaker et al., 1991), where they have the opportunity to make sequential decisions and adjust the timing and methods of their activities as a season progresses and more information becomes available (e.g. about rainfall, pest and disease incidence, and prices). These adjustments may try to maintain output and reduce variability in the face of adverse circumstances or withhold resource allocations from affected enterprises. Responsive or tactical changes in individual enterprise management within the season are receiving increasing attention from technical scientists and from economists (Stewart,

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1991; McCown et al., 1991; Fafchamps, 1993; Chavas et al., 1991; Kingwell et al., 1993), but enterprise specific adjustments are made in the context of resources available across the farm. Studies modelling whole-farm implications of enterprise specific tactical adjustments have been less common and tend to be relatively recent (Rae, 1971a, b; Kaiser and Apland, 1989; Adesina and Sanders, 1991; Dorward, 1991; Dorward, 1994, 1996; Lopez Pereira and Sanders, 1992; Kingwell et al., 1992, 1993; Shapiro et al., 1993; Torkamani and Hardaker, 1996).

Uncertainty in resource availability and prices may also demand tactical responses to embedded risk as may 'knock-on' effects where enterprises generate uncertain outputs within the production period as inputs for further production. Uncertainty in the quantity, quality or timing of outputs from these enterprises results in uncertainty in resource availability for other enterprises.

The importance of tactical, whole-farm responses to unfolding information is shown in West African studies where farmers adjust their activities as weather patterns unfold (Stewart, 1991; Matlon, 1991). Similar observations have been made in Kenya (McCown et al., 1991). Enterprise models and whole-farm models allowing for second- and third-level effects of rainfall uncertainty have come to similar conclusions (e.g. Fafchamps, 1993; Chavas et al., 1991; Shapiro et al., 1993; Adesina and Sanders, 1991). In another literature, household 'coping strategies' are tactical adjustments in farm and off-farm activities in the face of potential famine situations (Corbett, 1988; Davies, 1993).

Ignoring embedded risk can lead to a number of difficulties for farm management analysts, such as biased and inconsistent estimates of production function parameters (Antle, 1983) and biased ex post estimates of the efficiency and risk aversion of farmers' resource allocations (Palmer-Jones, 1979; Chavas et al., 1991). Kingwell et al. (1993) demonstrate that even for risk neutral farmers, tactical adjustments can increase returns in almost all seasons, as compared with the implementation of fixed pre-seasonal plans. Where there is uncertainty in resource supply or prices, then fixed pre-seasonal plans are likely to be non-feasible in less favourable states of nature, unless a strongly risk averse (e.g. safety first) strategy is followed.

It appears, therefore, that modelling of embedded risk can be important. Whole-farm embedded risk models are, however, demanding of data and analytical resources, and should only be applied where they generate information that justifies the extra costs incurred in their construction (Hardaker et al., 1991). Dorward and Parton (1997), therefore, postulate a set of four necessary (but not sufficient) conditions that must hold, if modelling of embedded risk is to be warranted and worthwhile in a particular situation:

1. there is uncertainty regarding quantities or prices of outputs or inputs
2. there are opportunities for making tactical responses to unfolding information as it becomes available during a season
3. uncertainty and tactical responses to uncertainty affect scarce resources
4. there are limited opportunities for using markets to maintain resources to the farm in sufficient quantities and at sufficiently low cost to allow a fixed pre-seasonal plan to be profitably implemented

Whereas conditions 1 and 2 are self-evident requirements for the existence of risk and of sequential responses to it, conditions 3 and 4 define particular circumstances where seasonal adjustments may or may not be appropriate. Dorward and Patton suggest, for example, that modelling embedded risk may not be so relevant in land-scarce agriculture as it is in labour-scarce agriculture, as the supply of land is less affected by uncertainty. They also argue that well-developed credit and labour markets may preclude the need for on-farm tactical responses to uncertainty. These propositions may partly explain both the relative lack of interest in modelling embedded risk (as opposed to non-embedded risk) in agriculture in the Indian subcontinent and in more developed economies, and recent interest in embedded risk models in parts of Africa, where land is more abundant and seasonal labour demands impose important constraints on farm activities.

The nature of Dorward and Parton's propositions makes it difficult to test them empirically. This paper adopts a case study approach and describes a test of Dorward and Parton's argument as it applies to farms in an area in northern Malawi by modelling farmers' responses to embedded risk under conditions of labour scarcity and of land scarcity, with and without access to production and consumption credit. We specifically test two hypotheses related to Dorward and Parton's conditions 3 and 4:

- When compared with labour-scarce situations, under land-scarce situations there may be lower, and sometimes zero, benefits to on-farm tactical responses to embedded risk affecting labour supplies
- Where farmers have free access to labour and credit markets there may be lower, and sometimes zero, benefits to on-farm tactical responses to embedded risk affecting labour and cash supplies as 'market-mediated adjustments' may provide a lower cost alternative to on-farm tactical responses.

We then compare two different forms of model (discrete stochastic programming, DSP, and semi-sequential programming, SSP) in an attempt to identify appropriate methods for modelling embedded risk. Subsequent sections of the paper briefly describe the farm model used in the study (with a description first of the farming systems modelled and then of model structure). The model is then used to examine first the conditions under which embedded risk is, and is not, important and then the relative merits of DSP and SSP models.

2. The study area

The study area is located in the northern part of Mzimba District, northern Malawi. The rainfall pattern is unimodal with a wet season running from November/December to March/April and average seasonal rainfall of $\approx$750 mm. Compared to southern Malawi, population density is low with an estimated population density of 46 persons per km^2 in 1995, although this has more than doubled over the last twenty years (Dorward, 1997).

Most people in the area depend on smallholder agriculture for employment. Simler, 1996 (personal communication) reports that, in the late 1980s, households in the vicinity obtained ca. 55% of income directly from agricultural activities, 25% from 'self-employment' and wage labour, and 20% from 'gross transfers' (primarily remittances). Maize is the dominant crop in terms of the area planted (occupying 70–85% of cultivated area in surveys conducted during the 1980s and early 1990s) and in its significance as the staple crop. Local, white semi-flint varieties have been favoured for processing (into flour), storage and eating qualities. Up to the period modelled in this paper (1990/1991), higher yielding dent hybrid varieties were grown as a cash crop by some farmers, with purchased seed and fertilisers. Local varieties of maize are generally grown with little or lower use of purchased inputs. Finger millet was originally the staple crop, but millet is now grown mainly for sale and for brewing beer.

Many poorer households engage in off-farm wage labour ('ganyu'), often in the fields of neighbours, to supplement depleted food stocks in the December–March period. Forty percent of households normally run out of food before the end of December, and 85% before the end of March (Malawi Government/UNICEF, 1993; Mzuzu ADD unpublished survey data). Selling small livestock and earning food or cash in off-farm employment are the two most commonly cited coping strategies for obtaining food.

Although the area might be considered one of the less poor areas of Malawi, many people are very poor, with high under-five mortality rates (213 deaths per 1000 live births in 1987), low literacy rates (63% for males and 49% for females in 1987), and low incomes (median incomes of US$ 30–40 in 1987-1989). The poor are particularly susceptible to the seasonal effects of periods of high rainfall coinciding with high temperatures, peak labour and energy requirements, and low food supplies as food stocks from the previous harvest run out. These pressures lead to high susceptibility to sickness during the period from January to March.

Risk and uncertainty affect farm households in the study area in a number of ways. Crop yields may be affected by low rainfall at critical periods, or by flooding, hail or insect damage. Apart from affecting yields, uncertainty about the timing of arrival of the rains affects the length of the cropping season, and hence the amount of labour effectively available in a season, with late arrival of the rains reducing the amount of time available for cropping activities. Early arrival of the rains, on the other hand, relaxes labour constraints and may allow an expansion of cropped area or more intensive crop management (Dorward, 1996).

Many farm households in the area are not maize purchasers, and uncertainty about maize consumer prices may encourage them to concentrate on the production of maize for home consumption rather than cash crops. Increasing maize prices during a crop season may lead to shortages of working and consumption capital, and force households to take up off-farm employment to earn food. This results in a reduction of labour available to the farm. Uncertainty in labour supplies and working and consumption capital also arises from high levels of sickness (particularly in the cropping season), and social conventions requiring attendance at funerals of relatives or neighbours.

3. Model construction

In order to test Dorward and Parton's argument (as outlined in Section 1), a set of farm-household models were constructed to enable study of the effects of embedded risk on farms with different characteristics: in labour- and land-abundant situations, and with and without access to credit and labour markets.

Despite persuasive arguments that more emphasis should be given to developing collective household models (Haddad, 1994), analytical and data difficulties involved in their development precluded their use in this study, and the use of a unitary household model should not materially affect the conclusions in this paper about farmer responses to embedded risk. The basis of the farm model was, therefore, taken to be a household acting as a decision-making unit integrating consumption and production activities to maximise achievement of a set of common objectives. These objectives were arranged in a hierarchy moving from short-term survival goals to longer-term goals of security and independence (Collinson, 1972; Chambers, 1988) with survival from one season to the next the basic objective, with eking out of food and cash from one harvest to the next, and, if stocks run out, immediate off-farm employment to obtain food for immediate consumption. Beyond this, households were assumed to aim at gaining an income and producing food, first to ensure survival and then increasing income, security and independence in the next, and subsequent, seasons.

A hierarchy of objectives was built into a linear-programming model with first-level goals (to survive the current season) described by monthly consumption levels of maize and cash to be satisfied within the model. Higher level goals were then to end the season with the same level of maize stocks as they began the season with, and then to maximise overall income over the current season. The hierarchy of goals was described by assigning substantially different weights to each of these goals in the objective function to ensure that there was little opportunity for trade-offs between achievements of objectives in different hierarchical levels.

Farm-household activities modelled included production and marketing of the main crops, off-farm employment, buying-in of maize and inputs, and hiring-in of labour. A range of different crop-management options were allowed for each crop, regarding planting time (by monthly period), plant density, one or two weedings in different months, and rate of fertiliser application. Yields under the different management regimes were calculated from production functions estimated from farm survey data gathered in the area over four seasons (see Dorward, 1997). Timing of activities is critical, as poorer households may be forced to give priority to off-farm employment to feed themselves during a season, and thereby delay or abandon some cropping activities, although this has costs as the timing of cropping activities is often critical in determining crop yields and returns. To capture the dynamics of these labour and cash and food flow constraints, the year was broken into six periods, five monthly periods in the cropping season from mid-November to mid-April (when labour, cash and maize availability are particularly constraining and activities are particularly sensitive to their timing) and a sixth month harvest and post-harvest period, mid-April to October. The timing of the labour requirements of different cropping activities, of their seed requirements, of their yields and of associated buying and selling activities were then tied into these periods. Hiring-in and hiring-out of labour was allowed in each period, with wage rates changing between months within each year. Data on prices, labour availability, wage rates and other coefficients in the model were obtained from a wide range of sources, including surveys carried out in the area during the period 1977–1991 and reports on agricultural and other activities and conditions in the study area and in Malawi as a whole.

Three sources of uncertainty were explicitly allowed for in the model: uncertainty in yields associated with dry spells in January/February or February/March (affecting yields of crops planted in November/December or December/January, respectively, as a result of moisture stress occurring at critical stages of plant growth), in the timing of the start of the rains (affecting the amount of labour available for farm work, and the availability of off-farm employment, in November/December), and in the availability of labour and household cash during December/January and January/February. Lack of data on the probability of different events affecting these variables, together with the complexity of modelling all these sources of uncertainty, precluded the use of subjective expected utility (SEU) approaches to describing risk, and instead more heuristic safety first approaches were used: these also tied in neatly with the lexicographic ordering of objectives discussed earlier.

Bringing all of the model components into a discrete stochastic programming (DSP) model gave the following formulation[1]:

$$\text{Max} \sum_g \sum_h w_g w_h \sum_k \sum_j w_k \sum_s w_{js} p_j q_{ghkjs} \qquad (1)$$

such that:

for $g = 1,2;\ h = 1,2;\ k = 1$ to $3;\ j = 1,2;$ and $s = 1,\ q_{ghkjs} \leq q'_j$ (2)

for $g = 1,2;\ h = 1,2;\ m = 1$ to $5;$ and $j = 1$ to $2,$

$$-t_{ghjm} + t_{ghj(m+1)} + \sum_i e_{ijm} x_{ghi} \leq -d_{jm} \qquad (3)$$

for $g=1,2;\ h=1,2;\ k=1$ to $3;\ m=6$ and $j=1$ to $2,$

$$-t_{jm} + \sum_i e_{ikjm} x_{ghi} + \sum_s q_{ghkjs} \leq 0 \qquad (4)$$

for $g = 1, 2;\ h = 1, 2;$ and for all $i,f,$ and m

$$\sum_i e_{ifmgh} x_{igh} \leq B_{fmgh} \qquad (5)$$

for pre-season commitments for cash and credit purchases of hybrid maize seed and

$$\text{fertilisers,} \quad X_{ghi(g=1)} = X_{ghi(g=2)} \qquad (6)$$

and for all activities decided on before December/January

$$X_{ghi(h=1)} = x_{ghi(g=2)} \qquad (7)$$

where

g, h and k are independent states of nature and $g = 1$ indicates rains starting by mid-November, $g = 2$ indicates rains starting after the end of November, restricting labour supplies by 50% in that month ($w_{g=1} = 5.\ w_{g=2} = 1$), $h = 1$ indicates normal labour and cash supplies in December/January and January/February, $h = 2$ indicates sickness affecting labour (loss of 20 h per month) and cash supplies (loss of a little under MK6.0 per month, ≈US$ 2.1 in 1990/91) in December/January and January/February ($w_{h=1} = 5$, $w_{h=2} = 1$), $k = 1$ indicates a normal harvest, $k = 2$ indicates a harvest after a dry spell in January affecting November/December planted crops, and $k = 3$ indicates a harvest after a dry spell in February ($W_{k=1} = 10, w_{k=2} = 0.5, w_{k=3} = 0.5$) affecting December/January planted crops;

w_{js}, p_j, q_{ghkjs} are, respectively, the objective function weights, prices and immediate post-harvest stocks of maize ($j = 1$) and cash ($j = 2$, $p_j = 1$), with $s = 1$ for stocks held for post-harvest consumption and to replenish pre-seasonal stocks, and $s = 2$ for stocks surplus to those requirements (for w_{js}, $w_{11} = 50$, $w_{12} = 0, w_{21} = 5$, $w_{22} = 1$);

q'_j are post-harvest consumption requirements plus pre-seasonal stocks;

x_{igh} are activities i (including different crop-management practices, purchases and sales) under conditions g and h with e_{ijmgh} use (production) of commodity j in time period m (for $m = 1$ to 5). e_{ikjmgh} use (production) of commodity j post-harvest (when $m = 6$) under conditions k, and e_{ifmgh} use (production) of resource f (e.g. labour, land, etc., and tie rows linking activities from one

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[1] DSP uses sub-matrices to describe each state or nature in each decision stage. Conventional DSP models use tie rows linking activities in different states of nature in later stages to activities in earlier ages. Using GAMS, it was easier to replace these tie rows by a simple duplication of the model for each set of states of nature with constraints equating activity levels in earlier stages before the different states of nature are revealed (Eqs. (6) and (7)).

time period to the next) in time period m under states of nature g and h;

t_{ghjm} are transfer activities carrying forward commodity j from time period m-1 to period m under states of nature g and h;

d_{jm} are household consumption requirements by commodity and time period; and B_{fmgh} are constraints for resource f in time period m under states of nature g and h.

Validity of the model was examined against four criteria identified by Ignizio (1982):

1. logical consistency in model construction;
2. reliability of the data on which the model was based;
3. logical consistency of model responses to simple stimuli; and
4. thc correspondence of model outputs with reality.

Model construction and data sources have been described briefly in the foregoing and are presented more fully in Dorward (1997). Extensive checks on consistency were performed at different stages of model construction and testing. The models responded in a logically consistent way to changes in price and rainfall patterns, and yielded predictions of cropping patterns broadly consistent with those observed in household surveys for 12 cropping seasons between 1979 and 1990 (Dorward, 1 997).

4. The effects of land scarcity and credit on embedded risk

In this section, we use the DSP model described above to test the two hypotheses developed earlier in the paper from the conditions identified by Dorward and Parton as necessary for worthwhile modelling of embedded risk

- When compared with labour-scarce situations, under land-scarce situations there may be lower, and sometimes zero, benefits to on-farm tactical responses to embedded risk affecting labour supplies
- Where farmers have free access to labour and credit markets there may be lower, and sometimes zero, benefits to on-farm tactical responses to embedded risk affecting labour and cash supplies as 'market-mediated adjustments' may provide a lower cost alternative to on-farm tactical responses.

The hypotheses were tested by examining the importance of on-farm tactical responses to embedded risk for a less poor and a poorer farm household in the study area under differing scenarios of relative land and labour scarcity and with and without access to credit markets providing cash sums during the cropping season. With such credit, households could borrow any amount of cash in December/January, as their circumstances required, with repayment at harvest with 10% interest. For each of these conditions, a DSP model was run using 1990/1991 prices. The different scenarios and results obtained are shown in Table 1.

The first part of Table 1 (after the definition of the different scenarios) shows for the different household types and scenarios the cropping activities and outcomes obtained in the optimal solution of the DSP model under favourable states of nature (i.e. where the rains arrive on time and where there are no adverse conditions affecting family labour and cash supplies in December/January and January/February). These solutions are not the same as would be obtained for a model with no allowance for embedded risk, as the 'favourable states of nature' solution is affected by the need to undertake activities which could be adjusted to allow for achievement of farmer objectives, should unfavourable states of nature occur.

For the less poor holding the introduction of a land constraint (scenario B) leads to a 40% reduction in local maize area as compared with scenario A, a 65% reduction in area under hybrid maize, and the complete elimination of millet from the cropping pattern, hiring-out of labour rather than hiring-in, more intensive cultivation with higher yields of hybrid and local maize (not shown in Table 1), and lower net income. Access to cash-on-credit (scenario C) leads to a 55% increase in holding size as compared with scenario A (up to the 5.0 ha allowed, previously not a constraint), a near doubling in local maize area, a 20% increase in hybrid maize area, no change in millet area, and a near tripling in labour hire and net income (defined as farm income and off-farm employment income net of purchased inputs, labour hire costs and household

Table 1
Effects of varying time of arrival of rains and cash and labour supplies

Farm type	Larger, less poor				Smaller, poorer			
Scenario A	A	B	C	D	A	B	C	D
Land available (ha)	5	1.5	5	1.5	0.75	0.75	0.75	0.75
Initial cash stocks	489	489	489	489	175	280	175	280
Access to credit as cash	no	no	yes	yes	no	no	yes	yes
Solution under favourable conditions (early rains, no sickness)								
Total holding (ha)	3.21	1.50	5.00	1.50	0.75	0.75	0.75	0.75
Local maize area (ha)	1.56	0.9	3.08	0.86	0.57	0.49	0.58	0.51
Hybrid maize area (ha)	1.35	0.6	1.62	0.64	0.05	0.04	0.04	0.22
Millet area (ha)	0.3	0	0.3	0	0.13	0.22	0.13	0.22
Labour income (expenditure) (1990/91 MK)	(165)	110	(486)	0	180	156	179	158
Net income(1990/91 MK)	79	(388)	214	(420)	(252)	(238)	(267)	(267)
Effects of late arrival of rains and/or November/January sickness								
Average difference as % of level in solution for favourable conditions								
Holding size	−10%	0%	−4%	0%	−42%	−10%	0%	0%
Local maize area	−20%	−4%	−6%	0%	−32%	0%	0%	0%
Hybrid maize area	−2%	−6%	0%	0%	0%	0%	0%	0%
Millet area	0%		0%		−100%	−35%	0%	
Labour income (expenditure)	8%	26%	3%		4%	7%	14%	16%
Net income	−142%	−14%	−42%	−10%	−47%	−26%	−13%	−13%

Note: Available land of 0.75 ha was constraining for all scenarios for the poorer household, but with low initial stocks of cash (the 'base' scenario, A) more family labour has to be hired out to meet current consumption requirements. Increasing initial cash stocks are, therefore, used to increase relative land scarcity.

subsistence requirements). Where holding size is already limited to 1.5 ha (scenario B), access to cash-on-credit (scenario D) leads to little further change.

For the poorer household, increasing initial cash stocks with holding size fixed at 0.75 ha (scenario B) leads to a 15% drop in local maize area compared with scenario A, an increase in millet area, more intensive cultivation with higher yields of both, the hybrid and local maize, less hiring out of labour, and a higher income. Similar changes result if cash can be obtained on credit (scenarios C and D) although a fall in net income is observed here. This occurs as credit allows greater achievement of short-term survival objectives (in terms of food production), but the fall in net income indicates that this may be achieved at the expense of increasing indebtedness.

Cropping patterns and outcomes were also calculated for adverse states of nature (late rains and/or reduced labour supplies in December/January and January/February). The second part of Table 1 gives a measure of the variation between the solutions obtained for favourable and adverse states of nature. These are shown as the difference between the value for a variable under favourable states of nature and its value averaged across solutions obtained under late arrival of the rains and reduced labour supplies, expressed as a percentage of the value obtained under favourable states of nature (as given in the first part of the table). Actual solutions for each type of farm household and each state of nature are given in Table 2 for scenario A only. This table shows the different cropping patterns adopted and incomes obtained under early and late arrival of the rains and 'good' and 'bad' labour supplies. Within each set of rainfall conditions, a semi-sequential approach (described more fully in Section 5) is used to show the effects of changes in labour supplies in terms of 'incremental' activities, activities which are incremental to core activities implemented as a high priority under all conditions. Incremental activities are progressively abandoned if, due to stochastic events, labour and cash resources are reduced below levels expected under normal or

Table 2
Cropping patterns under different states of nature: DSP solutions for scenario A

Farm type	Larger, less poor						Smaller, poorer					
Land available (ha)	5						0.75					
Initial cash stocks (1990/91 MK[c])	489						175					
Arrival of rains	Early rains			Late rains			Early rains			Late rains		
Semi-sequential activities	Base[a]	Inc.[b]	Total	Base[a]	Inc.[b]	Total	Base[a]	Inc.[b]	Total	Base[a]	Inc.[b]	Total
Area cultivated (ha)	2.99	0.22	3.21	2.72	0.21	2.93	0.61	0.14	0.75	0.09	0.52	0.61
Local maize (ha)	1.34	0.22	1.56	1.14	0.14	1.28	0.56	0.01	0.57	0.04	0.52	0.56
planted November	0.52		0.52	0.66		0.66	0.03		0.03	0.03		0.03
planted December	0.82	0.22	1.04	0.48	0.14	0.62	0.53	0.01	0.54	0.01	0.52	0.53
weeded twice	0.11	−0.11	0.00	0.00	0.06	0.06	0.00	0.03	0.03	0.00		0.00
fertilised	0.32	−0.32	0.00	0.56	−0.22	0.34	0.00		0.00	0.00		0.00
Hybrid maize (ha)	1.35		1.35	1.28	0.07	1.35	0.05		0.05	0.05		0.05
planted November	0.30		0.30	0.57		0.57	0.05		0.05	0.05		0.05
planted December	1.05		1.05	0.71	0.07	0.78	0.00		0.00	0.00		0.00
weeded twice	0.79	0.26	1.05	0.67	0.11	0.78	0.00		0.00	0.00		0.00
fertilised high	0.79	0.26	1.05	0.67	0.11	0.78	0.00		0.00	0.00		0.00
Finger Millet (ha)	0.30		0.30	0.30		0.30	0.00	0.13	0.13	0.00		0.00
Labour hire-in (hire-out)												
Nov–Feb (h)	152	52	204	156	29	185	(347)	(33)	(381)	(352)	30	(322)
harvest (h)	279	37	316	239	39	278	(355)	68	(288)	(407)	51	(356)
Net income (1990/1991 MK[c])	5	74	79	(91)	78	(13)	(333)	82	(252)	(439)	105	(334)

[a] 'Base' indicates activities as a priority with good or bad labour supplies.

[b] 'Inc.' indicates incremental activities undertaken during the season as far as resource availability allows.

[c] Malawi Kwacha.

favourable conditions. Thus, the favourable conditions of Table 1 are shown in Table 2 under the column 'Total'.

For the less poor household in scenario A the basic effect of late arrival of the rains or of loss of labour is a contraction of the overall effective cropped area (averaging 10% across the three less favourable states of nature) with an average 20% reduction in the area cropped to local maize (following loss of labour in December/January or January/February this would represent an abandonment or partial abandonment of some plots, a phenomenon observed in the field). Local maize yields are then raised (by an average of 23%) to maintain food production by transferring fertiliser and weeding labour across from hybrid maize and, with late arrival of the rains, more emphasis on planting rather than on weeding in November/December. The overall effect is a significant fall in net income.

The introduction of a land constraint (scenario B) leads to a marked reduction in variability in cropping pattern between different states of nature, indicating that there are few on-farm tactical responses: variations in labour supply can be accommodated by using the labour market, financed by abundant working capital. Variability still exists in net incomes, but is much reduced in percentage terms (although absolute income variability is only slightly reduced, this represents a smaller percentage of a larger net income). When cash can be obtained on credit (scenario C), then variability in holding size and in cropping pattern is again reduced. The combination of access to consumption credit and restricted access to land (scenario D) leads to total elimination of variability in cropping pattern.

For the poorer household, in scenario A the basic effect of late arrival of the rains or of loss of labour is again a reduction in cropped area, with first of all reduction or partial abandonment of finger millet cultivation, and then under more serious conditions abandonment of some local maize plots. These changes are tied in with changes in the amount of labour hired out. The household is very poor even under favourable circumstances (with a negative net income indicating reliance on remittances from relatives and/or severe reductions in the already low levels of consumption), and the effect of late arrival of the rains and/or loss of labour and cash during the season is further impoverishment.

Under scenario B, with higher initial cash stocks there is a large reduction in variability in holding size, related to reduced variability in local maize and millet areas. Overall income variability falls by half. When cash can be obtained on credit (scenarios C and D) then variation in cropping pattern is eliminated completely and variation in income is much reduced. This reduction is achieved by increased variation in hiring out of labour and in borrowing, to offset labour and cash shortages under adverse conditions.

It appears, therefore, that under the conditions described by the DSP model, both the hypotheses put forward earlier are supported, for both farm types.

5. A comparison, of embedded risk models

We now examine alternative methods for modelling embedded risk. Running separate versions of a non-embedded risk model with 'fat and thin coefficients' representing different states of nature will normally be a first step in any study where modelling of embedded risk is anticipated, to provide preliminary information on the potential effects and importance of embedded risk (Dillon and Hardaker, 1980). The method will not normally provide much more information than this, as it fails to link together solutions from different states of nature to represent the uncertainty facing the farmer at the beginning of a season: more sophisticated methods are needed to address this difficulty. We therefore now compare results from the discrete stochastic programming (DSP) model described earlier with results from a simpler semi-sequential programming (SSP) formulation.

Although DSP was developed in the late 1960s (Cocks, 1968), for many years its practical application was limited by demands for very substantial matrices and computing power, if it was to be applied to any realistic problem. Dorward (1994, 1996) has argued that, although it is now much easier to build and solve DSP models, the data requirements of DSP models are still significant and the information they generate may be difficult to interpret and apply in predictive and prescriptive analysis. He therefore proposed SSP as a low-cost alternative, with less demanding data and analytical requirements than DSP, generating simpler and more user-friendly sets of information, although providing less efficient solutions, particularly for problems where the main response to uncertainty is to reschedule activities.

Formulation of a problem into an SSP framework requires identification of adverse states of nature in each decision stage in the problem. These are taken together to define a set of adverse states across all decision stages. Productive (such as cropping) activities to be undertaken in this set of adverse states are constrained to be a subset of productive activities undertaken in the more favourable states, although exchange activities in the different states are independent, and borrowing activities in the more favourable states are constrained to be a subset of activities in more adverse states. Dorward (1994, 1996) describes the method in more detail, and argues that this describes a form of decision rule often used in decision-making under conditions of embedded risk, with a focus on a core set of 'safety activities' to be followed if at all possible under all circumstances, and then a set of 'incremental activities' which decision-makers pursue to the extent that circumstances allow (Dorward, 1991).

The SSP formulation used was identical to the DSP formulation, except that instead of Eqs. (6) and (7), the following constraints were introduced:

for activities carrying resources forward from one period to another (such as all cropping activities or transfer activities or maize or cash stocks),

$$x_{ghi(h=2)} \leq x_{ghi(h=1)} \qquad \text{for all } g \text{ and } i$$

$$x_{ghi(g=2)} \leq x_{ghi(g=1)} \qquad \text{for all } h \text{ and } i$$

and for activities carrying liabilities forward from one period to another (such as borrowing—credit—activities),

$$x_{ghi(h=2)} \geq x_{ghi(h=1)} \qquad \text{for all } g \text{ and } i$$

$$x_{ghi(g=2)} \geq x_{ghi(g=1)} \qquad \text{for all } h \text{ and } i$$

Table 3
Cropping patterns under different states of nature: SSP solutions for scenario A

Farm type	Larger, less poor						Smaller, poorer					
Land available (ha)	5						0.75					
Initial cash stocks (1990/91 MK)	489						175					
Arrival of rains	Early rains			Late rains			Early rains			Late rains		
Semi-sequential activities	Base[a]	Inc.[b]	Total	Base[a]	Inc.[b]	Total	Base[a]	Inc.[b]	Total	Base[a]	Inc.[b]	Total
Area cultivated (ha)	2.77	0.22	2.99	2.75	0.21	2.96	0.52	0.23	0.75	0.11	0.24	0.35
Local maize (ha)	1.19	0.21	1.40	1.16	0.21	1.37	0.49	0.09	0.58	0.08	0.24	0.32
planted November	0.64		0.64	0.64		0.64	0.08		0.08	0.08		0.08
planted December	0.55	0.21	0.76	0.52	0.21	0.73	0.41	0.09	0.50	0.00	0.24	0.24
weeded twice	0.00	0.15	0.15	0.00	0.15	0.15	0.00	0.00	0.00	0.00		0.00
fertilised	0.51	0.00	0.51	0.51	0.00	0.51	0.00		0.00	0.00		0.00
Hybrid maize (ha)	1.29		1.29	1.29	0.00	1.29	0.03		0.03	0.03		0.03
planted November	0.59		0.59	0.59		0.59	0.03		0.03	0.03		0.03
planted December	0.70		0.70	0.70	0.00	0.70	0.00		0.00	0.00		0.00
weeded twice	0.70	0.00	0.70	0.70	0.00	0.70	0.00		0.00	0.00		0.00
fertilised high	0.70	0.00	0.70	0.70	0.00	0.70	0.00		0.00	0.00		0.00
Finger Millet (ha)	0.30		0.30	0.30		0.30	0.00	0.13	0.13	0.00		0.00
Labour hire-in (hire-out)												
Nov–Feb (h)	83	27	110	164	27	191	(359)	(17)	(376)	(345)	(10)	(356)
harvest (h)	247	26	274	244	26	271	(361)	69	(292)	(408)	27	(380)
Net income (1990/1991 MK)	(22)	53	31	(80)	53	(27)	(341)	84	(257)	(440)	69	(371)

[a] 'Base' indicates activities as a priority with good or bad labour supplies.

[b] 'Inc' indicates incremental activities undertaken during the season as far as resource availability allows.

x_{ghi} are independent for activities neither carrying resources nor liabilities from one period to another (e.g. labour hiring or maize buying/selling activities).

In terms of Dorward's original formulation for SSP (Dorward, 1994), $x_{ghi(g=2,h=2)}$ are the 'adverse' activities, and rather than defining 'incremental' activities and solving for 'adverse' and 'incremental' activities, the model is solved for 'adverse' and 'normal' activities with the above inequalities ensuring the appropriate relationship between them.

Table 3 presents results obtained using the SSP formulation, and this may be compared with the results from the DSP formulation, presented earlier in Table 2. A comparison of net incomes in Tables 2 and 3 shows a number of interesting differences between solutions from the two formulations. For the less poor farm, the DSP formulation (in Table 2) gives higher net incomes under all circumstances, except the worst case scenario. The SSP and DSP models both divert fertilisers purchased for hybrid maize to local maize under conditions of adverse labour supply. However, the SSP formulation does not allow fertiliser applications on local maize to be switched to hybrid maize under more favourable conditions, as it leads to a negative incremental activity.

For the poorer farm, the two formulations give similar net incomes unless the rains are late and labour supplies are good. Here, the SSP formulation is constrained by the requirement that transfers of cash and maize stocks between months under adverse conditions should be less than or equal to transfers under more favourable conditions. The DSP formulation's larger incremental area of local maize under favourable conditions is achieved by hiring out less labour in December/January. Since this lowers cash transfers from February to March or April as compared with those needed under adverse conditions, it is not feasible with the SSP formulation, leading to substantial differences in cropped area, cropping pattern and net incomes between the two formulations.

These results indicate that the DSP formulation provides superior solutions (as measured by objective function achievement). This is due to rescheduling of activities; reallocation of resources between activities (rather than simple withdrawal of resources from incremental activities); and increased saving for consumption (as opposed to investment). Although these benefits do not always apply, and there may be little difference between DSP and SSP solutions in some situations, widespread access to computer hardware and software with the capability of handling relatively large and complex mathematical programming problems suggests that DSP is now generally to be preferred to SSP.

The presentation of results in Table 2 suggests that it will often be possible to present information from DSP models within a semi-sequential framework, if that is helpful for the users of the information. Although the results from the DSP formulation may include some negative activity levels, the inclusion of the 'incremental' column is helpful in the interpretation of results, and may allow a relatively simple explanation of appropriate tactics, suitable for the construction of decision rules or guidelines for discussion with farmers, or for informing policy. Thus, a semi-sequential interpretation of the results from the DSP formulation in Table 2 might be that, under adverse labour supply conditions or late arrival of the rains, the less poor farmers maintain their local maize production by making a small cut in hybrid maize area to release fertiliser for use on local maize, allowing a smaller but higher yielding area under local maize with more of it fertilised.

6. Conclusions

Using a model of particular Malawian farm-household systems, this paper has set out to test broad propositions regarding conditions under which tactical responses to embedded risk are important and may warrant explicit attention in farm-household models. The results from this case study support the proposition that on-farm tactical responses may be of limited importance for land-scarce farms or for labour-scarce farms with access to effective credit and other input markets. These markets allow farmers to buy-in resources to maintain planned farm activities (a response to uncertainty that can be modelled satisfactorily without the extra costs of models describing embedded risk). On-farm tactical responses may be more important for labour-scarce farms with limited access to effective credit and other input markets. Two issues of note arise here.

First, under these circumstances reductions in on-farm labour supply or in grain or cash stocks may lead to farmers responding in complex ways, with changes in patterns of labour hire (in or out), and partial abandonment of crops. For the less poor household shown earlier in Table 2. for example, late arrival of the rains leads to a substantial fall in net income and a lower hectarage of local maize, with diversion to local maize of some of the fertiliser purchased for hybrid maize (to maintain overall production of local maize). Both local and hybrid maize are planted earlier, but weeding intensity on hybrid maize is reduced. The ability of crop varieties and agronomic practices to allow such variability in crop management should be an important factor in research into new technologies and modified farming systems. Similarly, policy makers and development agencies should be aware of the importance of (and support) flexible access to labour and consumption credit markets as farmers cope with adverse rainfall patterns, sickness, or other sudden events affecting their cash or labour resources. Policy formulation regarding, for example, the design of safety nets for the poor or the development of private- or public-sector input and credit markets may need to take account of and support farmers' different coping strategies to respond not only to regular patterns of seasonal change, but also to the uncertainty and risk embedded within each season (Corbett, 1988). This may require greater attention to the development of markets for informal seasonal credit for consumption purposes (not a topic that is being addressed sufficiently within the current micro-finance movement), and to support for development of labour markets in African countries where land scarcity is emerging within the context of highly seasonal peaks in labour demand. These considerations may also be important, for example, in the design of recent relief and development interventions in Malawi involving food, fertiliser and seed distribution and work programmes.

A second point to be made here concerns the overall inhibiting effects of embedded risk even when the rains do arrive on time and the household is not affected by unexpected reductions in on-farm labour supply or in grain or cash stocks. In these circumstances, farm income may be lower than it would otherwise be if the farmer had not been required to adopt a set of farming activities that allowed for the possibility of responding to these events. If we compare, for example, results from the DSP model under favourable conditions with results from a non-embedded risk model under the same conditions, the less poor farm-household in Table 2 earns a net income of just under MK 80 under favourable conditions with the DSP model, as compared with potential earnings of over MK 90 in a non-embedded risk model of the same situation. A clear policy conclusion from this is that measures which reduce either embedded risk facing farmers or their aversion to such risk are likely to have a direct effect on farmers' average efficiency, productivity and welfare. This issue is well understood in the context of non-embedded risk (see, e.g. Ellis, 1993) but it is a point that first needs to be more widely understood in the context of embedded risk, and secondly may require policy analysts to have a greater understanding of when, where and how embedded risk is important in smallholder agriculture.

The limitations of a case study mean that the conclusions drawn need to be applied with caution to other situations. Ideally, more general empirical tests would be applied to the hypotheses examined in this paper. An approach that might be adopted in future might test for a relationship between variability observed in farmers' cropping activities in different farming systems with relative land and labour scarcity and market development.

The paper has also compared the performance of two different approaches to modelling embedded risk. The results support the contention of Hardaker et al. (1991) that DSP is the most generally appropriate formulation to use, but also highlight the importance of designing models and presenting their outputs to provide 'user-friendly' information accessible to the clients of the analysis. Interpretation of model outputs in terms of a semi-sequential strategy may be one means of achieving this.

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