SMALL FARM POLYPERIOD PLANNING MODEL FOR DEVELOPING ECONOMIES

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Farm planning in developed economies has reached the sophistication level of involving static and dynamic annual or polyperiod decision models. These models or frameworks range from unadorned linear programming to dynamic systems utilizing interdependence among time spans. Goal or criterion decisions range from unrestricted global profit maxamization to local profit comparisons restricted by risk and other considerations.

Systematic farm planning from the micro to the macro level is common in developed economies because of widespread knowledge of the planning tools and the availability of low-cost computational facilities. The potential increase in profits on large commercial farms makes the use of these planning tools profitable whether the farm unit bears the total cost or Extension Services or lending institutions subsidize their use.

Unfortunately, the same advantages are not present in developing economies, particularly for small subsistent farms. The farm units are too small for any potential change of income to support the cost of analyzing the farm operation via a sophisticated decision model. Regional agricultural decision models have been and are being designed for the agricultural segments of developing countries, but the decision level has been with the national or regional economy rather than the farm unit (Abkin; Byerlee and Halter; Stoecker, Nicol, and Sriplung).

International agencies have for some time been involved with planning agricultural economies for developing countries, but only recently have they shown an interest in small farm decision models. At least one small farm static linear programming model is available for general use in developing agricultural economies (Young and Rickards). However, we know of no polyperiod farm unit planning models in general use.

Currently, multiyear farm unit planning is being done for agricultural areas in developing countries without benefit of mathematical polyperiod decision models although Dean and De Benedicitis presented a framework for polyperiod models in 1964. Decisions are being made about crops, livestock systems, size of unit, government subsidies, and type of draft power through visual comparisons of relatively few budgets. Comparison among plans prepared by different personnel is a very tedious and inexact procedure. Further complications occur when plans are required to show discounted returns for a 20-year planning horizon, the time span often used by international development agencies. Annual decision models serve as aids in developing plans for these comparisons but do not answer time interaction questions, particularly those related to perennial crops and subsidy allocations.

Since Dean and De Benedicitis' work of 1964, the greater availability and lower costs of computing have enhanced the feasibility of polyperiod models for farm units in developing economies. Detailed annual restrictions which optimize the use of a limited resource over time, such as plant foods, are now feasible planning devices.

The purpose of this article is to describe the structure of a polyperiod model designed for use in developing economies. The goal of our research is to develop a polyperiod decision model encompassing planning horizons of up to 20 years with variable discounting capabilities.

The data and enterprise framework used to develop the model were obtained from planning work of project workers and consultants for FAO Project INS/72/005 in Indonesia. The annual crops considered are pasture, rice, ground nuts, cassava, maize, and soybeans. The perennial crops considered are cloves, rubber, palm oil, and coconuts. The cattle enterprise considered is native cattle suitable for draft and beef production.

Restrictions include a minimum of 0.67 hectares of rice for family consumption and a maximum family labor supply of 85 man-days per month. Size of farm units is one of the variables analyzed.

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MODEL DEVELOPMENT

Linear programming is chosen to permit the development of as simple a tool as possible given the time interrelationship and to provide global profit optimization for specified restrictions as the decision criterion. Because the aim is to develop a year-specific farm unit planning model to optimize investments and subsidies under restricted government and private monies, a detailed annual framework instead of group enterprises and blocks of years, as suggested by Dean and De Benedicitis, is used.

The first step in the model development is to devise a matrix or row and column labeling scheme. No scheme of labeling is perfect and thus the system for the small farm model has shortcomings. One of its major shortcomings is the complexity or size of the required label for each activity or row. An eight digit or space labeling system is used which is the maximum available on Mathematical Programming System-Extended (MPXS). The seventh and eighth places are reserved for year labeling, ranging from 01 to 20. The exception to this labeling scheme is in the objective row or income row over years which is labeled "D.INCOME." The D. refers to the potential for discounting. The fifth and sixth places are used for month designations on those rows or restrictions which require division by months and are labeled 01-12. These two spaces (5,6) are also used for distinguishing between enterprises or activities of the same crop that may differ by month of planting and/or draft power. The labels of all columns or activities begin with C.

The rows or restrictions may begin with any letter except C. Although columns or activities need only three letters for designation, the rows or restrictions require several schemes. The simplest encompasses yearly income rows which use the label INCOME plus the year designation in the seventh and eighth spaces. Rows that generate capacities for perennial crops use the same label as the activity column for which they are the generation capacity but are preceded by R instead of C. Land restrictions, in addition to the use of the month and year classification, have the potential for breakdown by type of land. Symbols used in model documentation include i for the first four spaces or name label, j for the fifth and sixth spaces, and k for the seventh and eighth spaces. These symbols are also used in the following tables to reduce size.

Income Transfer Section

The second step in developing the model is the framing of an income transfer section which transfers income of individual years to the planning period income (objective function of the model). The transfer activity is constructed to provide a summation of income for specific years and to permit discounting of annual income at either a fixed or variable rate over the planning horizon.

The section consists of two sets of annual income rows and an activity or column for each year to transfer income of that year to the objective function. The transfer activities are labeled from CDIN0001 through CDIN0020 (Table 1). The first row of the income transfer is the objective function labeled D.INCOME. The next 20 rows (the first set of annual income rows) are the income rows for the respective years which are labeled INCOME01 through INCOME20 (Table 1). The coefficient in the respective income row and the activity column is the actual income or net expense from that enterprise. The value of the coefficient in the income transfer activity and objective function row is the discount coefficient. Thus, the coefficient for CDIN0001 activity would be 1.0 and the coefficient for the income transfer activity for the second year would be 0.9 given a 10 percent discount rate. The coefficient for the twentieth year income row, assuming a constant discount of 10 percent per year, would be 0.13509. The coefficient of the income transfer activity and the yearly income row is 1.0; thus the level of the income transfer activity is the nondiscounted income for the year in question.

TABLE 1. INCOME TRANSFER SECTION

		Columns				
		Income Transfer Activities			Enterprise Activities[b]	
Rows	Restriction[a]	CDIN0001	CDIN0002 ...	CDIN0020	ij01	... ij20
D.INCOME	F	1.0	.90	.13509		
INCOME01	G	-1.0			ij01-I01	
INCOME02	G		-1.0			
...						
INCOME20	G			-1.0		ij20-I20
...						
MNIN0001	G				ij01-II01	
...						
MNIN0020	G					ij20-II20

[a]F means free and G on the INCOME01 through INCOME20 rows stands for greater than or equal to zero.
[b]Lowercase letter i denotes enterprise, e.g., rice, maize, cloves, and cattle; lowercase letter j denotes planting month and/or draft power and year of planting for perennial crops and age for cattle. Roman numerals denote a specific restriction or row equation (Ik = INCOMEk and IIk = M1N00k).

The second set of 20 rows encompasses the minimum income requirement rows for each year. These rows, MNIN0001 through MNIN0020, have the same coefficients in the activity column as the INCOMEk rows but do not have coefficients in the income transfer activities (CDIN00k).

As currently constructed, the model cannot reach a solution if income in any year is less than zero — income transfer activities would be required to operate at negative levels which are prohibited in linear programming.

Capital Accounting

Because both annual and investment capital are critical elements of a planning scheme, the model has a section allowing either restrictions on investment and annual capital by years or a framework by which the magnitude of these values can be easily determined by years. The capital accounting section consists of 100 rows (five for each year) and one transfer activity for each year (Table 2). RCAP01k represents annual capital for the kth year, RCAP02k symbolizes investment capital, RCAP03k stands for the sum of investment and annual capital, RCAP04k means cumulative investment capital required through the kth year for the perennial enterprise in question, and RCAP05k is a row developed to allow an interest charge on accumulated investment. If a greater-than-or-equal-to-zero restriction is placed on RCAP05k, such rows simply become duplicates of the RCAP04k rows. If a less-than-or-equal-to-zero restriction is placed on these rows, an interest charge is required on accumulated investment for respective years. Interest can vary by year. The coefficients of interest charging activities (CINT0001-CINT0020) and income rows are decimal values of the interest rate desired. The example in Table 2 uses 10 percent or 0.10.

TABLE 2. CAPITAL ACCOUNTING[a]

		Columns					
		Interest Charging Activities			Enterprise Activities		
Row	Restriction	CINT0001	...	CINT0010	ij01	...	ij20
INCOME01	G	-.1					
...							
INCOME20	G			-.1			
RCAP0101	L or G				ij01-III101		
...							
RCAP0120	L or G						ij20-III120
RCAP0201	L or G				ij01-III201		
...							
RCAP0220							ij20-III220
RCAP0301	L or G				ij01-III301		
...							
RCAP0320	L or G						ij20-III320
RCAP0401	L or G				ij01-III401		
...							
RCAP0420	L or G						ij20-III420
RCAP0501	L or G	-1			ij01-III501		
...							
RCAP0520	L or G			-1			ij20-III520

[a]Lowercase letter i denotes enterprise or activities, e.g., cloves or rubber, and j denotes difference in draft and/or month of planting (year of planting for perennial crops). Roman numerals denote a specific restriction or row equation: III1k = RCAP01k, III2k = RCAP02k, III3k = RCAP03k, III4k = RCAP04k, and III5k = RCAP05k. Note: coefficients for III3k = III1k + III2k and III5k = $\sum_{1}^{k}$III4k, where k denotes year.

[b]Greater-than-or-equal-to-zero restriction ("G" and zero RHS value) on the RCAP01k rows designates these rows as add-up rows. Less-than-or-equal-to a specific RHS value ("L" and RHS value) makes RCAP01k through RCAP04k restricted to the value in the RHS. Less-than-or-equal-to-zero ("L" and zero value in RHS) on RCAP05k rows forces the interest charging activities (CINT0001. . .CINT0020) to be utilized. The coefficient for the intersection of the INCOMEk rows and CINT00k columns is the decimal equivalent of the interest rate. Note: If greater-than-or-equal-to restrictions are used on both RCAP04k and RCAP05k, they become duplicates.

Land, Labor, and Draft Restriction

This section of the model bridges the land, labor, and draft restrictions over the 20-year planning period. In reality this section consists of 20 sets of individual restrictions. The interrelationships between years is accomplished via activities rather than rows. There are two sets of restrictions: one on an annual basis and one on a monthly basis. This division allows changes in farm size via parametric programming on an annual basis whereas activities (CLND1001-CLND1020) transform annual restriction into monthly restrictions for respective years (Table 3). The annual restriction rows are LND10001 through LND10020. The fourth digit of this coding scheme represents the space allotted for land quality or types. The monthly row restriction labels are similar, except that instead of zeros in the fifth and sixth places a two-digit labeling system 01-12 is used for the months.

TABLE 3. LAND, LABOR, AND DRAFT RESTRICTIONS[a]

		Columns					
		Land Activities			Enterprise Activities		
Row	Restriction	CLND1001	...	CLND1020	ij01	...	ij20
LND10001	G	1.0					
...							
LND10020	G			1.0			
LND10101	G	-1.0			ij01-IV0101		
...							
LND11201	G	-1.0			ij01-IV1201		
:::							
LND10120	G			-1.0			ij20-IV0120
...							
LND11220	G			-1.0			ij20-IV1220
LABR0101	G				ij01-V0101		
:::							
LABR1220	G						ij20-V1220
DRFT0101	G				ij01-VI(1)0101		
:::							
DRFT1220	G						ij20-IV(1)220
DRFU0101	G				ij01-VI(2)0101		
:::							
DRFU1220	G						ij20-VI(2)1220

[a]Lowercase letters i and j are used to designate segments of the activity labeling scheme — i represents an activity such as rice, maize, or cloves; j represents draft power and/or month of planting (year of planting for perennials). Roman numerals represent row equations or restrictions: IVjk = LAN1jk, Vjk = LABRjk, VI(1)jk = DRFTjk, and VI(2)jk = DRFUjk.

Labor restrictions are monthly. The label for labor begins as LABR and the next four spaces designate month and year as specified for land restrictions. The monthly draft restrictions, as currently set in the model, are for cattle. Two sets of rows are used for draft restrictions: DRFTjk, generating and limiting; and DRFUjk, summary of draft days used by month and year. The DRFTjk rows contain generating and using coefficients with the restriction that use cannot exceed generation; therefore, the activity level of these rows does not provide an easy means of summing actual use. The second set of rows, DRFUjk, are for convenience only and can be deleted if computer core limitation is a factor. Although the model uses only draft for animals, the addition of a series of activities can allow tractor power to substitute for animal draft.

Twelve hired labor activities for each year are in the model. These activities (one for each month) are man-day hiring activities, labeled CHLA0101 ... CHLA1201 through CHLA0120 ... CHLA1220. Upper limits can be placed on hiring activities by the addition of a row for each activity.

Annual Crop Enterprises

The basis for the annual crop enterprise section is the Indonesian case study of the annual small farm model developed by Young and Rickards. The annual crop enterprises in the Young and Rickards model are in the polyperiod model with a slightly different labeling system, i.e., numbers for months and additional code for years. The same system for distinguishing between animal draft and man power for preparing land is used in this model as is used in the Young and Rickards model, i.e., the first set of enterprises are for animal draft power and the second set for human labor in ground preparation for respective crops. That is, with rice as an example, CRIE01k uses animal draft power and CRIE02k uses man labor for preparing ground. This convention appears more convenient than using man labor and draft animal activities and having land preparation requirements for each enterprise. The model distinguishes between calendar years for labor requirements. Thus, a crop enterprise planted in year k in many instances requires land and labor in year k+1.

Income from annual crop enterprises includes returns to land, labor, and management. Thus, returns for annual enterprises equal value of production (sold or consumed) minus variable costs associated with fertilizer, seed, pesticides, and non-investment outlays. No capital investment is used in annual enterprises; therefore, capital entries are contained only in the RCAP01k and RCAP03k rows.

Entries for annual enterprises include annual income, capital, wet and dry feed, and monthly land, labor, and draft (when applicable) coefficients.

The rice enterprise has the only minimum level on any crop enterprise activity. Restrictions labeled RIEM00k are used to require .67 hectares of rice for food each year.

Livestock

Two distinct livestock enterprises are used for each year because an animal requires two years to develop into a mature animal from a calf. These are labeled CCAT01k for animals up to one year of age and CCAT02k for all older animals. Buying and selling activities are included for both cattle enterprises each year. The CCAT01k enterprise generates either a one-year-old animal to be sold at the end of the period or a one-year-or-older animal for the next period. The one-year-or-older animal generates draft power potential and capacity for young animals in the next period (k+1) or mature animals for sale (Table 4).

TABLE 4. LIVESTOCK ENTERPRISES[a]

	Activities or Columns					
	Cattle Buying		Cattle Selling		Cattle	
Rows	CBCT01k	CBCT02k	CSCT01k	CSCT02k	CCAT01k	CCAT02k
Income & Capital						
INCOMEk	-41250	-82500	37500	75000		
RCAP01k	41250	82500	-37500	-75000		
RCAP03k	41250	82500	-37500	-75000		
Cattle Transfer						
RCAT01k	-1		1		1	
RCAT01k+1						-.4
RCAT02k		-1		1		1
RCAT02k+1					-1	-1
Food Requirements						
WFED00k					12.4	24.8
DFED00k					6.2	12.4
Labor Requirements						
LABR01k					1.0	2.0
LABR12k					1.0	2.0
Draft Generating						
DRFT01k						-8.12
DRFT12k						-8.12

[a]Lowercase letter k is used for year designation.

The animals have forage requirements of wet feed (WFED00k) and dry feed (DFED00k) by year. These feed requirements can be supplied by pasture and/or crop refuse.

Perennial Crops

The perennial crops section allows the establishment of perennial crops during any part of the planning horizon. This capability also enables the model to determine optimum replacement policies (Faris). Although an unlimited establishment horizon drastically increases the size of the model, the flexibility of being able to compare influences of various capital structures on establishment options for various years and to include replacement policy as part of the decision process is deemed desirable. In reality, establishment potential beyond the year in which income can be realized within the planning horizon is wasted refinement. Thus, for a perennial crop with an eight-year maturation period, establishment potential beyond the tenth and eleventh years for a 20-year model is extraneous. The perennial crops section is developed from data obtained for the Indonesian WAI TUBA transmigration project by a French consulting firm.

Four perennial crops are used in this section: cloves, rubber, palm oil, and coconuts. Cloves and rubber have the potential of being planted in year 1 through year 10; palm oil, year 1 through 12; and coconuts, year 1 through 13. The labeling system is similar to that of annual crops except that spaces five and six designate the year of planting. Thus, space 1 has a C for designation of column or activity, spaces 2-4 are the actual name label, i.e., CLV for cloves, RUB for rubber, PMO for palm oil, and CON for coconuts.

Intercropping with annual crops is possible in the early development stage of some perennial crops (Table 5). The intercropping potential is captured by limiting the land needed for perennials to the part of the hectare actually used by the perennial plants.

TABLE 5. PERENNIAL CROPS

Crop	Label[a]	Years of Planting Possible	Years Intercropping Possible
Cloves	CCLVjk	10	0
Rubber	CRUBjk	10	3
Palm Oil	CPMOjk	12	2
Coconuts	CCONjk	13	4[b]

[a]Spaces 5 and 6 in the label are used to designate year of planting (denoted by lowercase letter j); j ranges from 01 through 10 for cloves and rubber, 01 through 12 for palm oil, and 01 through 13 for coconuts. The seventh and eighth spaces designate the calendar year (denoted by lowercase letter k). Thus, there are 10 separate enterprises for cloves and rubber, 12 for palm oil, and 13 for coconuts. These separate enterprises have multiple segments over years ranging from 20 segments, for those planted in year 1, to 8 segments, for coconuts planted in the thirteenth year. Spaces 7 and 8 in the label denote year of farm plan.

[b]From the fifth year to the end of the planning period 0.8 hectares of pasture are available per hectare of coconuts.

Coconut production, as used in this model, has a potential for generating pasture in adult coconut trees. This potential is accommodated by having a separate enterprise for each year called coconut pasture, labeled CCPS00k. A hectare of mature coconut trees generates 0.8 hectares of potential pasture.

Each perennial crop has a row generating the potential for the perennial crop to be grown in the succeeding year (k+1). For example, for cloves that were planted in year 1 there is a generating capacity row for each succeeding year through year 20. Also, a separate complement of rows is used for each year of planting. These rows have designations similar to those of the activity rows but start with R instead of C. The perennial crops have entries in investment capital, accumulated capital, interest on accumulated capital, and the respective perennial crop capacity rows for k and k+1 in addition to entries in labor, land, and annual capital during producing years.

MODEL SIZE

The model, as currently constructed, has approximately 1,900 non-slack rows, 2,400 activities, and approximately 46,700 non-zero elements. The perennial crop generating activity and 20 sets of annual activities are the main causal factors for low density. Solving the model without a basis on an IBM 370-158 required from 15 to 22 minutes of central processor unit (CPU) time. Starting with an established basis and making moderate revisions reduces the CPU time to 3 to 5 minutes. Although the model is too expensive for individual farm analysis, it is suitable as a planning tool for areas being developed or revitalized.

SMALL FARM POLYPERIOD MODEL RESULTS

Because of labor restrictions and estimated 1978 prices, the coconut enterprise was the only competitive perennial crop. Even with free investment capital, perennial crops of cloves, rubber, and palm oil did not enter maximum profit farm plans. However, many planners are currently promoting rubber and cloves for the case area for the purpose of providing a cash income.

The cattle enterprise was very competitive given the labor situation and availability of forage from crop residues. With no subsidy the cattle enterprise started very modestly (sharing cattle among units) and gradually developed to a 13-unit herd on 3.75 hectares (Table 6). Beginning the planning period with two calves merely decreased the time needed for the herd to reach 13 animals. All of the two-year-old animals were sold — none were used for draft. In fact, with the constraints and prices described, buying young calves was more profitable than raising them. In subsequent analyses the alternative of buying calves was removed because in some new agricultural areas a calf market with external supplies is unlikely.

To explore the relationship between animal draft and manual labor for land preparation,

TABLE 6. NUMBER OF TWO-YEAR-OLD CATTLE SOLD[a]

	Farm Planning Horizon											
	1	2	3	4	5	6	7	8	9	10	11	12
No. Cattle at start of planning period	0	0	0	0	0	.5	.5	1.0	2.5	4.5	8.0	13
Two Calves at start of planning period[b]	0	2	4	7	12	13	13	13	13	13	13	13

[a]Calf purchases permitted.
[b]The discounted income for the 20-year period increased 230 percent with the supplying of two calves at the beginning of the planning period (year 1).

two types of variations were performed: (1) with only annual crops considered, land was increased from 3.75 to 8.75 hectares in increments of 1.0, and (2) the option of hired labor was removed and family labor supply was reduced from 85 to 51 man-days per month, with both perennial and annual enterprises. With only annual crop enterprises considered, optimum farm plans included pasture after all the family labor was utilized on annual crops, but no enterprise requiring animal draft entered the optimum solution (Table 7). Reduced

TABLE 7. INFLUENCE OF INCREASE IN FARM SIZE

	Size of Farm (Hectares)					
	3.75	4.75	5.75	6.75	7.75	8.75
Number of two-year olds sold in 6th year[a]	13	17	21	25	29	33
Hectares of pasture	0.0	3.8	4.9	5.9	6.9	7.9
Percent change in income from addition of one hectare	-	123	119	114	112	111

[a]Purchase of calves permitted.

family labor and elimination of hired labor did not reduce the hectares of perennial crops. However, size of the cattle enterprise was reduced and animal draft was utilized for land preparation. In the analyses indicating animal draft in the optimum solution, a mature animal had to be supplied in the initial year in order to allow a solution.

The influence of costing or charging for cumulative investment in perennial crops was investigated by determining the optimum organization with and without an interest charge on accumulated capital. Removing the interest charge on accumulated capital involving perennial crops increased the total hectares of the entering perennial crop (coconuts) 3.7 percent, but the major influence resulted from increased plantings in the first and second year and reduced plantings in the third year. The size and type of cattle enterprise were unaffected.

Although the average annual present value was equivalent to $920, minimum annual income analyses showed that the minimum nondiscounted sum of cash sales plus value of product consumed of $95 per year could not be realized during the first four years without the combination of input subsidies and subsistence payments. These analyses substantiate the vulnerability to failure of the units in the beginning years and the need for financial subsidies for farm unit development.

Cattle prices were parametrically reduced to determine when cattle for sale would be removed from the farm plan. This point was not reached until cattle returns were reduced by 67 percent (Table 8).

TABLE 8. INFLUENCE OF CATTLE PRICE REDUCTIONS

	Cattle price as percent of original base price				
	87	73	60	47	33
Percent income reduction	36	61	71	75	78
Income elasticity with respect to beef price	2.76	2.60	1.50	.64	.34

CONCLUSIONS

Polyperiod linear programming is a feasible decision tool to use in farm unit planning for small subsistence farms in a developing economy. It is not economically feasible for use by the individual farm unit, but is very helpful in preparing agricultural plans for virgin areas and areas designated for revitalization.

The restrictions are relatively large in number and can be used as a decision aid if a logical plan of restriction variation is used in the programming. Unfortunately, perennial crops with an unrestricted establishment horizon increase the model size quickly, but the benefits far outweigh the costs.

In regions where poverty is so severe that increased food supplies are consumed because of the addition of relatives to the farm household, perennial cash crops can be a feasible means of maximizing cash income above food requirements. The flexibility of the small farm polyperiod model is sufficient to encompass such situations whether for social or political reasons, and thus is an excellent tool for planning and periodic reevaluation. The consideration of alternative strategies in most instances will be as important or more important than the actual delineation of optimum farm unit plans. The influences of the interaction among restrictions, price change, and time are also important objectives in themselves.

REFERENCES

Abkin, M. "The National Economy Model of KASM: Technical Documentation and Users Guide." Dep. Agr. Econ., Michigan State University, *KASS Special Report* 18, 1976.

Byerlee, D. and A. N. Hatler. "A Macro-Economic Model of Agricultural Sector Analysis." *Amer. J. Agri. Econ.* 56(1974):521-33.

Dean, G. W. and M. De Benedicitis. "A Model of Economic Development for Research Farms in Southern Italy." *Amer. J. Agr. Econ.* 46(1964):295-312.

Faris, J. E. "Analytical Techniques Used in Determining Optimum Replacement Policy." *J. Farm Econ.* 42(1960):755-66.

Stoecker, A. L., K. J. Nicol, and S. Sriplung. "Structure of a Recursive Model for Policy Analysis in Thailand." DAE-CARD *Sector Analysis Series* No. 11, 1978.

Young, D. F. and P. H. Rickards. "AGRIPLAN — A User's Manual for Small Farm Analysis." University of New England, Armidale, Australia, 1978.