MODELING AND ANALYZING SMALL FARM LIVELIHOOD SYSTEMS WITH LINEAR PROGRAMMING

AEB 5167
Economic Analysis of Small Farm Livelihood Systems

EXERCISES

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PREFACE

This set of learning exercises constitutes a manual designed for graduate students and others interested in agricultural development in countries where small-scale, limited-resource family farm livelihood systems are important to the national economy. It was developed for the course AEB 5167, Economic Analysis in Small Farm Livelihood Systems, in the Food and Resource Economics Department at the University of Florida. It has been used in short courses for international agricultural development workers (research and extension) as well. Because of the highly varied background of those interested in development, the exercises do not require a high level of mathematical nor economic sophistication, but a minimum level of computer literacy is assumed.

The course, AEB 5167, is based on the philosophy that the best way to analyze small-scale limited-resource family farms is to intimately understand the relationships and interactions integral to them. Responses of these men and women farmers to new technologies, modified infrastructure, or price or policy incentives are molded by the constraints on these livelihood systems because the *farms are a home, not just a business*. For this reason, *gender analysis* and *household composition* are critical components to be incorporated explicitly. It has also been found that *seasonal cash flow* and *seasonal food availability* are important drivers of these livelihood systems and must be incorporated on a multi-period basis within a year.

Relatively simple, single year models are very useful for many analyses. However, when livestock, fallow systems and perennial crops are involved, as is the general rule, then multiple-year, dynamic models are usually indispensable. The last set of exercises incorporates these aspects of analysis.

After an introduction to linear programming and the use of Excel ® (an example of a spreadsheet capable of solving linear programming problems) the exercises begin with a simple situation that is easy to model. Each additional exercise introduces a new procedure to help make the model more realistic. It is also suggested that when users begin to construct their own models, they follow the same step-by step procedure making sure that solutions are feasible and the matrix is behaving as anticipated prior to making it more complicated. Once a large matrix is constructed, it is much more difficult to trouble shoot. It is important also for users to interpret each solution in turn to help in improving the ultimate model.

The suggested matrices are not the only way to set up the exercises. There could be a number of "correct" ways to structure any particular situation. **Beginning with exercise one, it is strongly suggested that the user of**

this manual attempt to construct his or her own linear programming matrix before looking at the suggested matrix. *The important point is that there should be internal consistency and that the model reflects all the constraints and interrelationships that exist in the livelihood system being modeled. It is also necessary to determine and use appropriate objective functions (what the farm family is trying to achieve).*

By the time users of this manual have completed all the exercises, they should be able to begin construction of their own models using their own data for the number of purposes for which linear programming is useful.

CONTENTS

DYNAMIC PROGRAMMING

I. INTRODUCTION TO MATRIX CONSTRUCTION AND SOLUTION WITH MICROSOFT EXCEL®

Linear Programming (LP) is a useful, and with the wide availability of laptop computers, easily available method for describing and analyzing family farm livelihood systems. A livelihood system is the full range of activities available to the individuals in a particular set of small farm households. Farmers select from among these options those that comprise their livelihood strategies – those activities that best contribute to achieving the household's production and reproduction goals to survive and thrive. A well-designed linear program (LP) reflects these choices by selecting a combination of farm and non-farm activities that is feasible given a set of fixed farm constraints and that maximizes (or minimizes) a particular objective or family goal while achieving other goals such as food security. The LP model requires the following in each farm household situation: 1) the farm and non-farm activities and options available in the crop and livestock sub-systems with their respective resource requirements, and any constraints on their magnitude; 2) the fixed resources and other maximum or minimum constraints that limit farm and family activities; 3) cash costs and returns of each relevant activity; and 4) a defined objective or objectives.

An example is used to introduce matrix construction and solution using an Excel spreadsheet format. A hypothetical farm model is created in a hypothetical country. Crops considered are sweet potatoes, sorghum, beans and peanuts, Table A.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4											
5			Activities>	Sw. pot.	Sorghum	Beans	Peanuts				
6			Variables>	0	0	0	0		RHS	Resource	
7		Constraints v	Unit v >	ha	ha	ha	ha			Use	Constraints v
8		Land	ha	1	1	1	1	<=	2		Land
9		M. Labor	days	20	30	40	12	<=	40		M. Labor
10		F. Labor	days	20	0	10	4	<=	25		F. Labor
11		Beg. Cash	dollars	0	0	40	35	<=	30		Beg. Cash
12		End. Cash	dollars	80	20	45	55	>=	130		End. Cash
13											

Table A. Basic linear programming matrix

Land is limited to 2 ha (cell I8), male labor to 40 days, female labor to 25 days and beginning cash on hand to 30 dollars. Cash income (ending cash) for one hectare of each crop, assuming the product is sold, is as follows: sweet potatoes, $80; sorghum $20; beans, $45; and peanuts, $55. These values are in row 12. Labor and beginning cash requirements for one hectare of each crop are also shown in Table A. For instance, production of one hectare of sweet potatoes requires 20 days of male labor (cell D9), 20 days of female labor and no beginning cash. The Right Hand Side (RHS) represents the constraints on the resources (cells I8 to I11). The RHS also indicates that the family needs at least

$130 at the end of the year ($30 for the next year's crops and at least $100 for other necessary expenses), cell I12. The variable row (row 6, cells D to G) indicates how many units (hectares in this case) of each crop comprise the solution that best satisfies the objective or goal. Table A represents the basic structure of a linear programming matrix for this kind of farm situation.

The desire (objective or goal) of this hypothetical farm family is to maximize the amount of cash available at the end of the year. This is the sum of the amount of ending cash for each crop (when sold), per ha, multiplied by the area (hectares) of each crop that ends up in the solution. Excel has a convenient formula that can do this for us. It is called =**sumproduct**. The use of the formula is shown for cell J12 (the solution cell) in Table B. Notice that when you enter the formula, a number (zero at this point) shows in the cell.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4											
5			Activities>	Sw. pot.	Sorghum	Beans	Peanuts				
6			Variables>	0	0	0	0		RHS	Resource	
7		Constraints v	Unit v >	ha	ha	ha	ha			Use	Constraints v
8		Land	ha	1	1	1	1	<=	2		0 Land
9		M. Labor	days	20	30	40	12	<=	40		0 M. Labor
10		F. Labor	days	20	0	10	4	<=	25		0 F. Labor
11		Beg. Cash	dollars	0	0	40	35	<=	30		0 Beg. Cash
12		End. Cash	dollars	80	20	45	55	>=	130	=SUMPRODUCT(D12:G12,D$6:G$6)	End. Cash

Table B. Formula for objective function

When the computer is solving the problem, it must also keep track of the amount of each of the resources or constraints being used at each step (iteration) in the process. The =**sumproduct** formula is also used for this and the formula for land is shown in Table C. The $ sign before the 6 (C$6:F$6) is useful for copying the formula down to the other rows. The $ holds the row being multiplied to row 6 where the variables are. Otherwise, when you copy the formula down to the other rows, the spreadsheet would move that row down as well.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4											
5			Activities>	Sw. pot.	Sorghum	Beans	Peanuts				
6			Variables>	0	0	0	0		RHS	Resource	
7		Constraints v	Unit v >	ha	ha	ha	ha			Use	Constraints v
8		Land	ha	1	1	1	1	<=	2	=SUMPRODUCT(D8:G8,D$6:G$6)	Land
9		M. Labor	days	20	30	40	12	<=	40		0 M. Labor
10		F. Labor	days	20	0	10	4	<=	25		0 F. Labor
11		Beg. Cash	dollars	0	0	40	35	<=	30		0 Beg. Cash
12		End. Cash	dollars	80	20	45	55	>=	130		0 End. Cash
13											

Table C. Formula for resource use

Table D shows all four formulas for the RHS as well as for the objective function.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4											
5			Activities>	Sw. pot.	Sorghum	Beans	Peanuts				
6			Variables>	0	0	0	0		RHS	Resource	
7		Constraints v	Unit v >	ha	ha	ha	ha			Use	Constraints v
8		Land	ha	1	1	1	1	<=	2	=SUMPRODUCT(D8:G8,D$6:G$6)	Land
9		M. Labor	days	20	30	40	12	<=	40	=SUMPRODUCT(D9:G9,D$6:G$6)	M. Labor
10		F. Labor	days	20	0	10	4	<=	25	=SUMPRODUCT(D10:G10,D$6:G$6)	F. Labor
11		Beg. Cash	dollars	0	0	40	35	<=	30	=SUMPRODUCT(D11:G11,D$6:G$6)	Beg. Cash
12		End. Cash	dollars	80	20	45	55	>=	130	=SUMPRODUCT(D12:G12,D$6:G$6)	End. Cash
13											

Table D. All formulas

NOTE: When you set up the matrix for solution, follow the rows and columns carefully as shown in the examples.

To solve the linear program with Excel, use **Tools/Solver/**, (Figure 1):

Figure 1 Set-up of Solver dialog box
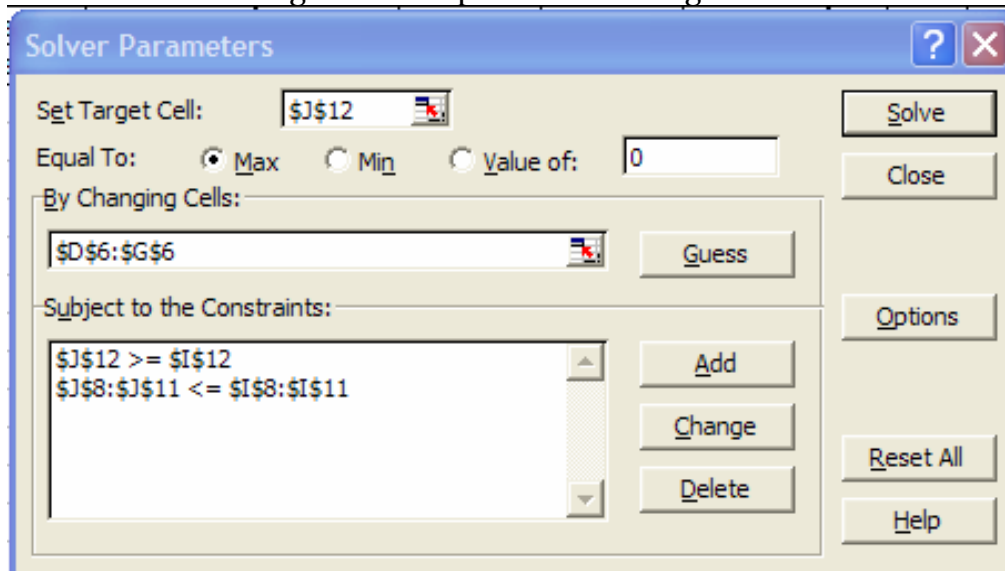
- ✓ Identify the **solution cell** (in this example) as $J$12. "$J$12" can simply be typed into the **Set Target Cell** box or you can click on the red arrow and highlight cell J12, and then minimize the parameters window.
- ✓ Make sure the problem is to "**Equal to: Max**" (select it by clicking).
- ✓ Identify the **variable cells** by clicking on the red arrow, then highlighting the variable cells ($D$6:$G$6) and then minimizing the parameters window.
- ✓ To incorporate the **constraints**, first click **Add** next to the "**Subject To Constraints**" box, then highlight the resource use cells (those with the formulas, or J8 to J11), then click <= (less than or equal to) and then click on the arrow for the constants (RHS) and highlight the constants (I8 to I11). This tells the computer that the solution cannot use any more of the resources than available (the use must be <= to the amount available).

- ✓ To incorporate the **minimum end cash**, click <u>**Add**</u> again, then click on cell J12 (or type it in the space), then click >= (greater than or equal to), and then click on the arrow for the constants (RHS) and highlight the cell with the minimum amount of ending cash (I12).
- ✓ It is also necessary to tell the computer that the variables cannot be negative. So go to **Options** and chose **Assume Non-Negative**.
- ✓ Still on **Options**, choose "**Assume Linear <u>Model</u>**" to make sure it uses only linear functions.

Figure 2. Solver options
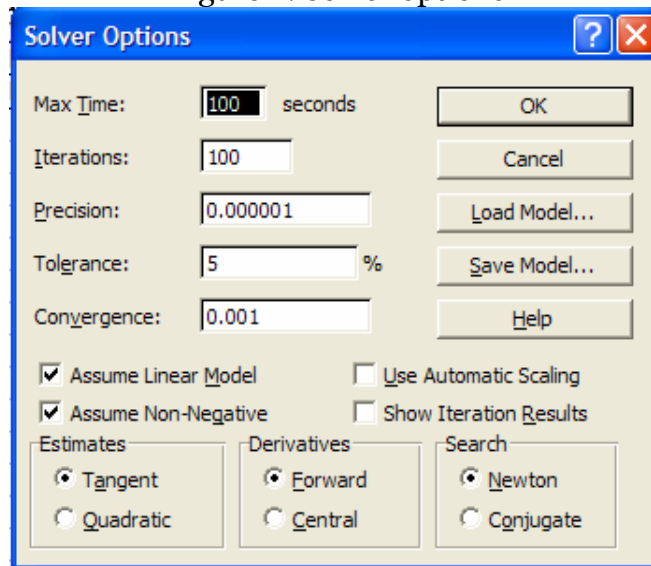
- ✓ Click **OK** on the Sover Options menu.
- ✓ To **solve** the model, click <u>**Solve**</u> on the Solver Parameters menu.
- ✓ When the solver results window appears, it will indicate that solver has found a solution and that all constraints and optimality conditions are satisfied. Leave marked (by default) <u>**Keep Solver Solution**</u> and highlight on <u>**Reports**</u> (Answer, Sensitivity, and Limits) and these will be posted in three new sheets. The Detail Report is not usually needed.

Figure 3. Solver results confirmation
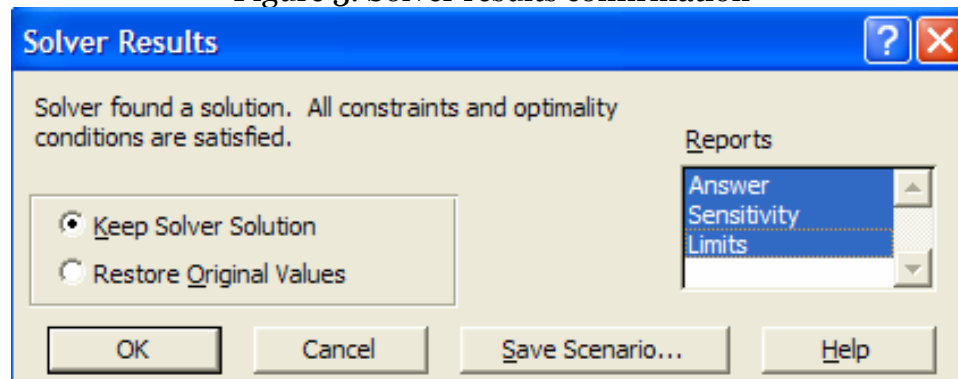
If you entered the problem correctly, this should provide you with a solution as in Table E which shows that the strategies for this farm, as specified in the model, are to produce 1.08 ha of sweet potatoes, 0.06 ha of sorghum, no beans, and 0.86 ha of peanuts. All the land is used, as well as all the female labor and beginning cash, but some male labor is unused (about 6.2 days) . End cash exceeds the minimum by nearly 5 dollars.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4											
5			Activities>	Sw. pot.	Sorghum	Beans	Peanuts				
6			Variables>	1.08	0.06	0.00	0.86		RHS	Resource	
7		Constraints v	Unit v >	ha	ha	ha	ha			Use	Constraints v
8		Land	ha	1	1	1	1	<=	2	2.00	Land
9		M. Labor	days	20	30	40	12	<=	40	33.79	M. Labor
10		F. Labor	days	20	0	10	4	<=	25	25.00	F. Labor
11		Beg. Cash	dollars	0	0	40	35	<=	30	30.00	Beg. Cash
12		End. Cash	dollars	80	20	45	55	>=	130	134.71	End. Cash

Table E. Solver solution of the simulated system

If you have successfully completed this exercise, you should be ready to begin formulating and solving the following exercises. Remember, in each exercise try to set up the matrix based on the discussion of the situation *before* you look at the suggested matrix.

II. INTRODUCTION TO EXERCISES

The following exercises are designed to introduce you to the concepts and mechanics of linear programming (LP). The software used is Excel ®, but other spreadsheets are also amenable to LP. Each of the nine exercises introduces a new concept and new mechanics. After you have understood and mastered these exercises you will know most of what you need to develop your own linear programming models. The values used in the problems are not necessarily realistic, but the exercises are set up in a realistic manner.

Scenario

A farming systems field team wants to pretest some technologies and be able to predict what responses the small-scale farmers in their area of responsibility might make to these potential changes. The first task is to *simulate the livelihood system available to the small farms in their area (a descriptive model).* Once they have a model that adequately reflects the livelihood system, the team uses the model to assess potential changes in livelihood strategies of individual households and then assess potential adoption of a proposed new technology. The model can also be used to provide information to the government about probable varying responses of diverse farmers to a proposed change in price policy *(predictive models).*

Exercises

The exercises present a situation and ask you to create a linear programming matrix that accomplishes what the team has in mind. Suggested matrices and the solutions are provided, but should not be used until after you have attempted to build your own matrix. Compare the solutions with your own.

Exercise 1. <u>Basic LP matrix</u>

Situation

You are a member of a team responsible for improving technology in an impoverished area of your country. The team has been working with farmers and has some ideas for improving the productivity of the farms in its area of responsibility and the cash income available to the families for discretionary spending.

The team members want to <u>pre-evaluate some alternatives</u> they think might interest the farmers. To do this, they want to use linear programming. First they must <u>simulate the livelihood system</u> in the area. That is, the first step is to create a <u>descriptive model</u> of the many activities available to all households for which the livelihood system is relevant. These activities must include those available to all members of the household, and whether conducted on or off the farm. As they begin to develop the model, they will work with a typical household and its set of resources.

Note: The values used in this and the following examples are not necessarily realistic. When you create your own models, they should be as realistic as possible.

The household the team starts working with produces goats, maize and hay, and some of the farm is often in fallow. The household (man, wife, adolescent male, child) farms 3 ha. For the year, they estimate 115 days of labor available for production activities and $700 of cash available for production. The team calculates that a goat requires 0.1 ha of pasture (not including the fallow), 7 days of labor and $49 of the beginning cash reserve. The annual cash income per goat is $330. A ha of maize would return $1800 cash income and a ha of hay, if sold, would return $300 cash. A ha of maize requires $200 of the cash reserve and 40 days of labor. A ha of hay requires $150 of the cash reserve and 30 days of labor. The farm family wants to maximize <u>cash available for discretionary spending</u> (the cash available after satisfying food and other household needs and necessary cash expenses). At the very least they need $1000 <u>non</u>-discretionary cash at the end of the year. This provides for the $700 cash needed at the beginning of the next year as well as for other necessities not produced on the farm. The amount of cash available at the end of the year above $1000, then, is available for discretionary spending.

Exercises

I. Construct the linear programming matrix following the format used in the introductory model. Carefully label all variables, constraints, and units for rows and columns. The objective is to maximize cash available for discretionary spending at the end of the year. *Remember; try to set up your model before looking at the suggested model on the next page.*

II. Solve the problem to determine if there is a feasible solution.

Note: An infeasible solution means all constraints cannot be met. An unbounded matrix means there is no effective limit to the objective function.

III. Discuss and interpret the solution if it is feasible. (See, for example, the discussion of this solution in the **Situation** statement for Exercise 2.)

	A	B	C	D	E	F	G	H	I	J
1										
2		VARIABLES >>		MAIZE	HAY	GOATS				
3		AMOUNT >>		1.31	0.00	8.93			RESOURCE	
4		RES/CONST		ha	ha	head		RHS	USE	RES/CONST
5		LAND	ha	1	1	0.1	<=	3	2.21	LAND
6		LABOR	days	40	30	7	<=	115	115.00	LABOR
7		CASH	$	200	150	49	<=	700	700.00	CASH
8		CASH INCOME	$	1800	300	330	>=	1000	5308.93	CASH INCOME

Table 1. Suggested matrix and the solution for exercise 1

Exercise 2. Intermediate products and accounting rows

Situation

In the solution to the first exercise, both maize and goats are produced, but no hay. However, the farmers say that goats must have hay to supplement the pasture and there is no real market for hay. This oversight in the elaboration of the first model must be corrected. The farmers estimate that a goat requires 0.6 tons of hay. One ha of land in hay produces 4 tons of hay.

Exercises

I. Modify the LP matrix from the first exercise to include a hay **accounting row**. Remember that if hay is fed to the goats and not sold directly, the value for hay in the objective function cannot reflect the value of the hay if it were sold (otherwise, you would be indicating you are selling it and feeding it as well).

Note: Because hay is produced in one activity and used in another (it is an **intermediate product**), it is necessary to have an **accounting row** in the matrix (hay accounting). The initial constraint (RHS) for this row would be <= zero if there is no hay in storage at the beginning of the year. A positive number in the RHS of the accounting row, such as 2, would indicate that two tons of hay were in storage at the beginning of the year and could be used before it would be necessary to produce more. Because resource-*using* coefficients are positive, an activity that *produces* a product or resource must have a negative coefficient in the accounting row. Also note that if this accounting row is added *inside* the matrix (say between labor and cash), the formulas in the *resource use column* will automatically adjust. You will only need to copy the resource use formula (the =*sumproduct* formula) from labor to hay accounting.

II. Discuss and interpret the solution.

	A	B	C	D	E	F	G	H	I	J
1										
2		VARIABLES >>		MAIZE	HAY	GOATS				
3		AMOUNT >>		2.88	0.00	0.00			RESOURCE	
4		RES/CONST		ha	ha	head		RHS	USE	RES/CONST
5		LAND	ha	1	1	0.1	<=	3	2.88	LAND
6		LABOR	days	40	30	7	<=	115	115.00	LABOR
7		HAY ACCTG	tn		-4	0.6	<=		0.00	HAY ACCTG
8		CASH	$	200	150	49	<=	700	575.00	CASH
9		CASH INCOME	$	1800	300	330	>=	1000	5175.00	CASH INCOME

Table 2. Suggested matrix and the solution for exercise 2

Exercise 3. Family consumption constraints, transfer activities and cash flow

Situation

In the second exercise, only maize entered the solution, and it was all sold (compared with the first solution, this reflects the fact that goats now require more resources – those needed to produce the hay they need – and therefore, return less cash to the resource base). However, *no maize was stored for family consumption*. The farmers estimate that 35 cwt of maize is required for family consumption (the **consumption constraint**, one of the family goals), and this is usually produced on the farm rather than purchased. The *dependable yield* of maize is about 30 cwt per ha. Surplus maize is often sold.

Exercises

I.   Modify the LP matrix from the second exercise to provide for at least 35 cwt of maize for family consumption. Also structure the matrix so that any surplus maize can be sold (at a price of $60/cwt). This requires a maize accounting row because there are alternative uses for the maize. The maize production activity *produces* maize (30 cwt/ha) into the maize accounting row (a negative coefficient), and the maize selling activity takes maize (*uses* it) out of this row (a positive coefficient). Maize must also be *transferred* out of the maize accounting row and into the maize consumption row with the use of a **transfer activity**.

Note: To simplify the manipulation of the matrix, *it is useful to consider the consumption requirement as a "sink,"* as opposed to the "*stock*" of resources. Because the stocks are positive values, the sink must be a negative value. The values that contribute to the "sink," that is the a_{ij} values, must also be negative. The inequality is then <= as in the other rows.

II. Change the concept of *cash income* to *cash balance* at the end of the year, CSH END YR. Because the ending year balance includes any cash not used from the beginning year balance, a **cash transfer** activity is also needed to transfer any unused funds from the beginning year balance to ending balance. Because in the CSH END YR row income is positive and expenses are negative, the transfer activity coefficient in the CSH END YR row will be positive (it increases cash balance). If maximum year end cash balance is the objective, all unused beginning year cash will be transferred to the year end cash when the sign of the CSH BEG YR is <=. If something other than maximum year end cash balance is the objective the CSH BEG YR row should be an equality to assure that all cash not used at the beginning of the year is transferred to the end.

III. Discuss and interpret the solution.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1					SELL	TRN							
2		VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	CASH	GOATS				
3		AMOUNT >>		2.88	51.25	35.00	0.00	125.00	0.00			RESOURCE	
4		RES/CONST		ha	cwt	cwt	ha	$	head		RHS	USE	RES/CONST
5		LAND	ha	1			1		0.1	<=	3	2.88	LAND
6		LABOR	days	40			30		7	<=	115	115.00	LABOR
7		HAY ACCTG	tons				-4		0.6	<=	0	0.00	HAY ACCTG
8		MZE ACCTG	cwt	-30	1	1				<=	0	0.00	MZE ACCTG
9		MZE CONS'N	cwt			-1				<=	-35	-35.00	MZE CONS'N
10		CSH BEG YR	$	200			150	1	49	<=	700	700.00	CSH BEG YR
11		CSH END YR	$		60			1	330	>=	1000	3200.00	CSH END YR

Table 3. Suggested matrix and the solution for exercise 3.

Exercise 4a. Gender disaggregating and gender analysis

Situation

In the solution to Exercise 3, no goats are produced, but it is from goats that women in this livelihood system receive income. The team is aware that some of the alternatives they may want to evaluate may be of more interest to one household member than others. Also, they are not completely satisfied with the solution so far achieved. For this reason they want to **disaggregate beginning and ending cash balances and labor for the men and the woman**.

The family and the team estimate that the men provide 70 of the 115 days of crop and animal labor and the woman 45. Labor requirements for the various farm tasks are:

	maize	hay	goats
men	30	25	1
woman	10	5	6

The man controls $500 of the CSH BEG YR and the woman $200. Cash requirements from each for the various farm tasks are:

	maize	hay	goats
man	200	150	10
woman	0	0	39

The man controls the cash from any maize sold and he splits the cash from the goats with the woman. The man must have a minimum annual income, above the CSH BEG YR, of $100 to meet family responsibilities and the woman needs $200 income annually plus their $200 CSH BEG YR. Income distribution for the income-producing activities is:

	Maize selling	goats
Man	60	130
Woman	0	200

Exercise

I. Separate CSH BEG YR, CSH END YR and labor constraints into those of the men (father and adolescent son) and those of the woman. Because both the man and the woman require a certain minimum CSH END YR balance, set minimum constraints so that the man has >= $600 and the woman >= $400 CSH END YR. It is convenient, also, to include a household or total CSH END YR row although this does not need a minimum value (the initial constraint will be >= zero).

II. Solve the program for objective functions that maximize 1) M CSH END YR, 2) F CSH END YR, and 3) TOT CSH END YR.

III. Compare the solutions and interpret the results.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2					SELL	TRN								
3		VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	TRN M $	TRN F $	GOATS				
4		AMOUNT >>		1.67	15.08	35.00	0.63	29.84	36.45	4.19			RESOURCE	
5		RES/CONST		ha	cwt	cwt	ha	$	$	head		RHS	USE	RES/CONST
6		LAND	ha	1			1			0.1	<=	3	2.72	LAND
7		M LABOR	days	30			25			1	<=	70	70.00	M LABOR
8		F LABOR	days	10			5			6	<=	45	45.00	F LABOR
9		HAY ACCTG	tons				-4			0.6	<=	0	0.00	HAY ACCTG
10		MZE ACCTG	cwt	-30	1	1					<=	0	0.00	MZE ACCTG
11		MZE CONS'N	cwt			-1					<=	-35	-35.00	MZE CONS'N
12		M CSH BEG YR	$	200			150	1		10	=	500	500.00	M CSH BEG YR
13		F CSH BEG YR	$						1	39	=	200	200.00	F CSH BEG YR
14		M CSH END YR	$		60			1		130	>=	600	1479.84	M CSH END YR
15		F CSH END YR	$						1	200	>=	400	875.16	F CSH END YR
16		TOT CSH END YR	$		60			1	1	330	>=	0	2355.00	TOT CSH END YR

Table 4a. Suggested matrix and the solution for exercise 4a (TOT CSH END YR).

Exercise 4b. <u>Creating input and output tables</u>

Small formulations of a linear program are relatively easy to understand from the solution and answer report. However, as the matrix gets larger, and as analysis begins (where prices, inputs, yields, resource amounts, etc.) may be varied, it is very convenient to construct input and output tables that interact directly with the LP matrix.

It is probably most convenient to create the tables on additional *pages* of the same spreadsheet. Table 4b, below, is the matrix, found on the page labeled LP. The input tables are found on the page labeled INPUT, and the output table is found on the page labeled OUTPUT.

a) Input tables

The function of the input tables is to provide an easy way to see what input coefficients were used in the matrix and to change them, if desired, for different analyses. Page INPUT shows the land, labor and consumption constraints, the yields and prices of crops, the labor required for the different activities, and the cash requirements. These are linked and interactive with the matrix (LP page) as shown in the table. For instance, the male labor requirement for maize, cell D11 in the matrix, shows the formula =**INPUT!C21**. This formula means that the coefficient for D11 in the LP matrix contains the value found in cell C21 on page INPUT (the number 30). Maize requires 30 units of male labor. *Notice that in order for the **formula** to appear in the cell, there is a space just prior to the formula.* ***Removing this space (or not putting in the space to begin with) allows the correct number to appear as shown in the second table.***

All formulas begin with the equal sign (=). Because all input table values are positive, using only the equal sign in the formulas will produce positive values in the matrix as well. When a negative value is needed in the matrix, the cell designation within the formula should be preceded by a minus sign (-). For example, the values in the matrix for maize yield, cell D14, and maize consumption, cell L15, should be negative. The formulas used are =**-INPUT!C28** and =**-INPUT!C13** respectively.

b) Output tables

Output tables take results from the solution of the matrix and put them in the output table. The output table for this matrix is found on page OUTPUT. Cell C4 on page OUTPUT has the formula =LP!D8. This means that the area in maize taken from the solution of the matrix on page LP, cell D8, will appear in cell C4 on page OUTPUT.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2					SELL	TRN								
3		VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	TRN M $	TRN F $	GOATS				
4		AMOUNT >>											RESOURCE	
5		RES/CONST		ha	cwt	cwt	ha	$	$	head		RHS	USE	RES/CONST
6		LAND	ha	1			1			0.1	<=	=INPUT!C6	0.00	LAND
7		M LABOR	days	=INPUT!C21			=INPUT!D21			=INPUT!E21	<=	=INPUT!C7	0.00	M LABOR
8		F LABOR	days	=INPUT!C22			=INPUT!D22			=INPUT!E22	<=	=INPUT!C8	0.00	F LABOR
9		HAY ACCTG	tons				=-INPUT!C29			0.6	<=	0	0.00	HAY ACCTG
10		MZE ACCTG	cwt	=-INPUT!C28	1	1					<=	0	0.00	MZE ACCTG
11		MZE CONS'N	cwt			-1					<=	=-INPUT!C13	0.00	MZE CONS'N
12		M CSH BEG YR	$	=INPUT!C35			=INPUT!D35	1		=INPUT!E35	=	=INPUT!C14	0.00	M CSH BEG YR
13		F CSH BEG YR	$						1	=INPUT!E36	=	=INPUT!C15	0.00	F CSH BEG YR
14		M CSH END YR	$		=INPUT!D28			1		130	>=	600	0.00	M CSH END YR
15		F CSH END YR	$						1	200	>=	400	0.00	F CSH END YR
16		TOT CSH END YR	$		=INPUT!D28			1	1	330	>=	0	0.00	TOT CSH END YR
17														
18														
19														
20					SELL	TRN								
21		VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	TRN M $	TRN F $	GOATS				
22		AMOUNT >>											RESOURCE	
23		RES/CONST		ha	cwt	cwt	ha	$	$	head		RHS	USE	RES/CONST
24		LAND	ha	1			1			0.1	<=	3	0.00	LAND
25		M LABOR	days	30			25			1	<=	70	0.00	M LABOR
26		F LABOR	days	10			5			6	<=	45	0.00	F LABOR
27		HAY ACCTG	tons				-4			0.6	<=		0.00	HAY ACCTG
28		MZE ACCTG	cwt	-30	1	1					<=		0.00	MZE ACCTG
29		MZE CONS'N	cwt			-1					<=	-35	0.00	MZE CONS'N
30		M CSH BEG YR	$	200			150	1		10	=	500	0.00	M CSH BEG YR
31		F CSH BEG YR	$						1	39	=	200	0.00	F CSH BEG YR
32		M CSH END YR	$		60			1		130	>=	600	0.00	M CSH END YR
33		F CSH END YR	$						1	200	>=	400	0.00	F CSH END YR
34		TOT CSH END YR	$		60			1	1	330	>=		0.00	TOT CSH END YR
35														

⊩ ◂ ▸ ▸⊩ \ **LP** / INPUT / OUTPUT /

Table 4b. LP page linked to INPUT and OUTPUT pages. The top matrix shows the links and the bottom matrix shows the values.

	A	B	C	D	E
2		**INPUT TABLES**			
4		Land and labor available			
6		Land	3		
7		Male labor	70		
8		Female labor	45		
11		Consumption and beginning-year cash			
13		Maize cons. (negative)	35		
14		M cash beg.	500		
15		F cash beg.	200		
18		Labor requirements for crops and livestock			
20			Maize	Hay	Goats
21		Male labor	30	25	1
22		Female labor	10	5	6
25		Yields and prices			
27			Yield	Price	
28		Maize	30	60	
29		Hay	4		
32		Cash requirements for crop production			
34			Maize	Hay	Goats
35		Male beginning cash	200	150	10
36		Female beg. cash	0	0	39

⊩ ◂ ▸ ▸⊩ \ LP \ **INPUT** / OUTPUT /

	A	B	C	D	E
2		**OUTPUT TABLE**			
4		Maize (ha)	=LP!D8		
5		Hay (ha)	=LP!G8		
6		Goats (head)	=LP!J8		
7		Maize sold (cwt)	=LP!E8		
8		Male end-year cash ($)	=LP!M18		
9		Female end-year cash ($)	=LP!M19		
10		Total end-year cash ($)	=LP!M20		

⊩ ◂ ▸ ▸⊩ \ LP / INPUT \ **OUTPUT** /

Table 4c. INPUT and OUTPUT pages linked to the LP matrix

Exercise 5. Resource flow and integer solutions

Situation

The simulation achieved in Exercise 4 by maximizing household income is more realistic than previous solutions or than solutions that maximize income to the woman or the man. However, the team and the family members note a few more discrepancies. By using all 70 days of the available male labor and all 45 of the available female labor, they are able to produce more maize than usual, allowing the man to sell 15 cwt. They feel that labor is being borrowed from one period to another so they decide to consider **labor and cash resources by semester**. *Note that smaller divisions such as month or week may be necessary in many cases.*

The men's labor is divided 50 units in the first semester and 20 in the second (when they spend time hunting). The woman, who does not hunt, has 25 units of labor available in the first semester and 20 in the second. They have also been over estimating the amount of cash used for production at the beginning of the year. They now estimate the amount to be $400 for the man and $50 for the woman. Of course, any cash not used in the first semester is available in the second. *Any cash earned **in** the first semester is available at the **beginning of the second semester**.* Maize can only be sold in the second semester, but goats can be sold in either. The woman's income from the goats is the same either semester ($200), but from selling the goats in the first semester the man receives $80 and $130 in the second. The man requires a minimum end of year cash of $500 and the woman $200. Any cash received in the second semester is considered year end cash.

Maize, produced in the first semester, uses 30 days of the men's labor and 10 of the woman's as well as $200 of the man's cash. The man sells maize only in the second semester. Hay uses 5 days of the men's labor in the first semester and 20 days in the second. The hay also requires 5 days of the woman's labor in the second. The goats require 0.5 days of the men's labor each semester and 3 days of the woman's labor each semester. Goats also use $5 of the man's cash each semester, $20 of the woman's the first semester and $19 the second.

Exercises

I. Separate labor and cash into two semesters for both the men and the woman. Previously there was only one time period, with cash balance rows for the beginning and the end of the year; now, with the year divided into two semesters, you will need cash balance rows for the beginning of each semester. Expenses are incurred at the beginning of the respective semester, and income is generated at the end of the semester, so is available at the beginning of the next semester or year end. Also, create separate year-end cash balance rows for the man, the woman, and for the household. Be sure that any cash left over in the beginning of semester one is transferred to the

beginning of semester two and that all cash that comes into the end of semester one is available at the beginning of semester two. Similarly, any cash left over in the beginning of semester two must be transferred to the end of the year. Year-end cash will include any leftover cash transferred from the beginning of semester two as well as any cash that comes in at the end of semester two. Goat production can still be one activity, but selling goats must be divided into two semesters (be careful not to sell the same goats more than once!).

II. Set up the new matrix, solve the problem, and interpret and discuss the solutions when end of year cash is maximized for 1) the man, 2) the woman and 3) the household.

III. In order not to have a fractional amount of goats in the solution, in the solver set an <u>integer constraint</u> on goat production *and* selling activities forcing them to be integers. With integers, also obtain solutions when labor is minimized (Chayanovian) or cash productivity of labor (end yr cash/total labor) is maximized. Discuss the implications of the different household goals.

Note: In order to maximize the cash productivity of labor, total labor must be summed and included in the denominator of the formula. Prior to running the LP, all resource use sumproducts, including labor, initially will be zero. In Excel, trying to divide any value by zero, or in this case by a formula that produces a value of zero (total labor), will produce an error term (#DIV/0), and the solver will not work. To avoid that problem, add a very small value (i.e. 1E-20) to total labor. Additionally you will need to uncheck the linear model assumption in the options prior to solving it.

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
2				SELL	TR		TR M $	TR M $	TR F $	TR F $		SELL	SELL					
3	VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	BI-BII	BII-EYR	BI-BII	BII-EYR	GOATS	GOAT I	GOAT II					
4	AMOUNT >>		1.58	12.50	35.00	0.30	28.33	98.33	10.00	172.00	2.00	1.00	1.00			RESOURCE		
5	RES/CONST		ha	cwt	cwt	ha	$	$	$	$	head	head	head		RHS	USE	RES/CONST
6	LAND	ha	1			1					0.1			<=	3	2.08	LAND	
7	M LABOR I	days	30			5					0.5			<=	50	50.00	M LABOR I	
8	M LABOR II	days				20					0.5			<=	20	7.00	M LABOR II	
9	F LABOR I	days	10								3			<=	25	21.83	F LABOR I	
10	F LABOR II	days				5					3			<=	20	7.50	F LABOR II	
11	HAY ACCTG	tons				-4					0.6			<=		0.00	HAY ACCTG	
12	MZE ACCTG	cwt	-30	1	1									<=		0.00	MZE ACCTG	
13	MZE CONS'N	cwt			-1									<=	-35	-35.00	MZE CONS'N	
14	GOAT ACCTG	head									-1	1	1	<=		0.00	GOAT ACCTG	
15	M CSH BEG I	$	200			150	1				5			=	400	400.00	M CSH BEG I	
16	F CSH BEG I	$							1		20			=	50	50.00	F CSH BEG I	
17	M CSH BEG II	$					-1	1			5	-80		=		0.00	M CSH BEG II	
18	F CSH BEG II	$							-1	1	19	-200		=		0.00	F CSH BEG II	
19	M CSH END YR	$		60				1					130	>=	500	978.33	M CSH END YR	
20	F CSH END YR	$								1			200	>=	200	372.00	F CSH END YR	
21	TOT CSH END YR	$		60				1		1			330	>=		1350.33	TOT CSH END YR	
22																		
23															T LABOR	86.33		
24															CSH/LAB	15.64		

Table 5. Suggested matrix and the solution for maximizing cash productivity of labor when goats are set integers for exercise 5

Model calibration and validation: Is it ready to use?

Linear programming models should never be considered as finished tools. Rather, they are always a work in progress, always capable of being improved with new information. However, before they can be used to help predict responses to changes in technology, infrastructure, prices, resource availability or policies, they need to be validated to assure the users that they do, in fact, *adequately* reflect conditions in the communities being modeled.

Validation of models is not an exact science. In models like those in this set of exercises, one method of evaluation is simply the modeler's sense of how well the model reflects the conditions being modeled. Care needs to be taken not to *force the model* into compliance artificially by setting limits on variables or constraints that do not really exist. For example, if farmers in the area normally have no more than one or two head of livestock, but the model consistently indicates many more, then the approach is *not* to set an *artificial limit* of two on the activity. Rather, the *reasons* no more than one or two head are found *must be determined*. Perhaps availability of grazing was not taken into consideration. It could be that yields of the livestock feed produced on the farm were too high, artificially allowing the model to select more livestock than really can be fed. Inputs in the livestock activity may be under estimated. This process of validation obviously helps improve the model and is valuable to the modeler. It also helps maintain *flexibility* in the model so it can respond to the kinds of stimuli that will be asked of it when it is being used for the purpose for which it was constructed. An artificially constrained model simply cannot respond to stimuli so it *loses its value* in use.

But if the model consistently shows one head or three rather than the more normal two, is this a serious problem? Here the modeler must depend on subjective evaluation. It may be decided that the model, in its present form, is adequately valid that it can be put into use, while at the same time, the modeler searches for more definitive data. For example, it may be that differences in household composition account for the human resources needed for livestock husbandry. Perhaps the presence or absence of an adolescent male may make the difference.

In some instances, a more methodical procedure can be used, but still subjectivity will be involved. If a relatively large number of households in a community have been modeled from a single base model, then a statistical comparison of the real-world data and the results of the model solutions could be compared. Areas in the main crops can be compared, for instance. The sampled area in maize on each farm can be compared with the area in maize from each of the model solutions. A "t" test can be used to ascertain the level of probability that these two series represent the same population. But here again, the modeler (or a superior) must decide at what level of probability to accept the validity of the model. Is a 5% level required or is 10%, 15% or even 20% adequate? If a modeler

or the modeler's organization insists on a 5% level prior to considering the model valid, the benefits of the model may never be realized. A flexible model that reflects a 20% level of confidence still will be better than an artificially constrained model that is forced to fit at a 1% or 5% level of confidence.

Exercise 6. <u>Assessing alternative technology (hypothesis testing)</u>

Situation

The integer solution to the fifth exercise, when maximizing the household end cash, <u>simulates the current livelihood strategies of the household in this livelihood system</u> quite well. Sufficient maize is produced to feed the household, and only a limited amount is sold. Two goats are produced in a small pasture (0.2 ha) and about a third of a ha of hay is produced for the goats. About one third of the farm is in fallow. Both the man and the woman have some time in the second semester (the man to hunt and the woman to make clothes). Reserve cash is not a constraint for the woman nor for the man. The woman has a limited amount of discretionary cash to spend ($372-$200=$172) and the man has $478. The team considers that the model is ready to use for **hypothesis testing or pre-evaluation of alternative technologies or activities.**

Note: In your own models, validation is a more thorough process.

Alternative to consider

The cash return to the household from the sale of goats is quite low ($280 in the first semester and $330 in the second). Because some land is in fallow, an alternative could be to produce more maize to feed the goats. It is anticipated by the team that maize-fed goats could increase household income. Estimates are that they could produce more and higher quality goats. This would require 4 cwt of maize per goat. About 0.625 tons of hay should be sufficient for each goat fed maize. Labor would increase to about 10 days per goat (0.75 days each semester for the man and 4.25 days each semester for the woman). The man's cash requirement would be the same ($5 each semester per goat) but the woman's cash would increase to $26.25 each semester. The value of the maize-fed goats would increase to $375 when sold in the first semester ($107 for the man and $268 for the woman) and $444 when sold in the second semester ($175 for the man and $269 for the woman).

Exercises

I. Assess a maize-fed goat activity as an alternative to possibly be incorporated into the present system, or perhaps substituted for the present goat production system. *To do this, the present matrix (and system) is left as satisfactorily simulated in Exercise 5. The new activity, the maize-goat activity, is <u>added</u> to the matrix in Exercise 5 so that the linear program solves for maximum household year end cash when **the proposed new activity is in competition with existing farm activities.** Note that because the price received for the different kinds of goats is different, it is necessary to have separate selling activities for each class of goat. The solution should incorporate the integer constraint on numbers of goats produced and sold.

II. State a hypothesis to be tested by solving this linear program.

III. Solve, discuss and interpret the solution and use it to accept or reject the hypothesis.

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1																					
2				SELL	TR		TR M $	TR M $	TR F $	TR F $	MAIZE	SELL	SELL		SELL	SELL					
3	VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	BI-BII	BII-EYR	BI-BII	BII-EYR	GOATS	MGOAT I	MGOAT II	GOATS	GOAT I	GOAT II					
4	AMOUNT >>		1.58	12.50	35.00	0.30	28.33	98.33	10.00	172.00	0.00	0.00	0.00	2.00	1.00	1.00			RESOURCE		
5	RES/CONST		ha	cwt	cwt	ha	$	$	$	$	head	head	head	head	head	head		RHS	USE	RES/CONST	
6	LAND	ha	1			1								0.1			<=	3	2.08	LAND	
7	M LABOR I	days	30			5					0.75			0.5			<=	50	50.00	M LABOR I	
8	M LABOR II	days				20					0.75			0.5			<=	20	7.00	M LABOR II	
9	F LABOR I	days	10								4.25			3			<=	25	21.83	F LABOR I	
10	F LABOR II	days				5					4.25			3			<=	20	7.50	F LABOR II	
11	HAY ACCTG	tons				-4					0.625			0.6			<=		0.00	HAY ACCTG	
12	MZE ACCTG	cwt	-30	1	1						4						<=		0.00	MZE ACCTG	
13	MZE CONS'N	cwt			-1												<=	-35	-35.00	MZE CONS'N	
14	GOAT ACCTG	head												-1	1	1	<=		0.00	GOAT ACCTG	
15	M GOAT ACCTG	head									-1	1	1				<=		0.00	M GOAT ACCTG	
16	M CSH BEG I	$	200			150	1				5			5			=	400	400.00	M CSH BEG I	
17	F CSH BEG I	$							1		26.25			20			=	50	50.00	F CSH BEG I	
18	M CSH BEG II	$					-1	1			5	-107		5	-80		=		0.00	M CSH BEG II	
19	F CSH BEG II	$							-1	1	26.25	-268		19	-200		=		0.00	F CSH BEG II	
20	M CSH END YR	$		60				1					175			130	>=	500	978.33	M CSH END YR	
21	F CSH END YR	$								1			269			200	>=	200	372.00	F CSH END YR	
22	TOT CSH END YR	$		60				1		1			444			330	>=		1350.33	TOT CSH END YR	

Table 6. Suggested matrix and the solution for exercise 6

Exercise 7. Policy analysis (Prediction)

Situation

The country is forced to import maize for consumption in the urban areas because there is not enough sold by the small producers who produce about 80% of the country's maize. The Ministry of Agriculture has argued with the Ministry of Finance that the import duty on fertilizer needs to be dropped so that farmers can afford to purchase it. Their farming systems teams have told them that small farmers feel the cost of purchasing and transporting nitrogen to the farm comes to an average of about $2.475 per kilogram of N, too high to use on maize. On-farm trials with small producers, however, indicate that the use of 100 kg of N per ha should increase maize yield by 50%.[1] The President of the country is excited by the possibility of increasing production by 40% (50% increase in production by 80% of the maize) and even thinks of exporting maize. He wants to convince the Minister of Finance to eliminate the import duty on nitrogen but needs a more complete analysis of what would happen if small farmers could obtain the nitrogen at half the current cost.

The team you are with estimates that the application of nitrogen would require about 6 additional days of the men's labor during the first semester and about 2 additional days of the woman's.

Exercises

I. Modify the matrix from Exercise 5 to include the new activity of fertilized maize (remember to keep the present maize activity so the program has to choose between ways to produce maize).

II. Analyze and interpret the solution. Write a report to the President including not only what happens on the farms represented by your model of a typical household in this livelihood system, but also what might happen to maize production and amount marketed for the country as a whole, assuming the price of maize stayed the same.

III. The farming systems team thinks that if farmers used nitrogen to produce maize it might make their maize goats alternative more attractive. Take another look at the maize goats alternative (Exercise 6) by adding the fertilized maize. Discuss the results.

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[1] The average small farm production function is estimated as $Y = 30 + 0.2175 N - 0.000675 N^2$, where Y is kg ha-1 of maize and N is kg ha-1 of nitrogen.

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
			FERT	SELL	TR		TR M $	TR M $	TR F $	TR F $		SELL	SELL				
VARIABLES >>		MAIZE	MAIZE	MAIZE	MAIZE	HAY	BI-BII	BII-EYR	BI-BII	BII-EYR	GOATS	GOAT I	GOAT II				
AMOUNT >>		1.18	0.3383	15.54	35.00	0.30	0.00	70.00	10.00	172.00	2.00	1.00	1.00				
RES/CONST		ha	ha	cwt	cwt	ha	$	$	$	$	head	head	head		RHS	USE	RES/CONST
LAND	ha	1	1			1					0.1			<=	3	2.02	LAND
M LABOR I	days	30	36			5					0.5			<=	50	50.00	M LABOR I
M LABOR II	days					20					0.5			<=	20	7.00	M LABOR II
F LABOR I	days	10	12								3			<=	25	21.83	F LABOR I
F LABOR II	days					5					3			<=	20	7.50	F LABOR II
HAY ACCTG	tons					-4					0.6			<=		0.00	HAY ACCTG
MZE ACCTG	cwt	-30	-45	1	1									<=		0.00	MZE ACCTG
MZE CONS'N	cwt				-1									<=	-35	-35.00	MZE CONS'N
GOAT ACCTG	head										-1	1	1	<=		0.00	GOAT ACCTG
M CSH BEG I	$	200	323.75			150	1				5			=	400	400.00	M CSH BEG I
F CSH BEG I	$								1		20			=	50	50.00	F CSH BEG I
M CSH BEG II	$						-1	1			5	-80		=		0.00	M CSH BEG II
F CSH BEG II	$								-1	1	19	-200		=		0.00	F CSH BEG II
M CSH END YR	$			60				1					130	>=	500	1132.69	M CSH END YR
F CSH END YR	$									1			200	>=	200	372.00	F CSH END YR
TOT CSH END YR	$			60				1		1			330	>=		1504.69	TOT CSH END YR

Table 7a. Suggested matrix and the solution for exercise 7-I

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
			FERT	SELL	TR		TR M $	TR M $	TR F $	TR F $	MAIZE	SELL	SELL		SELL	SELL				
VARIABLES >>		MAIZE	MAIZE	MAIZE	MAIZE	HAY	BI-BII	BII-EYR	BI-BII	BII-EYR	GOATS	MGOAT I	MGOAT II	GOATS	GOAT I	GOAT II				
AMOUNT >>		1.18	0.338	15.54	35.00	0.30	0.00	70.00	10.00	172.00	0.00	0.00	0.00	2.00	1.00	1.00				
RES/CONST		ha	ha	cwt	cwt	ha	$	$	$	$	head	head	head	head	head	head		RHS	USE	RES/CONST
LAND	ha	1	1			1								0.1			<=	3	2.02	LAND
M LABOR I	days	30	36			5					0.75			0.5			<=	50	50.00	M LABOR I
M LABOR II	days					20					0.75			0.5			<=	20	7.00	M LABOR II
F LABOR I	days	10	12								4.25			3			<=	25	21.83	F LABOR I
F LABOR II	days					5					4.25			3			<=	20	7.50	F LABOR II
HAY ACCTG	tons					-4					0.625			0.6			<=		0.00	HAY ACCTG
MZE ACCTG	cwt	-30	-45	1	1						4						<=		0.00	MZE ACCTG
MZE CONS'N	cwt				-1												<=	-35	-35.00	MZE CONS'N
GOAT ACCTG	head													-1	1	1	<=		0.00	GOAT ACCTG
M GOAT ACCTG	head										-1	1	1				<=		0.00	M GOAT ACCTG
M CSH BEG I	$	200	323.8			150	1				5			5			=	400	400.00	M CSH BEG I
F CSH BEG I	$								1		26.25			20			=	50	50.00	F CSH BEG I
M CSH BEG II	$						-1	1			5	-107		5	-80		=		0.00	M CSH BEG II
F CSH BEG II	$								-1	1	26.25	-268		19	-200		=		0.00	F CSH BEG II
M CSH END YR	$			60				1					175			130	>=	500	1132.69	M CSH END YR
F CSH END YR	$									1			269			200	>=	200	372.00	F CSH END YR
TOT CSH END YR	$			60				1		1			444			330	>=		1504.69	TOT CSH END YR

Table 7b. Suggested matrix for and the solution for exercise 7-III

Exercise 8a. Household composition, food security and production labor stress

Linear programs can be used to model individual farms or can be representative of a type of farm within a livelihood system. When they are meant to be representative of a group of farms, they often are based on average values found from a survey. The problems with using averages are 1) *averages represent very few of the real farms from which the survey was taken*, and 2) *averages mask diversity and individual household differences*. An "average" household will have some fraction of young children and some fraction of older children. Older children are considered to be available to help with adult tasks, either in or around the house (*reproduction* tasks, most common for older female children) or the field (*production* tasks, most common for older male children). Consumption requirements reflect the needs of a *household average*, not the *individuals*. Hence, solutions based on averages may be very misleading.

It is tempting to aggregate results of a linear program based on an individual, average farm and/or household to the level of a community or higher scale. Such an aggregation will be misleading for the reasons explained above. However, **when a range of household compositions representative of a community is utilized, and solutions obtained, these can be aggregated with much more realistic and valid results.**

Situation

The team has noticed that the model in **Exercise 5** does not reflect what many other households do. They have decided that household composition is one of the keys that needs to be explored. The household used in the previous models included a mother, father, one male adolescent, and one young child.

The team looked further into the situation regarding household composition, labor availability, and food requirements. They then made the following estimates. Male labor I should be based on 30 units from an adult male and 20 from each adolescent male. Male labor II should be based on 10 units from each. Female labor I should be based on 30 units from an adult female and 20 from any adolescent female *less* 5 units of female field or production labor for each child in the family. Female labor II should include 25 units from an adult female and 20 from any adolescent female *minus* 5 units for each child. The females seldom help the males with their work. Annual maize consumption should be based on the following needs: adult male, 12 cwt; adult female, 10 cwt; adolescent male, 10 cwt; adolescent female, 8 cwt; and each child, 3 cwt.

Exercises

I. Construct three input tables to incorporate the values above. One table will be for family composition. Another will be maize consumption, and a third will be available labor. Incorporate these tables into the matrix from Exercise 5 to make them interactive.

II. Solve for the following household compositions:

HH No.	Adult male	Adult female	Adoles. Male	Adoles. Fem	Children	
1	1	1	0	0	0	
2	1	1	0	0	1	
3	1	1	0	0	2	
4	1	1	1	0	1	(Exercise 5)
5	1	1	0	1	1	
6	1	1	1	1	0	
7	1	1	0	1	0	(male leaves 1st)
8	1	1	1	0	0	(female leaves 1st)

In some cases there is no feasible solution because male labor is constraining at a level too low to produce sufficient maize for family consumption. Estimate how much additional male labor is needed (this is a measure of stress on the male members of the household) in order to satisfy stated household food needs. Using this level of male labor availability, obtain a feasible solution. Using the original male labor availability, also estimate how much less maize consumption would be required to get a feasible solution. This would reflect the consumption of a less than satisfactory diet by members of this household.

III. Compare the maize consumption, excess male labor requirements (male stress level), and end year cash for each of the solutions obtained above with Exercise 5 (1-1-1-0-1).

Exercise 8b. Aggregating to a higher scale

IV. Within the community where the team is working, the proportion (percentage) of households that falls into each of the above household composition groups is as follows: 15, 5, 12, 20, 20, 12, 8, and 8, respectively.

Calculate the weighted, average household composition for the population of the community (1-1-0.375-0.375-0.625). Solve your model for this household composition. How does this solution compare with the others?

V. What are the implications for modeling potential responses to new technology or policy incentives?

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1																		
2					SELL	MZE		M CASH	F CASH	M CASH	F CASH		SELL	SELL				
3		VARIABLES >>		MAIZE	MZE	TRN	HAY	TRN I-II	TRN I-II	TRN II-E	TRN II-E	GOAT	GOAT I	GOAT II				
4		AMOUNT >>		1.58	12.50	35.00	0.30	28.33	10.00	848.33	172.00	2.00	1.00	1.00			RESOURCE	
5		RES/CONST		ha	cwt	cwt	ha	$	$	$	$	head	head	head		RHS	USE	RES/CONST
6		LAND	ha	1			1					0.1			<=	3	2.08	LAND
7		M LABOR I	days	30			5					0.5			<=	50	50.00	M LABOR I
8		M LABOR II	days	0			20					0.5			<=	20	7.00	M LABOR II
9		F LABOR I	days	10			0					3			<=	25	21.83	F LABOR I
10		F LABOR II	days	0			5					3			<=	20	7.50	F LABOR II
11		HAY ACCTG	tons				-4					0.6			<=		0.00	HAY ACCTG
12		MZE ACCTG	cwt	-30	1	1									<=		0.00	MZE ACCTG
13		MZE CONS'N	cwt			-1									<=	-35	-35.00	MZE CONS'N
14		GOAT ACCTG	head									-1	1	1	<=		0.00	GOAT ACCTG
15		M CSH BEG I	$	200			150	1				5			=	400	400.00	M CSH BEG I
16		F CSH BEG I	$	0			0		1			20			=	50	50.00	F CSH BEG I
17		M CSH BEG II	$	0	-60		0	-1		1		5	-80		=		0.00	M CSH BEG II
18		F CSH BEG II	$	0			0		-1		1	19	-200		=		0.00	F CSH BEG II
19		M CSH END YR	$							1				130	>=	500	978.33	M CSH END YR
20		F CSH END YR	$								1			200	>=	200	372.00	F CSH END YR
21		HH CSH END YR	$							1	1			330	>=		1350.33	HH CSH END YR

Table 8a. Suggested matrix and the solution (family 1-1-1-0-1) for exercise 8

Table 1: Family Composition

Adult male	1
Adult female	1
Adoles. male	1
Adoles. female	0
Children	1

Table 4: Maize Consumption

	Cwt per	Total cwt
Adult male	12	12
Adult female	10	10
Adolescent male	10	10
Adolescent female	8	0
Children	3	3
	Total	35

Table 3: Labor Availability

	I	II
Adult male	30	10
Adult female	30	25
Adolescent male	20	10
Adolescent female	20	20
Children	-5	-5
Total male labor	50	20
Total female labor	25	20

Table 8b. Suggested input tables connected to the matrix

Household summary

Household composition	1-1-0-0-0	1-1-0-0-1	1-1-0-0-2	(Exer 5) 1-1-1-0-1	1-1-0-1-1-	1-1-1-1-0	1-1-0-1-0	1-1-1-0-0	Average
			not feasible		not feasible		not feasible		
Maize (ha)	0.92	0.92		1.58		1.58		1.58	1.21
Hay (ha)	0.30	0.30		0.30		0.30		0.30	0.15
Goats (head)	2.00	2.00		2.00		2.00		2.00	1.00
Maize sold (cwt)	5.50	2.50		12.50		7.50		15.50	5.63
Male cash end balance ($)	691.67	511.67		978.33		678.33		1158.33	593.33
Female cash end balance ($)	372.00	372.00		372.00		372.00		372.00	211.00
Total cash end balance ($)	1063.67	883.67		1350.33		1050.33		1530.33	804.33

Table 8c. Different solutions for different household compositions

Exercise 9. Dynamic programming

Many activities on a farm are not completed during a year. Most livestock and any perennial crops are examples. In order to analyze these kinds of enterprises adequately, it is necessary to extend a model over more than one year. Multiple year models are called dynamic because what happens in one year affects what happens in others. Trees planted in one year may not produce for three or four years. Two-year-old trees are different from three-year-old trees. Animal inventories must be maintained to keep track of births, young stock prior to breeding age, older animals, death losses, sales, and home consumption.

Exercise 9a. Animals

Beginning with Exercise 5, the farming systems field team has decided that it needs to be more realistic with respect to goats.

Situation

The team wants to build a three-year model of the farm. The team found that 2 young goats (kids) are required for family consumption every year and that these are produced on the farm. The birth rate is usually two kids per female per year. Surplus kids are often sold on the market; this requires a kids accounting row. Older goats as well as kids must be transferred from the first to the second year and so on. In the second year, kids are considered yearlings. Consider a 20% annual death loss of the goats during the year. Start the 3-year period with a flexible size herd. That is, let the model decide how many animals it would include, but consider only female goats. Do not consider purchasing goats. Labor, land and pasture requirements for the yearlings are half that of the adult goats. Yearlings require no cash inputs. Prices for the kids sold are the same as that used for goats in Exercise 5. You will need to transfer the male and female cash separately from one year to the next.

Exercises

I. Expand the matrix from Exercise 5 into a three-year period. This will require about three times as many rows and three times as many columns as you used for Exercise 5. That is, you will have a set of columns (activities) for each year and a set of rows (constraints) for every year. Although the matrix is very large, it is not very dense because most coefficients are blanks.
II. Solve the program for objective functions that maximize 1) the sum of year-end cash balance over the three-year period, and 2) number of adult goats (size of the goatherd) in the third year. Other objectives could also be maximized if you like.
III. Try setting an integer constraint on the goat production and selling activities forcing them to be integers.
IV. Discuss and interpret the results.

Table 9a1. Suggested structure of the three year matrix

Variable	Unit	D MAIZE	E SELL MAIZE	F TR MAIZE	G HAY	H TRM$ BI-BII	I TRM$ BII-EYR	J TRF$ BI-BII	K TRF$ BII-EYR	L GOATS	M TRN G1-2	N TRN KCONS	O TRN K1-2	P SELL GOATI	Q SELL GOATII	R TRN MCSH YR1-2	S TRN FCSH YR1-2	T MAIZE	U SELL MAIZE	V TR MAIZE	W HAY	X TRM$ BI-BII	Y TRM$ BII-EYR	Z TRF$ BI-BII	AA TRF$ BII-EYR	AB ADULT GOATS	AC YRL GOATS
AMOUNT >>		1.56	11.88	35.00	0.38	18.75	25.25	0.00	0.00	2.50	2.00	2.00	0.00	0.24	2.76	596.88	352.50	1.58	12.50	35.00	0.30	225.21	215.21	312.50	274.50	2.00	0.00
RES/CONST		ha	cwt	cwt	ha	$	$	$	$	head				head	head												
LAND	ha	1			1					0.1																	
M LABOR I	days	30		5						0.5																	
M LABOR II	days			20						0.5																	
F LABOR I	days	10								3																	
F LABOR II	days			5						3																	
HAY ACCTG	tons				-4					0.6																	
MZE ACCTG	cwt	-30	1	1																							
MZE CONS'N	cwt			-1																							
KIDS GOAT	head									-2		1	1	1	1												
CONS'GOAT	head											-1															
ADULT GOAT	head									-0.8	1																
M CSH BEG I	$	200			150	1				5																	
F CSH BEG I	$							1		20																	
M CSH BEG II	$					-1	1			5						-80											
F CSH BEG II	$							-1	1	19							-200										
M CSH END YR	$		60				1									130	-1										
F CSH END YR	$								1							200	-1										
TOT CSH END YR	$		60				1		1							330											
LAND	ha																	1		1						0.1	0.05
GOAT BEG	head										-1															1	
GOAT YLG	head												-0.8														1
M LABOR I	days																	30		5						0.5	
M LABOR II	days																			20						0.5	
F LABOR I	days																	10								3	
F LABOR II	days																			5						3	
HAY ACCTG	tons																				-4					0.6	0.3
MZE ACCTG	cwt																	-30	1	1							
MZE CONS'N	cwt																			-1							
KIDS GOAT	head																									-2	
CONS'GOAT	head																										
ADULT GOAT	head																									-0.8	-0.8
M CSH BEG I	$															-1		200		150	1					5	
F CSH BEG I	$																-1							1		20	
M CSH BEG II	$																					-1	1			5	
F CSH BEG II	$																							-1	1	19	
M CSH END YR	$																		60				1				
F CSH END YR	$																								1		
TOT CSH END YR	$																		60				1		1		
LAND	ha																										
GOAT BEG	head																										
GOAT YLG	head																										
M LABOR I	days																										
M LABOR II	days																										
F LABOR I	days																										
F LABOR II	days																										
HAY ACCTG	tons																										
MZE ACCTG	cwt																										
MZE CONS'N	cwt																										
KIDS GOAT	head																										
CONS'GOAT	head																										
ADULT GOAT	head																										
M CSH BEG I	$																										
F CSH BEG I	$																										
M CSH BEG II	$																										
F CSH BEG II	$																										
M CSH END YR	$																										
F CSH END YR	$																										
TOT CSH END YR	$																										

Table 9a2. Suggested matrix and the solution (three year end cash) for exercise 9a (part I)

	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	RHS	USE	RES/CONST
1								3																		
2–3	TRN G1-2	TRN K CONS	TRN K1-2	SELL GOAT I	SELL GOAT II	TRN MCSH YR1-2	TRN FCSH YR1-2	MAIZE	SELL MAIZE	TR MAIZE	HAY	TR M$ BI-BII	TR M$ BII-EYR	TR F$ BI-BII	TR F$ BII-EYR	ADULT GOATS	YRL GOATS	TRN G1-2	TRN K CONS	TRN K1-2	SELL GOAT I	SELL GOAT II				
4	1.60	2.00	0.00	0.00	2.00	725.21	474.50	1.60	13.00	35.00	0.24	361.21	353.21	442.50	412.10	1.60	0.00	1.28	2.00	0.00	0.00	1.20			RESOURCE	
5																										
6																							<=	3	2.19	LAND
7																							<=	50	50.00	M LABOR I
8																							<=	20	8.75	M LABOR II
9																							<=	25	23.13	F LABOR I
10																							<=	20	9.38	F LABOR II
11																							<=		0.00	HAY ACCTG
12																							<=		0.00	MZE ACCTG
13																							<=	-35	-35.00	MZE CONS'N
14																							<=		0.00	KIDS GOAT
15																							<=	-2	-2.00	CONS' GOAT
16																							<=		0.00	ADULT GOAT
17																							=	400	400.00	M CSH BEG I
18																							=	50	50.00	F CSH BEG I
19																							=		0.00	M CSH BEG II
20																							=		0.00	F CSH BEG II
21																							>=	500	500.00	M CSH END YR
22																							>=	200	200.00	F CSH END YR
23																							>=		1649.38	TOT CSH END YR
24																							<=	3	2.08	LAND
25																							<=		0.00	GOAT BEG
26																							<=		0.00	GOAT YLG
27																							<=	50	50.00	M LABOR I
28																							<=	20	7.00	M LABOR II
29																							<=	25	21.83	F LABOR I
30																							<=	20	7.50	F LABOR II
31																							<=		0.00	HAY ACCTG
32																							<=		0.00	MZE ACCTG
33																							<=	-35	-35.00	MZE CONS'N
34			1	1	1	1																	<=		0.00	KIDS GOAT
35		-1																					<=	-2	-2.00	CONS' GOAT
36	1																						<=		0.00	ADULT GOAT
37																							=		0.00	M CSH BEG I
38																							=		0.00	F CSH BEG I
39						-80																	=		0.00	M CSH BEG II
40						-200																	=		0.00	F CSH BEG II
41						130	-1																>=	500	500.00	M CSH END YR
42						200		-1															>=	200	200.00	F CSH END YR
43						330																	>=		1899.71	TOT CSH END YR
44								1		1						0.1	0.05						<=	3	2.00	LAND
45	-1															1							<=		0.00	GOAT BEG
46			-0.8														1						<=		0.00	GOAT YLG
47								30		5						0.5							<=	50	50.00	M LABOR I
48										20						0.5							<=	20	5.60	M LABOR II
49								10								3							<=	25	20.80	F LABOR I
50										5						3							<=	20	6.00	F LABOR II
51										-4						0.6	0.3						<=		0.00	HAY ACCTG
52								-30	1	1													<=		0.00	MZE ACCTG
53										-1													<=	-35	-35.00	MZE CONS'N
54																-2		1	1	1		1	<=		0.00	KIDS GOAT
55																	-1						<=	-2	-2.00	CONS' GOAT
56																-0.8	-0.8	1					<=		0.00	ADULT GOAT
57						-1		200		150	1					5							=		0.00	M CSH BEG I
58							-1				1					20							=		0.00	F CSH BEG I
59												-1	1			5					-80		=		0.00	M CSH BEG II
60														-1	1	19					-200		=		0.00	F CSH BEG II
61								60					1									130	>=	500	1289.21	M CSH END YR
62															1							200	>=	200	652.10	F CSH END YR
63								60						1								330	>=		1941.31	TOT CSH END YR
64																								SUM 3 YR	5490.39	

Table 9a2. Suggested matrix and the solution (three year end cash) for exercise 9a (part II)

Exercise 9b. Perennial crops

Situation

The farm family decides it would like to consider banana production. They estimate that the household could consume 100 kg of bananas and hope surplus bananas would be sold. The team estimates men's labor for bananas is 5 units in the first semester and 20 units in the second. The woman would contribute 5 units of labor in the first semester and 10 in the second. After the first year, the man and the woman each would contribute 5 units of labor each semester. The first year the bananas would require $50 of the man's beginning cash. After that no cash is required for the bananas. Banana yield is estimated at about 6000 kg/ha beginning the second year. The price of bananas for sale is $0.30 per kilogram. The man would control the cash from any bananas sold.

Note: Remember that banana land has to be transferred from the first year to the second year and from the second to the third year and so on. But also remember that once the land is put in bananas it is not available for other uses in future years. Consequently, it is necessary to introduce a banana land constraint each year, and only non-banana land is available in future years for other activities. For the purpose of this exercise consider planting bananas only the first year.

Exercises

I. Modify the LP matrix from the Exercise 9a to introduce bananas in the multiple year model. Solve the program for an objective function that maximizes the sum of the three year end cash balances over the three year period. You might also try maximizing the area in bananas subject to all the other constraints.

V. Discuss and interpret the results.

Row	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
1			1																	2													
2				SELL	TR		TR M$	TR M$	TR F$	TR F$	YR1		TRN	TRN	TRN	SELL	SELL	TRN MCSH	TRN FCSH		SELL	TR		TR M$	TR M$	TR F$	TR F$	YR2	SELL	TRN	ADULT	YRL	TRN
3	VARIABLES >>		MAIZE	MAIZE	MAIZE	HAY	BI-BII	BII-EYR	BI-BII	BII-EYR	BANANA	GOATS	G1-2	K CONS	K1-2	GOAT I	GOAT II	YR1-2	YR1-2	MAIZE	MAIZE	MAIZE	HAY	BI-BII	BII-EYR	BI-BII	BII-EYR	BANANA	BANANA	BANANA	GOATS	GOATS	G1-2
4	AMOUNT >>		1.47	9.06	35.00	##	9.38	15.88	0.00	0.00	0.56	2.50	2.00	2.00	0.00	0.24	2.76	418.75	352.50	1.49	9.69	35.00	0.30	1048.33	1038.33	312.50	274.50	0.56	3275.00	100.00	2.00	0.00	1.60
5	RES/CONST		ha	cwt	cwt	ha	$	$	$	$		head				head	head																
6	LAND	ha	1			1					1	0.1																					
7	M LABOR I	days	30			5					5	0.5																					
8	M LABOR II	days				20					20	0.5																					
9	F LABOR I	days	10								5	3																					
10	F LABOR II	days				5					10	3																					
11	HAY ACCTG	tons				-4						0.6																					
12	MZE ACCTG	cwt	-30	1	1																												
13	MZE CONS'N	cwt			-1																												
14	KIDS GOAT	head										-2	1	1	1	1																	
15	CONS' GOAT	head												-1																			
16	ADULT GOAT	head										-0.8	1																				
17	M CSH BEG I	$	200			150	1				50	5																					
18	F CSH BEG I	$							1			20																					
19	M CSH BEG II	$					-1	1				5						-80															
20	F CSH BEG II	$							-1	1		19						-200															
21	M CSH END YR	$		60				1											130	-1													
22	F CSH END YR	$								1									200	-1													
23	TOT CSH END YR	$		60				1		1									330														
24	LAND	ha									1										1			1								0.1	0.05	
25	GOAT BEG	head										-1																				1		
26	GOAT YLG	head												-0.8																			1	
27	BANANA YR 2	ha									-1																		1					
28	M LABOR I	days																			30			5					5			0.5		
29	M LABOR II	days																					20						20			0.5		
30	F LABOR I	days																			10								5			3		
31	F LABOR II	days																						5					10			3		
32	HAY ACCTG	tons																						-4								0.6	0.3	
33	MZE ACCTG	cwt																			-30	1	1											
34	MZE CONS'N	cwt																					-1											
35	KIDS GOAT	head																														-2		
36	CONS' GOAT	head																																
37	ADULT GOAT	head																														-0.8	-0.8	1
38	BANANA ACCTG	kg																											-6000	1	1			
39	BANANA CONS'T	kg																												-1				
40	M CSH BEG I	$									-1										200		150		1					-0.3		5		
41	F CSH BEG I	$										-1															1					20		
42	M CSH BEG II	$																							-1	1						5		
43	F CSH BEG II	$																									-1	1				19		
44	M CSH END YR	$																				60				1							
45	F CSH END YR	$																										1						
46	TOT CSH END YR	$																				60				1		1						
47	LAND	ha									1																							
48	GOAT BEG	head																																-1
49	GOAT YLG	head																																
50	BANANA YR 3	ha																											-1					
51	M LABOR I	days																																
52	M LABOR II	days																																
53	F LABOR I	days																																
54	F LABOR II	days																																
55	HAY ACCTG	tons																																
56	MZE ACCTG	cwt																																
57	MZE CONS'N	cwt																																
58	KIDS GOAT	head																																
59	CONS' GOAT	head																																
60	BANANA ACCTG	kg																																
61	BANANA CONS'T	kg																																
62	ADULT GOAT	head																																
63	M CSH BEG I	$																																
64	F CSH BEG I	$																																
65	M CSH BEG II	$																																
66	F CSH BEG II	$																																
67	M CSH END YR	$																																
68	F CSH END YR	$																																
69	TOT CSH END YR	$																																
70																																		

Table 9b1. Suggested matrix and the solution (three year end cash) for exercise 9b (part I)

Column key (col letter: row2 / row3 / row4 value):

- AI: TRN / K CONS / 2.00
- AJ: TRN / K 1-2 / 0.00
- AK: SELL / GOAT I / 0.00
- AL: SELL / GOAT II / 2.00
- AM: TRN MCSH / YR 1-2 / 1379.58
- AN: TRN FCSH / YR1-2 / 474.50
- AO: / MAIZE / 1.51
- AP: SELL / MAIZE / 10.19
- AQ: TR / MAIZE / 35.00
- AR: / HAY / 0.24
- AS: TR M$ / BII-BII / 2016.83
- AT: TR M$ / BII-EYR / 2008.83
- AU: TR F$ / BII-BII / 442.50
- AV: TR F$ / BII-EYR / 412.10
- AW: YR 3 / BANANA / 0.56
- AX: SELL / BANANA / 3275.00
- AY: TRN / BANANA / 100.00
- AZ: ADULT / GOATS / 1.60
- BA: YRL / GOATS / 0.00
- BB: TRN / G 1-2 / 1.28
- BC: TRN / K CONS / 2.00
- BD: TRN / K 1-2 / 0.00
- BE: SELL / GOAT I / 0.00
- BF: SELL / GOAT II / 1.20

Row	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	RHS	USE	RES/CONST
6																									<=	3	2.66	LAND
7																									<=	50	50.00	M LABOR I
8																									<=	20	20.00	M LABOR II
9																									<=	25	25.00	F LABOR I
10																									<=	20	15.00	F LABOR II
11																									<=		0.00	HAY ACCTG
12																									<=		0.00	MZE ACCTG
13																									<=	-35	-35.00	MZE CONS'N
14																									<=		0.00	KIDS GOAT
15																									<=	-2	-2.00	CONS' GOAT
16																									<=		0.00	ADULT GOAT
17																									=	400	400.00	M CSH BEG I
18																									=	50	50.00	F CSH BEG I
19																									=		0.00	M CSH BEG II
20																									=		0.00	F CSH BEG II
21																									>=	500	500.00	M CSH END YR
22																									>=	200	200.00	F CSH END YR
23																									>=		1471.25	TOT CSH END YR
24																									<=	3	2.55	LAND
25																									<=		0.00	GOAT BEG
26																									<=		0.00	GOAT YLG
27																									<=		0.00	BANANA YR 2
28																									<=	50	50.00	M LABOR I
29																									<=	20	9.81	M LABOR II
30																									<=	25	23.71	F LABOR I
31																									<=	20	10.31	F LABOR II
32																									<=		0.00	HAY ACCTG
33																									<=		0.00	MZE ACCTG
34																									<=	-35	-35.00	MZE CONS'N
35	1	1	1	1																					<=		0.00	KIDS GOAT
36	-1																								<=	-2	-2.00	CONS' GOAT
37																									<=		0.00	ADULT GOAT
38																									<=		0.00	BANANA ACCTG
39																									<=	-100	-100.00	BANANA CONS'N
40																									=		0.00	M CSH BEG I
41																									=		0.00	F CSH BEG I
42					-80																				=		0.00	M CSH BEG II
43					-200																				=		0.00	F CSH BEG II
44					130	-1																			>=	500	500.00	M CSH END YR
45					200		-1																		>=	200	200.00	F CSH END YR
46					330																				>=		2554.08	TOT CSH END YR
47								1			1						0.1	0.05							<=	3	2.47	LAND
48																		1							<=		0.00	GOAT BEG
49		-0.8																	1						<=		0.00	GOAT YLG
50															1										<=		0.00	BANANA YR 3
51								30			5					5	0.5								<=	50	50.00	M LABOR I
52									20				5				0.5								<=	20	8.41	M LABOR II
53								10					5			3									<=	25	22.67	F LABOR I
54										5			5			3									<=	20	8.81	F LABOR II
55											-4						0.6	0.3							<=		0.00	HAY ACCTG
56								-30	1	1															<=		0.00	MZE ACCTG
57										-1															<=	-35	-35.00	MZE CONS'N
58																		-2		1	1	1	1		<=		0.00	KIDS GOAT
59																					-1				<=	-2	-2.00	CONS' GOAT
60												-6000	1	1											<=		0.00	BANANA ACCTG
61														-1											<=	-100	-100.00	BANANA CONS'N
62																	-0.8	-0.8	1						<=		0.00	ADULT GOAT
63					-1			200			150	1			-0.3			5							=		0.00	M CSH BEG I
64						-1												20							=		0.00	F CSH BEG I
65											-1	1		1				5						-80	=		0.00	M CSH BEG II
66													1	-1	1			19						-200	=		0.00	F CSH BEG II
67								60			1													130	>=	500	2776.08	M CSH END YR
68												1												200	>=	200	652.10	F CSH END YR
69								60			1	1												330	>=		3428.18	TOT CSH END YR
70																										SUM	7453.52	

Table 9b2. Suggested matrix and the solution (three year end cash) for exercise 9b (part II)

III. INTERACTIVE LINEAR PROGRAMMING WITH VISUAL BASIC

PREFACE

This set of learning exercises constitutes a manual designed for graduate students and others with linear programming literacy and familiarity with Microsoft Excel®. It is intended to make the linear programming analysis more efficient in representing diverse households and respecting the diversity of household strategies. The objective is to achieve individual household analyses with accuracy and speed.

Recent computer development has made it possible for farming systems teams to use linear programming on farm. Visual Basic could become an essential tool for updating and testing different situations working directly with the farmers. Visual Basic makes the simulation process user friendly.

This set of exercises is divided into eight sections and 10 exercises. The first two sections deal with the simplest operations of "macros" and with inserting Visual Basic Objects in a spreadsheet. The third and the seventh sections present common linear programming tasks as input and output tables, respectively, linked to Visual Basic codes.

The fourth, fifth, and sixth sections deal with all the needed tools to control the "solver" function directly from codes in Visual Basic. And, finally the last section presents and describes advanced "solver" codes.

A.   Macros

Macros are routines and sub-routines of tasks in Excel. Usually we do many of these routines and sub routines manually and frequently (e.g. copy and paste, cell and sheet selection, calculations, solve, etc.).

Many times these routines are repetitive, time consuming, and with a chance of error. The use of macros for handling large amounts of data, saves time, reduces the chance of errors, and is very convenient.

Macros can do any task that it is possible to do using the mouse and the keyboard in an Excel document. The principle of macros can better be understood if we think of it as analogous to a tape-recording process; we can record any routine and recall it at any time by simply using a shortcut (usually Ctrl + "letter").

Exercise 1   Copy and Paste Macro

1.   In an Excel spreadsheet. Go to **Tools/Macro/Record New Macro**
         A Record Macro window will appear.
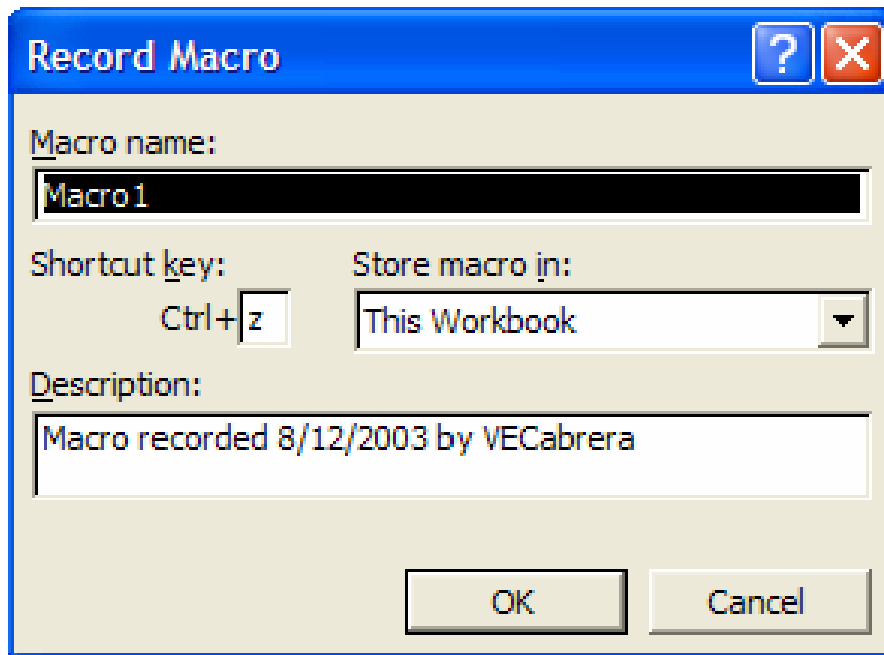
2.   In the Record Macro window. Leave the Macro name as Macro1, assign "z"
         as the Shortcut key, Store the macro in: This Workbook, and click OK.
         A Stop Rec window will appear.

3. Now the recording process starts. Select cell C5, go to **Edit/Copy**. Select cell C10, go to **Edit/Paste**. Click in the blue square of the Stop Rec window.   The macro is ready to use.

4. Watch the macro work. Select cell C5 and write a number (e.g. 100), press Enter and press Ctrl + z.
    The number in the cell C5 will be duplicated and assigned to cell C10. Play with this.
    You will realize that this simple principle could be applied to many useful routines

Exercise 2   Locate and run the macro in other ways

1. You must be able to find where your macros are located. Let's continue with the previous exercise. Go to **Tools/Macro/Macros**...
    A Macro window will appear.
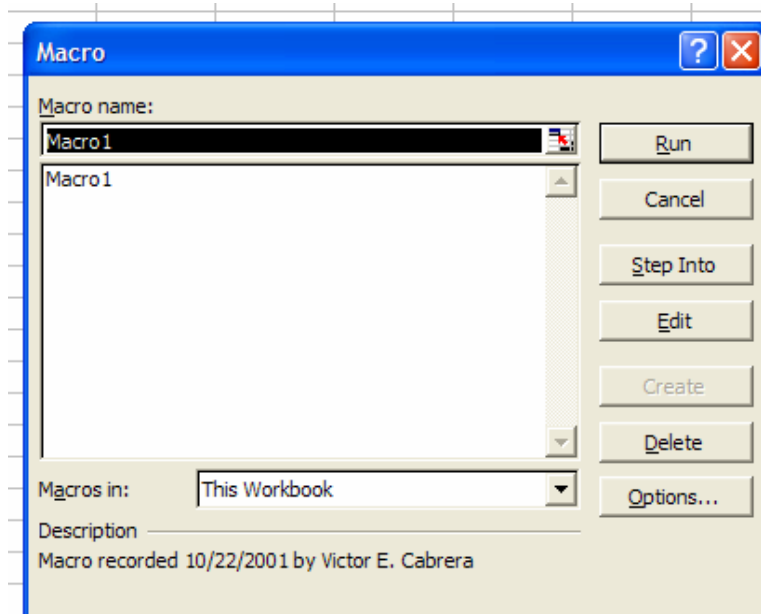
2. Make sure This Workbook is selected and Macro1 is highlighted. Then press the Run button. This is another way to call the macro.

3. Let's do it directly from the Visual Basic Editor. Go to
    Tools/Macro/Visual Basic Editor (VBE)
    Microsoft Visual Basic Editor will appear.
    You will see three frames in the Visual Basic Editor: in the upper left, the project directory; in the lower left the properties; and on the right a window for the CODES (it may contain visual basic codes or could just be empty).
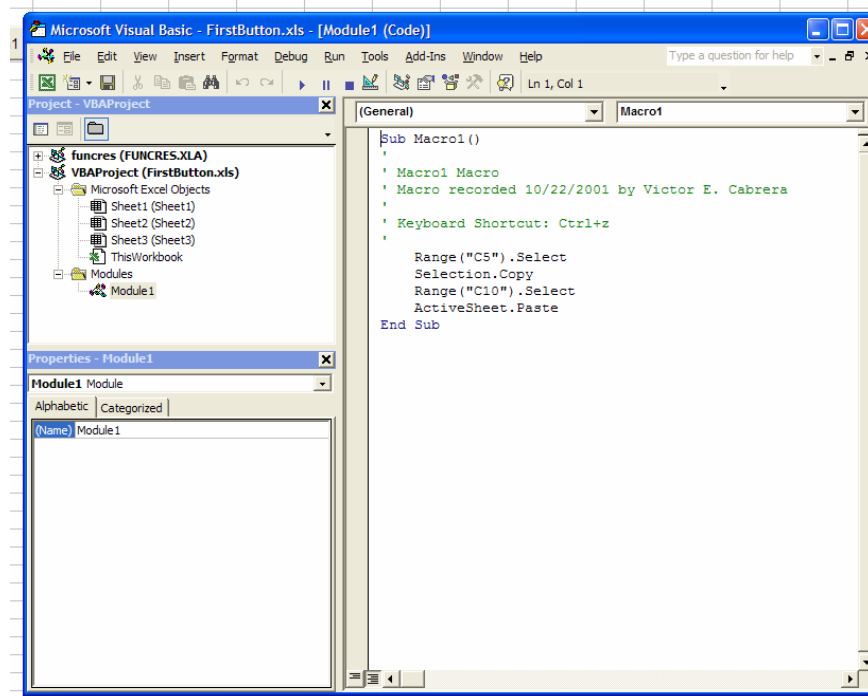
4.   You may need to locate your "Macro1" inside the Module1 in the Project Directory, double click in Modules folder and again double click in Module 1. Once you have it, you will see the codes of this simple macro, in the codes window.
Any routine has a **Sub**Name( ) that is the starting point and an **End Sub** that is the end.
Between these commands you will see comments (green and starting with an apostrophe) and the real codes.
In this example the name of the routine is Macro1, the comments refer to the date and author of the macro and the keyboard short cut. The codes are a set of select, copy, and paste.

5.   Return from VBE to the spreadsheet by clicking on the Excel icon in the bottom tool bar:

and delete whatever is in cell C10.
Return from the spreadsheet to VBE by clicking on the VBE icon in the bottom tool bar

Now, first make sure that the cursor is anywhere inside the routine "Macro1", then look for the run icon in the middle top of the screen, click on it and going back to Excel check to see if cell C5 is copied to C10 in the spreadsheet.
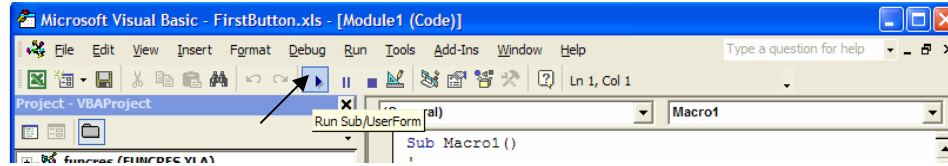
Now you are able to create and run Macros in Excel. Save the workbook with the name of **FirstMacro** but keep in mind that at any time you ask to open this file, Excel may warn you of the existence of macros (which are similar to viruses) and you will need to enable them.

B.   Visual Basic Objects and Buttons
Microsoft Excel has a feature to insert objects and buttons in any spreadsheet. These are useful in the linear programming work.

Exercise 3   Locate and familiarize yourself with VB objects

1.   Open the **FirstMacro** file, go to **View/Toolbars** and check **Control Toolbox**
      A Control Toolbox will appear

2.   Let's concentrate for now on the six middle buttons of the window: Check Box, Text Box, Command Button, Option Button, List Box, and Combo Box. (You can find these names by pointing and stopping the cursor on them).

3.   Click on the Command Button. Go with the mouse to cell C4 in the spreadsheet (you will note that instead of an arrow for the mouse cursor, now you have a cross). Locate the cursor on the lower-left corner of C4 and drag it to the top-right corner of D3. A button will appear
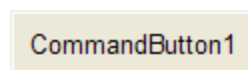
4.   Double click in the middle of the new CommandButton1. VBE will open and the cursor will be right in the middle of a program routine; write Macro1 and close VBE.

In the spreadsheet you will see that the Design Mode (Ruler, Triangle Pencil icon) is selected; deselect it by clicking on it.
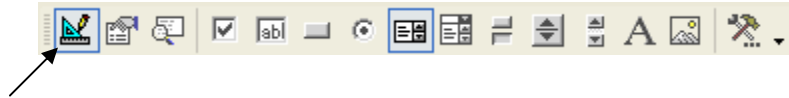
5.   Go to cell C5. Write a number (e.g. 1000), press enter. Now click on the CommandButton1.
      You will see that the number you put in C5 is copied into cell C10.
      You called Macro1 directly from the CommandButton1.

6.   Play and insert other VB objects in the spreadsheet. Save your file as **FirstButton**

Exercise 4   Set up a Combo Box

1.   Open the **FirstButton** file and repeat step 1 of Exercise 3. In the Control Toolbox click on the Combo Box option. Insert a Combo Box in cells H2-I3.

2.   Write successive numbers 1 to 10 in cells J1 to J10. Make sure that the design mode is selected in the Control Toolbox and then double click on the Combo Box. The VBE window will appear.
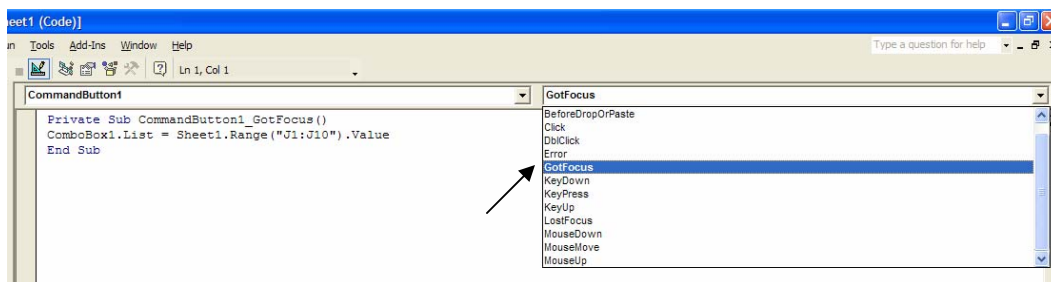
3.   In the VBE window, first thing, select GotFocus option from the drop menu in the top-right combo box (as seen in above figure), and then, write this code:

ComboBox1.List = Sheet1.Range("J1:J10").Value

between Sub and End Sub of the CommandButton2.

      You will generate this routine:

> Private Sub ComboBox1_GotFocus()
> ComboBox1.List = Sheet1.Range("J1:J10").Value
> End Sub

4. Return to the spreadsheet, make sure the design mode is deselected. Click on the drop menu option of the ComboBox you just created.
You will see that the numbers of cells J1 to J10 are now selection options in the ComboBox. Imagine that each number represents a specific household and links to its input data in your matrix and you could select any of them easily. Save your file as **FirstList**.

C.   Filters-Inputting Data
A critical function in individual household LP analysis is being able to insert each household's information in the matrix efficiently and rapidly without a chance of error. The Filter function of Excel, macros or routines, and Visual Basic objects will help in this task.

Exercise 5   Filter and Special Paste

1. Open the file **filter1.xls**. Available at:
http://nersp.nerdc.ufl.edu/~vecy/vbe/
Save the file in your local hard drive.

2. Take a look at the file. You should be familiar with this, it is the solution to Exercise 5 of the Linear Programming manual. Note that there are two sheets: MATRIX and INPUT. Some RHS numbers in the MATRIX sheet (labor and maize consumption) are linked to the input sheet; they are highlighted with yellow. Whenever we change family composition in the INPUT table, the labor available and the consumption requirement change in the MATRIX. Let's see how Visual Basic can do that for us.

3. To understand the FILTER function, go to the INPUT sheet, select cell H9 and write in Household then select cell H10 and write the number 5. Click Enter and look in the Excel main menu for:
Data/Filter/Advanced Filter…
The Advanced Filter window will appear
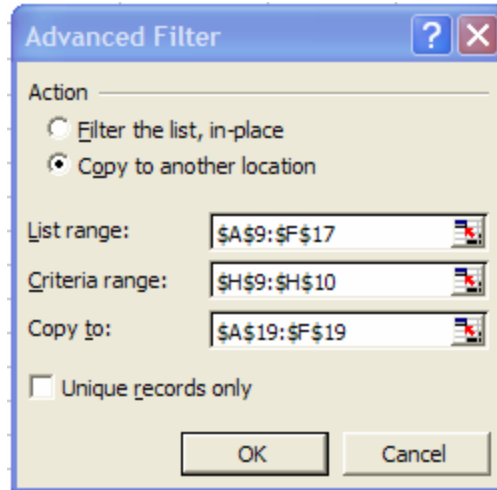
In the Advanced Filter window, select Copy to another location. Make sure that in the List range, the household table: $A$9:$F$17 is selected and in the Criteria range, our criterion just written: $H$9:$H$10 is selected. Finally, for the Copy to, make sure $A$19:$F$19 is selected, as seen in the above Figure. Click OK.

You will realize that this Filter function is very useful. It uses the Criteria range to find an exact match inside the List range (register number inside column heading). After finding it, it takes the whole matched row (family composition) and Copies it to the selected cells. Change the number of household in cell H10 and go to the Advanced Filter again. Play with this.

4.   Now you are ready to make a macro called filt with a shortcut Ctrl+f. Save the macro in this workbook and make sure it works properly.

5.   The next step will be to put the household composition (selected in cells B20 to F20) into the input table (Cells B2 to B6). Manually, the easiest way is to just copy B20 to F20, and Transpose them in a Paste Special. Do it.
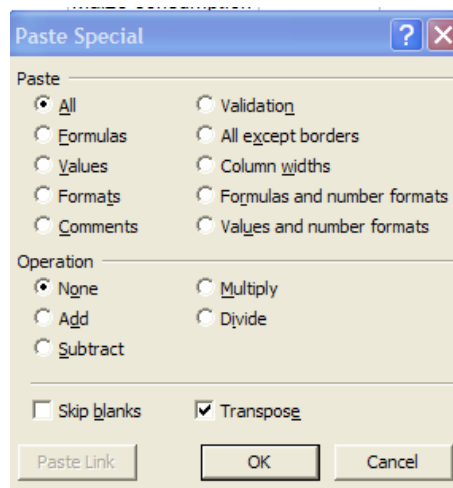
6.   Create a new macro called hhcopy with shortcut Ctrl+h that makes this Paste Special for you. Make sure it works correctly.
This is neat. Change the H10 number, do Ctrl+f, the household selected changes, now do Ctrl+h, the labor available and consumption change not only in the above tables but also inside the matrix.
Save this file as **filter2**.

Exercise 6   Select Households from the Matrix Sheet

1.   Start by opening the **filter2.xls** file.

2.   Select the MATRIX sheet. Insert a ComboBox between F27 and G27. Write Household in F26.

3.   Double click on the ComboBox and similarly to exercise 4, step 3, write:
Private Sub ComboBox1_GotFocus()
ComboBox1.List = Sheets("INPUT").Range("a10:a17").Value
End Sub
This code is assigning the values of the household numbers (1 to8) to the Combobox.

4.   Insert a CommandButton in the MATRIX sheet, between cells K26 and L27. Double click on this second button and write:
Private Sub CommandButton2_Click()
Sheets("INPUT").Range("H10") = ComboBox1.Value
Sheets("INPUT").Select
filt
hhcopy
Sheets("MATRIX").Select
End Sub
Note: you do not need to go to GotFocus for this routine.
These codes are a little more complex. In the first line we are assigning the current ComboBox value to cell H10 in the INPUT sheet. In the second line we are indicating that we will work for a while in the INPUT sheet. The third and fourth lines are calling the macros filt and hhcopy respectively. The last line is only to return to our worksheet, MATRIX.

5.   Deselect the Design Mode in the Control Toolbox, pick up some number in the ComboBox and click on the second CommandButton. Note that the numbers in the RHS of the matrix change automatically with each change in the household number, so you may solve the matrix for different households.

        Play with it by changing the numbers. Save your file as **filter3**.

D.   Visual Basic Solver Function

It is possible to call the solver function directly from the Visual Basic through codes or macros. If we call the function from macros we need to previously setup the solver parameters manually (Target Cell Max/Min/etc, Changing cells, Constraints, etc.).

There are two important things to take into account before starting with the next exercises:

1.   The solver can not be called if some cell in the sheet is being edited or if no specific cell is selected in a sheet. Taking this into account can avoid many frustrations.
2.   The solver can only work from codes or macros in Visual Basic if a reference to them exists. Exercise 7 deals with this topic.

E.   Visual Basic Reference to Solver

Exercise 7   Including the Solver Reference

1.   Open your previous file **filter3.xls**

2.   Open the Visual Basic Editor (VBE). (See exercise 2 & 3). In the top left window, highlight the VBAProject (filter3.xls), go to **Tools/References**. The VBAProject window will appear. In this window check solver and click OK. The Project window must have Refernces/Reference to SOLVER.XLA:
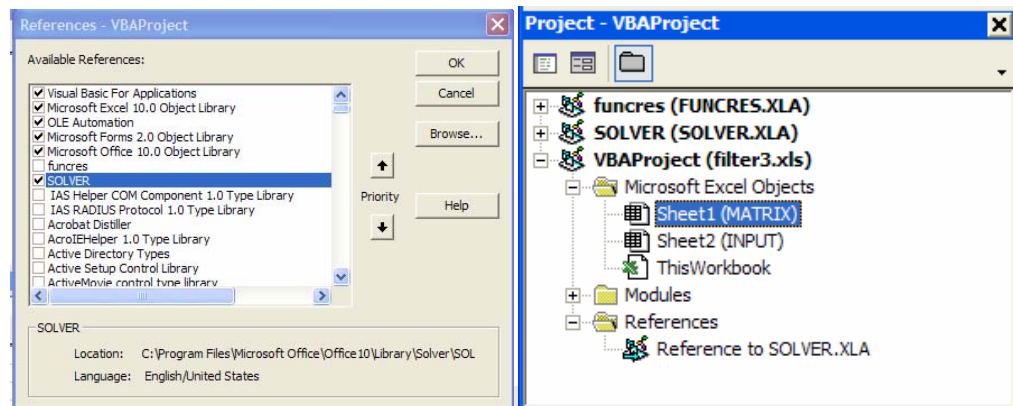
Note that there is a new folder (References) inside which is the reference to the solver. You can put the reference in another path and it will still work, but it is always a good idea to insert it in the file you are working on to make sure it will work in other computers.

3.   Close the VBE and save your file as **filter4**.

F.   Direct Solver Call

Exercise 8   Solver Button

1.   Open your file **filter4.xls**

2.   Record a new macro called *sol* with the "Ctrl+s" shortcut to call the solver and solve the matrix.

3.   Record another new macro called *del* with the "Ctrl+d" shortcut that deletes the variable cells of the matrix.

4.   Now you can control all the actions in just one button. Select design mode (see exercise 3), double click in the existing command button, insert at the end of existing commands the new commands *del* and *sol* and you will get this:

> Private Sub CommandButton1_Click()
> **   S** **heets("INPUT").Range("H10") = ComboBox1.Value**
> **   Sheets("INPUT").Select**
> **   filt**
> **   hhcopy**
> **   Sheets("MATRIX").Select**
> **   del**
> **   sol**
> End Sub

5.   Try it. You must choose one household in the ComboBox, then click in the CommadButton2 and everything is done.

6.   Play with this and make sure all the solutions are correct. Which households obtain non-feasible solutions?

7.   Save your file as **solv1**.

G.   Listing Results

Exercise 9 Output Tables

1.   Open your file **solv1.xls**

2.   Go to Insert/Worksheet (right click on INPUT and click on insert, then worksheet). Right click on the new sheet1 and click on rename and rename it OUTPUT. In cell B5 in OUTPUT, write household and in the next columns copy the names of the variables of the matrix. After that, in the same row copy all the names of the resources and constraints (hint: use Paste Special/Transpose). Then you will get column headings B5 to AC5.

3. In cells C4 to AC4 (yes, above not below) refer or link to the values of the matrix.

4. Refer or link cell B4 to the INPUT sheet (H10).

5. Create a new macro that inserts copied cells from the row 4 to row 6 using row 3 as a bridge.
    Call this macro *output* and use "Ctrl+o" as a shortcut.
    Right click on number "4" (of row 4) and select "Copy"
    Right click on number "3" (of row 3) and select "Paste Special..." and select "Values." Then click OK.
    Right click on number "3" (of row 3) and select "Copy"
    Right click on number "6" (of row 6) and select "Insert Copied Cells"

6. Go to the MATRIX sheet. Select design mode and double click on the Command button. In the VBE, write at the end of the commands (after Sol)
    Sheets("OUTPUT").Select
    output
    Sheets("MATRIX").Select
    Then close VBE.

7. Deselect design mode in Excel and try it to see if it works properly. Solve households 1 to 8 in order and see the differences at the end in the OUTPUT sheet.
    Save your file as **solv2**.

H.   Solver with Commands

The solver in Microsoft Office can be called through commands in the VBE. For example, we could just write SolverSolve and refer it to some command button in the spreadsheet and it would work exactly the same as recording a macro. But the main advantage of calling the solver by commands is that we can control all the parameters directly from buttons in the spreadsheet. With that in mind, here is an exercise and a list of all the commands that control the solver. These commands only work with Microsoft Excel 97 (or above) and the regular solver engine. For other versions, there are slight differences and you may need to find the exact commands in the help files or in the manuals. Sometimes tutorial software handles these topics as well.

Exercise 10 Advanced Solver

1. Open your file **solv2.xls**

2.   Go to VBE. Find your codes that call the solver (hint: double click in module2). You will see a series of codes. Some of them set up the parameters and the last code SolverSolve takes the action of the solver.

Sub sol()
'
' sol Macro
' Macro recorded 8/12/2003 by VECabrera
' Keyboard Shortcut: Ctrl+s

SolverOk SetCell:="$P$24", MaxMinVal:=1, ValueOf:="0", ByChange:="$C$7:$M$7"
SolverSolve
End Sub Sub sol()

3.   The first two lines (bold) were set in the solver for exercise 5; Excel does not include the constraints in this macro, however we could include them if desired by using the command SolverAdd (see following list). The constraints are not inside these parameters. Rather it is using the current constraints in the solver window. We can delete or change them to comment mode (not active) and control the parameters directly from the spreadsheet. Put an apostrophe before the first codes line:

'SolverOk SetCell:="$P$24", MaxMinVal:=1, ValueOf:=0, ByChange:="$C$7:$M$7"

Letters will turn green indicating they are not active. Now, we are using the most important code only to call the solver function. Try it in the spreadsheet. Once it is working, you can go to the **Tools/Solver** and for example delete the ">=" constraints. Now solve directly from the CommandButton. How do the solutions in the different households change? Are there more or fewer non-feasible solutions?.

4.   Save your file as **solv3**.

List of Solver VBE Commands

SolverAdd:
Adds constraints to a Solver model. Takes three arguments:
• cellRef—Reference to a cell or a range of cells that forms the left side of a constraint.
• relation—1 (<=), 2 (=), 3 (>=), or 4. (Cells referenced by cellRef must contain integers.)
• formulaText—Right side of the constraint.

SolverChange:
Changes an existing constraint. Takes three arguments:

• cellRef—Reference to a cell or a range of cells that forms the left side of a constraint.
• relation—1 (<=), 2 (=), 3 (>=), or 4. (Cells referenced by cellRef must contain integers.)
• formulaText—Right side of the constraint.

SolverDelete:
Deletes an existing constraint. Takes three arguments:
• relation—1 (<=), 2 (=), 3 (>=), or 4. (Cells referenced by cellRef must contain integers.)
• formulaText—Right side of the constraint.

SolverFinish:
After solving a problem, tells Excel to keep the results and to create a report. Takes two arguments:
• keepFinal—1 keep final results; or 2 discard results and return to original values.
• reportArray—1 create an Answer report; 2 create a Sensitivity report; or 3 create a Limit report.

SolverFinishDialog:
Equivalent to SolverFinish; however, also displays the Solver Results dialog box after solving a problem. Takes two arguments:
• keepFinal—1 keep final results; or 2 discard results and return to original values.
• reportArray—1 create an Answer report; 2 create a Sensitivity report; or 3 create a Limit report.

SolverGet:
Returns information about the Solver model. Takes two arguments:
• typeNum—Takes values from 1 through 18 to return information about the Solver model. For details, use the
Object Browser to view the SolverGet help topic in the XLM Function Reference section in Excel 5's online Help.
• sheetName—Name of the sheet containing the Solver model.

SolverLoad:
Loads parameters for an existing Solver model that have been saved to the worksheet. Takes one argument:
• loadArea—Range on the active sheet that contains the Solver model.
SolverOk:
Defines a Solver model. Takes four arguments:
• setCell—Target cell for the Solver model.
• maxMinVal—1 maximize target; 2 minimize target, 3 match target to a specific value.
• valueOf—If the maxMinVal argument is set to 3, you must specify the value to which the target cell is to be

matched.
• byChange—Cell or range of cells that will be changed in setting the target cell.

SolverOkDialog:
Same as SolverOk but also displays the Solver dialog box. Takes four arguments:
• setCell—Target cell for the Solver model.
• maxMinVal—1 maximize target; 2 minimize target; 3 match target to a specific value.
• valueOf—If the maxMinVal argument is set to 3, you must specify the value to which the target cell is to be
matched.
• byChange—Cell or range of cells that will be changed in setting the target cell.

SolverOptions:
Allows you to specify advanced options for your Solver model. Takes 10 arguments:
• maxTime—Maximum time Excel will spend solving the problem.
• iterations—Maximum iterations Excel will use in solving the problem.
• precision—Number between O and 1 that specifies the degree of precision to be used in solving the problem.
• assumeLinear—If True, Solver assumes that the underlying model is linear.
• stepThru—If True, Solver pauses at each trial solution.
• estimates—1 for tangent estimates; 2 for quadratic estimates.
• derivatives—1 for forward, 2 ffir central.
• search—1 for Quasi Newton search; 2 for Conjugate Gradient search.
• intTolerance—Number between O and 1 that specifies tolerance.
• scaling—If Scaling is True and two or more constraints differ by several orders of magnitude, Solver scales the constraints to similar orders of magnitude during computation.

SolverReset:
Resets Solver options (cell selections and constraints in the Solver Parameters dialog box and all settings in the Solver Options dialog box) to their default values.

SolverSave:
Saves a Solver model definition to a range of cells on the worksheet. Takes one argument:
• saveArea—The range of cells to which the Solver model is to be saved.

SolverSolve:
Starts a Solver solution run. Takes two arguments:

• userFinish—If True, Solver returns results without displaying anything. If False, Solver returns results and displays the Solver Results dialog box.
• showRef—This argument is used only if True is passed for the step thru argument of the
SolverOptions function.
 If so, you can pass the name of a subroutine (as a string) as the showRef argument—this routine will be called whenever Solver returns an intermediate solution.

Other proposed exercises

You can try these exercises using your file **solv3.xls**

1. Make the last window of "solver results" disappears at the end of the solver. After clicking on the solver button only results must appear.

2 Control the cash constraints with buttons. With a button take out these constraints, with another button include them before solving.

3. If you have some literacy in Visual Basic, you could try to make a "loop" in which you could solve the eight households with only one click.

4. If you have some literacy in Visual Basic, you could try to insert "if–then" statements that control constraints.

5. Your imagination is the limit.