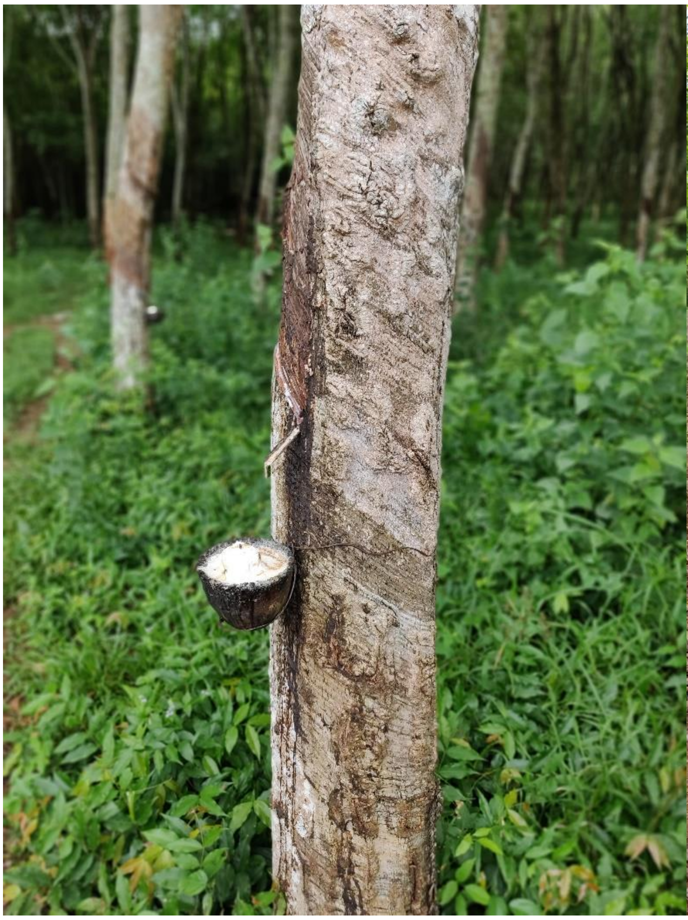
Thailand Rubber Farm Model

Technical Note

Deliverable 3

Authors: James Lowenberg-DeBoer, Montchai Pinitjitsamut, Sophon Yamklin, Nithicha Thamthanakoon, Nararat Rattanamanee, Pim Pinitjitsamut, Katy James, Iona Y Huang



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Author(s)	James Lowenberg-DeBoer[1], Montchai Pinitjitsamut[2], Sophon Yamklin[2], Nithicha Thamthanakoon[2], Nararat Rattanamanee[2], Pim Pinitjitsamut[2], Katy James[1], Iona Y Huang[1] 1 Harper Adams University, Newport, Shropshire, TF10 8NB 2 Kasetsart University, 50 Ngam Wong Wan Rd, Ladyaow Chatuchak Bangkok 10900, Thailand
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Executive Summary

The price of natural rubber fluctuates with worldwide industrial demand and this creates challenges for smallholder rubber farmers in Thailand. Diversification of farm crop and livestock enterprises is a key strategy they can use to survive the low price periods, but some combinations are more effective than others. The Thai Rubber Farm Model provides a tool that can be used by researchers, Rubber Authority of Thailand (RAOT) staff and farmers to develop economically efficient diversification strategies. This note summarizes the development of a deterministic linear programming (LP) model and a risk management model that uses the Target Minimization of Total Absolute Deviations (i.e. Target MOTAD) approach. The LP model parameters were based on information collected from rubber farmers in Chumphon and Surat Thani provinces in southern Thailand, complemented by data from secondary sources. The target MOTAD model was developed by augmenting the model with states of nature defined by output commodity prices from Thailand Agricultural Statistics over a decade long period (2007-2016). Because of data limitations the TARGET MOTAD model only reflects output price variability. The deterministic linear program shows that because Thailand has rain year round, and because of the crops and livestock produced in Thailand are not seasonal, crop growth or labour synergies are very modest, but the Target MOTAD model shows that there are enterprise combinations that reduce income variability over time due to price changes. In particular, to diversify most effectively rubber production should be combined with fruit, vegetable or livestock enterprises. Which fruit, vegetable or livestock enterprise would be more effective depends on local production conditions and markets. To be even more useful the MOTAD model should include input price, yield and other variability.

Contents

1. Introduction

Thailand is the world's largest producer of natural rubber (36.3% of the world total). Almost 4.5 million hectares are planted with natural rubber in Thailand. Of the 1.1 million Thai rubber growers, 93% of rubber plantations are small to medium farms (i.e. < 4 ha), of which 79% are smallholdings (i.e. < 2.4 ha). The monthly income of Thai rubber growers averaged 9,236 THB (£215) per month in 2015, but some 40,000 rubber growers face poverty with a monthly income of only 2,341THB (£54, poverty line defined as 2,667 THB or £62, NESDB 2015). The major threat to livelihood derives from price volatility on world markets. Over the long term natural rubber has been quite a profitable crop, but when the price of rubber is low, the income of small-scale rubber farmers declines because a large majority do not manage risk through diversification. The overall objective of the "Sustainable Agribusiness Model for Poverty Reduction among Thai Small-scale Rubber Farmers" implemented by Harper Adams University in the United Kingdom and Kasetsart University in Thailand, and funded by the British Council Newton Fund, is to help Thai rubber growers develop diversification plans that fit their circumstances. One of the tools used to develop those plans is a farm linear programming model that could be used by researchers, by the Rubber Authority of Thailand (RAOT) and by farmers to develop economically efficient diversification plans. The specific goal of this technical note to describe the models developed and provide examples of their use.

1.1 State of the Art

A variety of tools have been used to develop management strategies for rubber farmers. Budgeting studies are relatively simple to develop and easy to understand, but comparisons become too complex if there are many options (e.g. Esekhade et al., 2014; Esekhade et al., 2006; Esekhade et al., 2003; Jongrungrot and Thungwa, 2014; Jongrungrot et al., 2014; Wijesuriya and Thantil, 2001; Choengthong, and Choengthong, 2014; Snoeck et al., 2013; Tajuddin, 1986). Simulation approaches can accommodate more complexity, and typically include a higher level of detail on biological factors (e.g. Somboonsuke et al., 2017; Penot, 2004; Penot et al., 2016; Stroesser et al., 2018; Lehebel-Peron et al., 2010; Simien and Penot, 2011; Wulan et al., 2007), but are open to interpretation differences. Studies using Net Present Value (NPV) focus on the pattern of returns over time for various rubber management alternatives and diversification (e.g. Belcher et al., 2004; Guo et al., 2006; Stirling et al., 1998; Majid et al., 1990). Policy Analysis Matrix (PAM) studies focus on the policy issues, not the farm level economic survival (e.g. Rodgers et al. 2010). Mathematical programming is used to identify economically optimal input levels, enterprise choices and labour allocation (Etherington and Nainggolan, 1987; San and Deaton, 1999, Lowenberg-DeBoer et al., 2017). It has the advantage of providing an explicit structure for optimization that can accommodate a great many alternatives. Non-linear optimization has some of the advantages of simulation in incorporating biological detail, but still sorts through the alternatives to produce an optimal result at the cost of a more fickle optimization process (e.g. Wojkowski et al., 1991). Only a few of those mathematical programming studies concentrated on rubber farm diversification (San and Deaton, 1999; Wojkowski et al., 1991; Lowenberg-DeBoer et al., 2017). None of the math programming studies used risk analysis methods (e.g. Quadratic programming, MOTAD) to identify optimal portfolios.

For agriculture in general mathematical programming models have been extensively used to aid in planning since the 1950s (see e.g. Heady, 1954). This approach has distinct advantages over partial budgeting because (a) it can select a single plan that produces maximum net returns, and (b) it allocates the scarce resources (land, labor, machinery) of the farm so as to use them as efficiently as possible in the economic sense and (c) for complex farming operations it can quickly and efficiently sort through thousands of alternatives. Numerous books have addressed the subject (e.g. Hazell and Norton, 1986; Kaiser and Messer, 2011), and these models can be adapted for use with farms that include both crop and livestock enterprises (e.g. Morrison, et al., 1986). A survey of applications of these types of models can be found in Glen (1987).

1.2 Objectives of this Technical Note

With the overall goal of providing a tool that could be used to develop farm diversification plans this project focused on farm linear programming (LP) including a Target Minimization of Total Absolute Deviations (MOTAD) version that would explicitly model portfolio optimization. LP was selected as a model with relatively modest data requirements and easy to run, but providing easily interpretable results. Target MOTAD models are more complicated than deterministic LP, but they can still be solved with LP software and provide specific solutions that are easy to interpret. The deterministic LP and Target MOTAD models could be used by researchers, by the Rubber Authority of Thailand (RAOT) and by farmers to develop economically efficient diversification plans. The objective of this note is to describe the LP and MOTAD models and provide some examples of use.

2. The Model

The Thai Rubber Farm LP model was based on a well tested and particularly flexible system for model farming operations known as the Purdue Crop/ Livestock Linear Program (PC/LP) (Preckel et al., 1992; Dobbins et al., 1990; Dobbins et al., 1992; Dobbins et al., 1994). This model accommodates both crop and livestock production, taking into account the use of crop outputs as feedstuffs. Crop modeling allows for sole crops, multi-year crop rotations, and multiple cropping – the raising of more than one crop on the same piece of land within the same year. Categories of resources can be distinguished including owned and hired labor, plots of land with different soil types, and different types of livestock facilities. This system was used from the mid-1990s through about 2010 as an analytical tool for Purdue's Top Crop Farmer Workshop. Farmers from across the Midwestern United States came to Purdue each summer and developed a linear programming model for their farm to evaluate alternative technologies and resource investments. An updated version of the PC/LP system has been developed in the GAMS modeling language. This GAMS version was used by the Purdue University Orinoquia Initiative to help the government of Colombia evaluate proposals for agricultural development in the Orinoco River basin. Examples of the Orinoquia LP analysis are available at: https://www.purdue.edu/colombia/partnerships/orinoquia/. The Thai Rubber Farm model is a modified version of the PC/LP model using GAMS software. In many ways it is also similar to the Audsley (1981) UK farm LP, but taking advantage of more recent software.

The Thai Rubber Farm model can be expressed in the standard summation notation used by Boehlje and Eidman (1982) as:

(1) $$Max\ \Pi = \sum_{j=1}^{n} c_j X_j$$

subject to:

(2) $$\sum_{j=1}^{n} a_{ij} X_j \le b_i \text{ for } i = 1 \ldots m$$

(3) $$X_j \ge 0 \text{ for } j = 1 \ldots n$$

where:

X_j = the level of the *j*th production process or activity,

c_j = the per unit return (gross margin) to fix resources (b_i's) for the *j*th activity,
a_{ij} = the amount of the *i*th resource required per unit of the *j*th activity
b_i = the amount of the *i*th resource available.

The gross margin (cj's) is total crop sales revenue minus total direct costs, and can be considered returns to fixed costs. In other words net returns from the operation equals gross margin minus fixed costs. In the Thai Rubber Farm analysis, the objective function was to maximize gross margin for each land and labour scenario. Fixed costs are land, farm facilities, equipment, and compensation for management, risk taking and labour provided by the operator.

Because agricultural activities are often seasonal, the choice of time step is crucial. The Thai Rubber Farm model assumes a monthly time step. This is a compromise between accurate modelling of the seasonal pattern of work and need keep the model relatively simple. A quarterly time step would be too coarse; there are important differences between July and October, or September and November.

Because of rain and inclement weather crop activities the number of days each month when field work is possible is substantially less than the number of calendar days in the month. In each month the number of good field days can be estimated based on meteorological data. The primary mechanism for modelling risk aversion in the deterministic model is the level of probability assumed for the good field days. The standard PC/LP assumption was to use the good field data available in the 17th worst year out of 20 (McCarl et al. 1974). This would be the number of good field data available 85% of the time. The number of good field days for initial runs of the Thai Rubber Farm model were estimated by the project team and the number of calendar days in the month, minus Sundays and holidays, and less the average number of days with heavy rain as reported by rainfall monitoring stations in Thailand:

Jan	24
Feb	23
Mar	25
Apr	20
May	21
Jun	24
Jul	21
Aug	23
Sep	22
Oct	21
Nov	25
Dec	21

Note that most of the field operations on Thai Rubber Farms are manual, so soil dry enough to support equipment is not a major concern.

The primary constraints are:

- *Land* – The sum of land used in production activities is less than or equal to the arable land available. If q crops or crop growth stages are in a given rotation, the land used for a unit of a rotation is the fractional unit 1/q of each crop or perennial crop growth stage. For example, one hectare of rubber with a productive life of 25 years is composed of one year of planting stage rubber, six years of pre-production rubber and 18 years of rubber in the production stage. In the example, q=25.
- *Labour* – the sum of the labour needed in each month for each crop in the rotation multiplied by the fractional unit (1/q) of each crop or stage of perennial crop growth in a given rotation. The sum of the human labour required must be less than the labour available from the operators, permanent farm labour, and temporary farm labour on the number of good field days.
- *Cashflow* – sum of the variable costs for each crop in a rotation in a given month multiplied by the rotation fraction must be less than or equal to the working capital available.

***GAMS* –** The Thai Rubber Farm Model uses the General Algebraic Modelling System (GAMS) software developed by the World Bank. It is the most commonly used mathematical programming software for agricultural research. A demo version of the GAMS software is available at:

https://www.gams.com/download/

The demo version will solve problems with up to 300 constraints and is adequate for learning. The deterministic version of the Thai Rubber Farm Model is designed to run on the demo version. The full licensed version of GAMS is required for the Target MOTAD model. There are some GAMS learning materials on the GAMS site:

https://www.gams.com/products/introduction/

Following the example of the Orinoquia LP model, the Thai Rubber Farm Model software has two parts. The first of these is the GAMS source program. The source program should be modified with care, except for the third line of the program as will be explained below. The second part of the inputs is in the form of a spreadsheet that contains a series of worksheets that contain the data for the LP. The GAMS code for the deterministic Thai Rubber Farm Model is in Appendix A and the input spreadsheet is in Appendix B. To be used, the GAMS code must be in a file with the “gms” ending, but the GAMS code has been pasted into an MSWORD file to provide easier access for readers who have not yet installed the GAMS software.

As mentioned, the GAMS source file should be modified with care, except for one exception – the third line of the program. This line is used to link the GAMS program with the correct data spreadsheet. For the example in Appendix A & B, the data spreadsheet is named ThaiRubber-270120.xlsx and the third line of the GAMS code should read:

```
$call copy ThaiRubber-270120.xlsx Orinoquia_Tables.xlsx
```

Any time the relevant spreadsheet name changes, this third line must also be changed so that the correct data is used.

3. Estimation of Parameters by Activity

Parameters in the Thai Rubber Farm Model were estimated mainly from data collected on rubber farms in southern Thailand, complemented by secondary data from rubber intercropping and multicropping research. The farm data were collected through detailed face-to-face semi-structured interviews with 20 rubber farmers who have practiced on-farm diversification in two southern provinces of Thailand (Chumphon and Surat Thani). The farmers were selected with the help of the Rubber Farmer's Council of Thailand to represent farmers who are diversifying farm enterprises. The inclusion criteria were:

a. Farm land size is less than 8 hectare.
b. Farmers grow rubber trees as their main crop.
c. Farmers grow other crops in addition to rubber (not just during the first 3 years of rubber plants).
d. Farmers grow multi-crops for commercial purposes.

Based on monthly labour inputs, materials input, outputs, and physical and climate constraints, a series of scenario-based modelling of economic optimisation of land use and on-farm diversifications have been developed for small-scale rubber farmers. Preliminary analysis suggests that in Southern Thailand the potential for intercropping rubber with other species is modest because rubber plantations are usually densely planted to maximize latex production and to reduce wind damage to trees. Consequently, few commercial crops can grow under the rubber trees and most diversification is multi-cropping with other species on nearby fields. There is some potential for farmers to capitalize on complementary labour requirements. For example, rubber can be tapped all year round in Southern Thailand, but some farmers reduce tapping at the beginning of the rainy season in March, April and May which is the time when vegetables, pineapple, fruit trees, coconut and oil palm can be planted.

In appendices C1 to C11 are spreadsheets used to estimate the coefficients in the "Labor Use-(R)", "Cash_use_(R)" and "Commodity_produced_(R)" worksheets of the input spreadsheet in Appendix C1 to C11:

- Appendix C1 - Baegu (*Gnetum gnemon*) – In Thailand leaves used as vegetable. The labour, cost and yield parameters are based on information provided by the farm interviews and Saetiew (2008). Baegu is a perennial bush. It was arbitrarily given a 25 year productive life in this analysis.
- Appendix C2 - Chickens for free range egg production. The parameters are based on information provided by the farmers interviewed. The hens are free range but have a netted enclosure for protection at night. Eggs are collected from the enclosure when the food is put out for the chickens. They are fed paddy rice and water from bowls in

the enclosure. One hour of family member labour per month for feeding and 1 hour per month for collecting eggs. Data indicates 70 hens lay 1500 eggs per month (average 21eggs per month). Space requirement is estimated at 4 m^2 per hen which is the European Union standard for free range hens. In the output the free range chicken activity is accounted in hectares; at 4 m^2 per hen one hectare is 2500 hens.
On average laying hens will be productive for about 1 year, consequently the parameter spreadsheet has one column of data. When the hen is 12 months old it is replaced by a new young hen (not chicks) that is ready to lay. The price for a replacement young hen is 180 baht. The new chickens are kept in the enclosure until they are sure it is able survive free range. The new chickens are fed the same paddy rice as the older chickens.

- Appendix C3 - Chinese kale is a short season vegetable crop with a 40 to 45 day cycle. It is marketed locally. Chinese kale is assumed to be repeated continuously throughout the year. Consequently, its spreadsheet has only one year. The parameters are based on information provided by the farm interviews and Supuntee (2012).
- Appendix C4 – Parameters for coconut production were estimated from the farmer interviews. Establishment estimates came from Jaikrajang and Thitithanakul (2017). Coconut trees are long lived, so the analysis assumed a 50 year productive life.
- Appendix C5 - Durian fruit is a tree crop. The fruit has a foul odour, but the taste is appreciated by Thai consumers and many other people around the world. Parameters for durian fruit establishment and production were estimated from the farmer interviews.
- Appendix C6 – Mangosteen is a tree crop. Parameters for mangosteen establishment and production were estimated from the farmer interviews. Mangosteen trees are long lived and were assumed to have a 50 year productive life.
- Appendix C7 - Oil palm is an industrial tree crop. Oil for cooking and biodiesel is extracted from the palm fruits and a protein meal is made from the palm “kernels”. Establishment and production parameters were estimated based on the farmer interviews. Oil palm trees start producing fruit in the 3rd year after planting, reach peak production about years 9 and 10, and decline slightly until about year 25. The relationship of yield and tree age was based on Ismail and Mamat (2002).
- Appendix C8 - Pineapple can either be grown as a monocrop or intercropped in young rubber trees. When intercropped, it is assumed that a one meter strip is left every five meters for the young rubber trees and the remaining 4 meters in every row is planted to pineapple (about 80% of the field to pineapple). For the analysis it is assumed to be productive for three years, with the main production at the end of year 1, and harvest of side shoots in years 2 and 3. The establishment and production parameter estimates were based on farmer interviews.
- Appendix C9 - Para rubber cup lump produced with family labor parameters are based on data from farmer interviews supplemented with information from Siriwan (2014) and Chanthawong (2015). The cup lump is the coagulated latex found in the collection cup. It is natural rubber in its least processed state. The estimates assumed 420 trees per ha, or about 20 rows almost five meters wide. In Thailand rubber trees are typically productive for about 25 years. Yield by age percentages approximated as increasing linearly in years 7 to 10 by 25% each year, plateau at 100% years 11 to 20, decline by 10% per year years 21-25. At the end of its useful life rubber trees in Thailand are sold, often for furniture production.

- Appendix C10 - Rubber sheet production with family labour is based on farmer interviewers. The establishment cost is assumed to be the same as for rubber cup lump. Only the processing after harvest is changed.
- Appendix C11 - Para rubber Cup Lump Production with intercropped by another farmer the first three years. In this case it is assumed that another farmer is producing pineapple or other short cycle crop in the spaces between rubber tree rows. The rubber producer does not receive rent, but does benefit because the farmer producing the short cycle crop weeds the field and the fertilizer applied to the short cycle crop benefits the rubber trees.

The structure of the Appendix C spreadsheets is with separate worksheets for labour, variable costs and yield. Each worksheet has a number of active rows that correspond to the number of years for the cycle of each crop or livestock activity, plus a month column and a weighted sum column. Because of the steady state assumption the model assumes that all stages of the crop or livestock activity are done every year. The easiest way to model this is to assume that hectare is made up of "slices" with each slice corresponding to a year in the cycle. The coefficient for that activity in a given month is the average over the years of the cycle.

In Thailand many rubber tappers are compensated with a share of the harvest, rather than monetary wages. For model rubber share tapping activities it is assumed that the share tappers do all the activities during the production stage of the rubber trees (i.e. years 7 to 25). The farmer landowner is still responsible for the establishment phase and for all cash costs. In the models presented in this note the tapper share is assumed to be 50%.

4. Example solutions for deterministic LP

To give readers a sense of the economic relationships in the model presented above, it was solved for a baseline case assuming two ha of land, 1 adult family member and no hired labour available. The prices used are contemporary from farmer interview data or the supplementary information:

Table 2 – Prices used in example solutions:

Baegu	75	THB/kg
Eggs	3	THB/egg
Kale	16.85	THB/bag
Coconut	10.0	THB/piece
Durian	80	THB/kg
Mangosteen	30	THB/kg
FFB	2.73	THB/kg
Pineapple	6	THB/kg
CupLump	35	THB/kg
RubberSheet	43	THB/kg

Table 3 – Thai Rubber Farm Model Baseline Solution with Shadow Prices

	LOWER ha	LEVEL ha	UPPER ha	MARGINAL THB/ha
Baegu	0	0	2	-300300
Chickens	0	0	2	0
Chinese_Kale	0	0	2	-395200
Coconut	0	0	2	-504600
Durian	0	2	2	166690
Mangosteen	0	0	2	-581000
Oil_Palm	0	0	2	-556200
Pineapple	0	0	2	-533900
CupLump	0	0	2	-639100
CupLumpIntercrop	0	0	2	-638700
RubberSheet	0	0	2	-623100
RubberSheetIntercrop	0	0	2	-622600
ShareRubberSheet	0	0	2	-638600
ShareRubberSheetIntercrop	0	0	2	-638200
ShareRubberGovtPlant	0	0	2	-637800

The solution without market size limits or other constraints on land allocation shows all land devoted to durian fruit (Table 3) with a gross margin of 1,638,714 THB/year and not binding labor constraints on this small farm. Durian is the most profitable crop given the prices, labour requirements and cash inputs assumed. The marginal (i.e. shadow price) column would provide 166,690 THB/ha if an additional hectare could be acquired. The free range chicken activity is almost equally profitable; it has a zero shadow price. Forcing the other activities into the solution would results in substantially losses.

If there are market size limits or other constraints on durian, the solution switches to free range chickens. If free range chickens are not an alternative, the solutions goes to baegu, which has the next smallest negative shadow price (i.e. -300,300 THB/ha). At current price relationships, it only includes rubber if all alternative enterprises are not available. For example rubber might be the only cash crop alternative in isolated areas where there is no local market for fruits, vegetables and eggs, and transportation infrastructure does not allow shipping the food products to market.

Note that the most profitable alternative among the rubber activities is Rubber Sheet production because of the slightly higher price. Allowing another farmer to intercrop young rubber trees with pineapple improved the returns only slightly (i.e. 1500 THB/ha). If rubber sheet and cup lump rubber prices are set at their highs from the recent decade (i.e. 170 THB/kg for rubber sheet, and 160 THB/kg for cup lump), the unconstrained solution is still all durian fruit, but the rubber sheet production now becomes competitive with some of the fruits. The shadow prices indicate that in this high rubber price case, rubber sheet or cup lump would come into the solution before mangosteen, oil palm or pineapple. At those high rubber prices rubber comes into the solution for larger farms.

In the situation where a farmer already has some rubber and want to know what is the best diversification enterprise, a lower limit on rubber can be specified. For example, if in the baseline scenario with a 2 ha farm a lower limit on Rubber Sheet with family labour is set at 1.9 ha, then the solution shows 1.9 ha of rubber sheet and 0.1 ha of durian fruit. The gross return on that solution is 138,172 THB.

The mechanisms for these results is pointed out by Pinitjitsamut et al (2019). Because Thailand is a country blessed with year round rainfall, crop synergies driven by seasonality of rainfall or labour requirements are limited. Sometimes planting of perennial crops is done in May to benefit from the slightly higher rainfall in the May to November period, but in Thailand there are no “dry season crops” for the slightly dryer December to April period.

In contrast, Lowenberg-DeBoer et al. (2017) found that in the Orinoquia region of Colombia, cashew and cacay (both edible nuts) had complementary labour requirements to oil palm and natural rubber. In the Orinoquia, the harvest season for cashew and cacay is during the dry season when labour required for rubber and oil palm is at its lowest. Thus for the Orinoquia, the deterministic LP solution combines cashew, cacay, natural rubber and oil palm to achieve the highest labour productivity.

Pinitjitsamut et al. (2019) also point out that many farm enterprise combinations are driven by risk management. Farmers try to find enterprises with negative price correlations so that when one product price is down (and profits low) the other price is likely to be up. They point out that in the last decade, rice, maize, cassava, oil palm and coconut prices have been positively correlated with rubber prices, while prices of fruits and livestock products have been negatively correlated. The Target MOTAD model introduced in the next section is a tool for selecting the combination of enterprises that minimizes risk while maximizing returns.

5. Target MOTAD version

Most farmers and other decision makers prefer enterprises that provide a stable income. They especially want to avoid periods of low income. Much the early risk management theory focused on symmetric distributions of income for which minimizing variability was identical with minimizing downside risk. Early attempt to optimize risk management with mathematical programming also concentrated on symmetric distribution. For example, quadratic or semivariance programming models maximized the mean returns, while discounting those alternatives with high variance.

However, farm returns are often not symmetric. In many cases they are skewed negatively or positively. In addition, many farmers would like to be in a position to capture the higher returns when they occur. This led to the development of MOTAD and Target MOTAD (Hazell, 1971; Tauer, 1983). Target MOTAD has the advantage over MOTAD that it is possible to show that Target MOTAD solution are Second Degree Stochastic Dominant, while it is not possible to show that for MOTAD alone.

To convert a deterministic LP model to Target MOTAD, the following constraints must be added:

$$T = -\Sigma c_{rj} X_j - Yr \leq 0$$

$$\Sigma p_r Y_r = \lambda$$

X_j, $Y_r \geq 0$ for j=1….n and r=1……s

Where:
T = target level of return
P_r = probability of a state of nature
r = the state of nature
λ = parameter from 0 to M (where M is a large number)

These constraints force the algorithm to select only among those solutions which limit the downside risk quantified in the form of expected deviations from the target. In practice the target level of return might be the minimum level of income to provide family living and debt service, or in the case of a policy oriented analysis it might be the official poverty level or other measure of minimum income. The states of nature are often based on data for annual (or other periodic) returns. The lambda parameter is the allowable level of deviation. As lambda become larger the solutions are allowed a wider range of alternatives.

Appendix D has the Thai Rubber Farm Model GAMS code modified for Target MOTAD. There are numerous code modifications and additions required to define new variables, but the key change to the code occurs on the last page of Appendix D:

```
targetreturn(y) ..

 Target - (sum(fnt,save(fnt))- sum(t,sum(c,sprc(c)*sell(c,t)))

 + sum(c,price(y,c)*sum(t,sell(c,t))))- dev(y) =l= 0;

maxrisk ..

 sum(y,dev(y))/N =e= Lambda ;
```

This change only reflects variability in output prices, not in input cost, yields, etc. The LP model stored the annual return in the matrix cell “save(fnt)”. The term in parenthesis in the “target return” equation calculates the return at annual prices. The gross value of sales at current prices “sum(t,sum(c,sprc(c)*sell(c,t)))” us subtracted from save(fnt) and the gross value at annual prices “sum(c,price(y,c)*sum(t,sell(c,t)))” is added back.

The parameter spreadsheet is modified to include a price history worksheet (see example in Appendix E). That price history is drawn from the Thai national statistics (Office of Agricultural Economics, 2017). It is used to create the “price(y,c)” matrix in GAMS and to calculate the targetreturn equation for each year of data.

6. MOTAD Example with the Target set at the poverty line

The most recent Thai national poverty line is 2667 THB per month per person (NESDB, 2018). For a family of four this would be an annual income of 128,016 THB. Even with a 2 hectare farm and 1 adult family worker achieving this target in the unconstrained scenario is easy. The Target MOTAD formulation has no effect on solutions because the target is achieved in all the years of data (2007-2016) used to define the states of nature, but if we start with the 1.9 ha of rubber scenario the solutions become more interesting (Table 4).

Table 4 - TARGET MOTAD Solutions assuming 1.9 ha rubber and T=128,016 THB

Lambda THB	Gross Margin, THB	Chickens ha	Durian ha	Rubber Sheet ha
1000	124039	0.085	0.015	1.9
5000	133159	0.03	0.07	1.9
10000	137396	0.005	0.095	1.9
20000	138172	0	0.1	1.9
30000	138172	0	0.1	1.9

If wide deviations are allowed (i.e. Lambda >20,000), the MOTAD constraints have no effect and the risk neutral solution of 1.9 ha rubber and 0.1 ha durian prevails. When the allowable deviation is tightened, free range chickens start to enter the solution to stabilize income, but that stabilization comes at a cost, the gross margin drops. When expected deviations (i.e. lambda) are limited to 1000, the expected gross margin with current prices does not even reach the 128,016 THB target, but it is very stable.

The calculated negative deviations from the target in the 10 states of nature are given in Table 5. As required by the arithmetic, the deviations sum to 100,000 and when divided by the number of states of nature (i.e. 10), gives a lambda=10,000. Because MOTAD only track negative deviations, the zeros in Table 5 indicate states of nature in which the deviation was positive. This still allows some relatively large deviations (29,125 THB below target in 2009 with the expected gross margin less than 100,000 THB/year), but if the lambda is raised to 20,000, all the negative deviations are over 20,000 THB and some much larger.

Table 5 – Calculated Deviations from the Target in States of Nature when Lambda = 10,000

	Deviation, THB/ha
2007	-20634
2008	-9082
2009	-29125
2010	0
2011	0
2012	0
2013	0
2014	-19747
2015	-21413
2016	0
Sum of Deviations	100000

7. Conclusions

The Thai Rubber Farm Model provides a tool that can be used by researchers, RAOT staff and farmers to identify economically efficient diversification strategies. The deterministic LP shows that because Thailand has rain year round and because of the crops produced there not much in the way of expected crop growth or labour synergies to be exploited, but the MOTAD model shows that there are enterprise combinations that reduce variability over time due to price changes. To be even more useful the MOTAD model should include input price, yield and other variability.

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Appendices: (Available on request by emailing ihuang@harper-adams.ac.uk or JLowenberg-DeBoer@harper-adams.ac.uk)

Appendix A – Deterministic GAMS code

Appendix B – Input Spreadsheet for LP example

Appendix C1-C11 – LP parameter calculation spreadsheets

Appendix D – MOTAD GAMS Code

Appendix E – Input Spreadsheet for the MOTAD example