A REVIEW OF MATHEMATICAL PROGRAMMING APPROACHES TO FARM PLANNING UNDER RISK CONDITIONS

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ABSTRACT

The paper reviewed some of the mathematical programming approaches to farm planning under risk and uncertainty conditions. Traditionally, agricultural enterprises are risk inherent at all levels. There is need for experts in the field of agricultural economics to develop proper farm plans guided by proper scientific planning tools for agriculture for the smallholder farmers who keep depending on trial and error method in making enterprise decisions. The review found in literature that quadratic risk programming, MOTAD and T-MOTAD techniques are the most common mathematical programming methods applied to farm planning under risk conditions by researchers. The T-MOTAD technique was concluded to be more appropriate and advantageous over other techniques and was therefore recommended to be adopted by researchers for future studies on farm planning under risk conditions.

Keywords: mathematical programming, farm planning, risk conditions, smallholder farmers

INTRODUCTION

Agricultural risks seem to be prevalent throughout the world and are particularly worrisome to smallholder farmers in developing countries such as Nigeria. Most smallholder farmers in Nigeria who are resource poor concentrates mainly on crop production which is subjected to a high degree of uncertainty in yield (income) and employment due to variability in weather and prices among others. Smallholder farmers' production decisions are generally made under the conditions of risks and uncertainties. Risks in agriculture according to Kobza *et al.* (2002) include production risk, price and market risks, institutional risk, human or personal risk, business risk and financial risk. Product prices, yield and to a more limited extent, input prices and quantities are usually not known with certainty when investment decisions are being made. Adubi (1992) had also defined risk as a pervasive phenomenon in any economic activity which is particularly important in traditional agriculture where it affects production decisions and adoption of technology among others. Under risk conditions, more secure plans may involve producing less of risky enterprises, diversifying into a greater number of enterprises to spread risks, using established technologies rather than venturing into new technologies and, in the case of small scale farmers, growing larger of family food requirement.

Farm planning has become an important and special area of interest for specialization in agricultural economics review. According to Sarker and Quaddus (2002), it the most important factor of agricultural planning. Foster and Rauser (1991) opined that smallholder farmers have two alternative decision criteria in farm planning. The first one is to allocate resources in a way to maximize farm profit, while the second one is to allocate resources in such a way that utility will be maximized by striking a balance between increasing expected income and minimizing variability to reflect risk behaviour. Udo *et al.* (2015a) also argued that agriculture has recently experienced successive and concurring severe shocks often as a direct consequence of extreme weather events, raising concerns about greater uncertainties in agricultural production to a higher profile in the international community. Agricultural enterprises including crops, livestock and fisheries among others are indeed risk inherent at all levels due to variability in yields and prices. Smallholder farmers suffer from a dearth of valuable optimum farm enterprise guide and are struggling to optimize their production objective(s) subject to their resource constraints and risk conditions.

Mathematical programming as an optimization tool for studying the economic aspects of farm management has contributed immensely to agricultural development as its techniques such as the deterministic linear programming model has been used to study the problems of resource allocation among farmers. It provides prudent solutions to whole farm planning problems (Reddy *et al.*, 2004). There is a relatively abundant body of literature on how the deterministic linear programming model has been applied to analyse the potentialities of improving agricultural productivity and income among farmers through efficient utilisation of limited resources only under conditions of certainty. In fact, the works of Tanko (2004), Hassan *et al.* (2005), Igwe *et al.* (2011), Bamiro *et al.* (2015), Adewumi *et al.* (2018) and Jirgi *et al.* (2018) among others have shown that the mathematical programming approach have been successfully used for studies in optimum combination of farm enterprises and resource requirements in Nigeria. These researchers have all attempted to derive optimum farm plans for the smallholder farmers under the embodied assumption that all coefficients are determined with perfect knowledge.

Nonetheless, there is still a knowledge gap in literature to be filled as only a little evidence is available of research efforts aimed to inquire into the possibilities of maximising farm production and income under the conditions of risk and uncertainty in Nigeria. As it were, not many studies have adequately addressed the problem of what the optimum farm plan is under risk conditions using risk programming models. Udo *et al.* (2015a) argued that formulating farm plans in a risky environment with condition of certainty is inappropriate. Again, most of the research efforts to determine optimum farm plans for farmers under the conditions of risk and uncertainty in Nigeria such as those of Umoh and Adeyeye (2000), Olarinde (2004), Umoh (2008), Salimonu *et al.* (2008), Udo *et al.* (2015a) and Udo *et al.* (2015b) has focused only on the cropping enterprises. No effort has been made to consider other farm enterprises such as the livestock and fisheries in the risk programming models.

Some mathematical programming tools such as the quadratic programming (QP) along with linear programming/minimization of total absolute deviation (LP/MOTAD) models as seen in the works of Umoh (2008), Salimonu *et al.* (2008), Udo *et al.* (2015a) and Udo *et al.* (2015b) are the most recent and popular methods in the agricultural economics literature on risk – return analysis particularly in Nigeria. In the present stage of development, the focus is on incorporating risk into farm planning model to derive

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integrated optimum farm enterprise combinations that will offer more realistic solutions and increase farm income for the smallholder crop, livestock and fishery farmers in Nigeria. It is hoped that this review will help to fill the knowledge gap in literature and extend the frontiers of knowledge particularly in the area of incorporating risk into farm planning models. Agricultural researchers and students will therefore greatly benefit from this review as its will provide basis for further research on the subject matter.

Some Approaches to Incorporating Risk into Farm Planning Models

Mathematical programming (MP) methods are very well adapted for farm optimisation models. Linear risk programming (LP) is a widely applied MP method used for farm planning. It may be used to maximise expected profit subject to the farm resource constraints and other restrictions without taking into account risk factors. Ignoring risk-averse behaviour in farm planning models often leads to results that are unacceptable to the farmer, or that bear little relation to the decisions he actually makes. To resolve this problem, several techniques for incorporating risk-averse behaviour in mathematical programming models have been developed in recent years. Some of the risk–return analysis in agriculture has been conducted using Mean – variance (EV) analysis based on Markowitz portfolio decision theory which is the traditional framework for most risk – return analysis in agriculture (Udo *et al.*, 2015b). Risk programming models, such as Quadratic programming (QP) along with Linear Programming/Minimization of Total Absolute Deviation (LP/MOTAD) are the most popular mathematical programming methods in the agricultural economics literature on risk – return analysis. The advantages of linear risk programming models over non-linear ones were important in the past when reliable non-linear computer codes were less widely available (Kobza *et al.*, 2002). Here reviewed are three common risk programming approaches in agriculture.

1. Quadratic risk programming (QRP)

Stovall (1968) used variance-covariance quadratic equation of enterprises for explaining the total variance of income to determine the product mix. The choice of particular enterprise that according to the author will supplement or reduce the variation of net income depends on the sign of covariance of that enterprise. Thus, addition of seemingly risky enterprise would actually reduce the total variation of income if its covariance was negative and large. The author further concluded that income variance was an important variable in choosing the farm enterprise-mix by the farmers. The efficiency frontier set of expected value and the variance of outcomes of farm can be derived by means of quadratic programming developed by Hazell and Norton (1986). In this case the coefficients used in the model could be non-stochastic, the costs are constant and income distribution of farm plan is totally specified be the total gross margin distribution. Based on the farm activities the variance - covariance matrix has to be denoted in equation (1) as: (1)

$$V = \sum_j \sum_k X_j X_k \sigma_{jk}$$

Where:

V = income variance,

X_j and X_k = level of j or k activity, and

σ_{jk} = covariance of these activities.

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Equation (1) shows that the variance of total gross margin is an aggregate of the variability of individual enterprise returns, and of the covariance relationship between them. Covariances are fundamental for efficient diversification among farm enterprises as a means of hedging against risk (Markowitz, 1959). Combinations of activities that have negatively covariate gross margins will usually have a more stable aggregate return than the return from more specialised strategies. Also, a crop that is risky in terms of its own variance of returns may still prove attractive if its returns are negatively covariated with other enterprises in the farm plan. To obtain the efficient set of expected value and the variance of outcomes it is required to minimise variance - covariance set for each possible level of expected income, while retaining feasibility with respect to the available resource constraints.

2. Minimization of total absolute deviation (MOTAD) programming

Kobzar *et al.* (2002) stated that minimisation of total absolute deviations (MOTAD) model was developed when quadratic programming (QP) failed to generate desired results on computational facilities. The crucial merit of the model over quadratic programming was that functions could be changed to linearity and solved on conventional linear programming computed codes. The results obtained from the model were having intended statistical properties and found at par with the recognised model of farm planning under risk and uncertainty compared to the quadratic programming. Hazell (1971) developed the MOTAD model which could be solved on conventional linear programming codes with parameteric options while retaining most of the desired properties of the quadratic programming. The application of the MOTAD approach entails use of the same technical input-output tableau as for the LP and QRP models, but augmented with additional constraints (like absolute deviation of revenue, income deviation or probabilities) for the calculation of deviations for each state together with an additional constraint to calculate the mean absolute deviation. The deviations of the activity net revenues by state are calculated from the adjusted gross margins by deducting the corresponding expected gross margin from each. Also added to the tableau are further activities to calculate the negative deviations for each state. The model is then solved with mean absolute deviation set to an arbitrarily high value which is then progressively reduced until no further solutions of interest are found. In matrix notation, the MAD model is specified in equation (2).

$$M = \frac{1}{N}(/\sum_{j=1}^{n}(C_{tj} - \bar{C}_j)/) \qquad (2)$$

Where:

M = Mean Absolute Deviation that can be minimized for a level of expected profit

N = Number of years

C_{tj} = Gross margin per unit of j^{th} crop or livestock activity in the t^{th} year.

$\bar{C}_j$ = Sample mean gross margin per unit of j^{th}crop or livestock activity.

j = Refers to j^{th} activity (j=1 to n activities)

t = Refers to t^{th} year (t=1 to s years)

// = Modulus denotes absolute value of the figures, that is, ignoring the signs within the two vertical bars.

3. Target minimization of total absolute deviation (T-MOTAD)

The Target MOTAD is a modification of MOTAD in that it entails a constraint on

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income deviations, this time from a target level of income. Target MOTAD involves three parameters: expected profit, deviation from the target and target income. Efficient set of solutions is obtained for a given value of the target income. The main advantage is that the solutions are second-degree stochastically dominant (regardless of the distribution of income), and so are efficient for risk-averse decision makers. The model usually is solved maximising profit for a relatively large number of combinations of target income and deviation from the target (Kobzar *et al.*, 2002).

In using the target MOTAD model, Udo *et al.* (2015b) stated that a measure of risk of gross margin or profit which is given in the modulus is incorporated into LP model of a whole farm-planning problem. The Mean Absolute Deviation (M) is minimized for a given level of expected gross margin or profit E(Z) which varies parametrically over zero to some desired range (M). The computational procedure of the model involves two steps-first a conventional linear programming maximization problem is formulated and solved to determine the maximum return without risk constraints. This gives the highest point on the efficiency frontier. Second, the element of risk is formulated as a matrix of gross margin or net returns deviations from expected returns. Points on the risk efficiency frontier are obtained by decreasing the value of (M) parametrically in arbitrary decrement along the efficiency frontier. The Target-MOTAD model minimizes the Mean Absolute Deviation for any given expected return (Ochai, 1996). The formulation of T-MOTAD model is as follows in equation (3).

$$\text{Max } E(Z) = \sum C_j X_j \quad (3)$$

Subject to: (4)

$$\sum C_{ij} X_j \leq \beta_i \quad (5)$$

$$\sum C_{rj} X_j + y_r \geq T_r \quad (6)$$

$$\sum P_r Y_r = \lambda \quad (7)$$

Where:

$E(Z), x, y > 0$

$E(Z)$ = Expected return of the plan (₦)

C_j = Expected return per unit enterprise (₦)

X_j = level of enterprise j

C_{ij} = Technical resource i requirement of enterprise j

β_i = Level of resource i

C_{rj} = Return of enterprise j for state of nature r

Y_r = Negative deviation below T_r for state of nature r

T_r = Target level of return (₦) derived from the mean absolute deviation

P_r = Probability that state of nature r will occur

λ = A constant parameterised from M to 0

Although, risk programming models depends heavily on the availability of historical data of enterprise output, the application of these models in agriculture to develop risk efficient farm plans and other similar research studies have increased continuously.

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Synopsis to the Reviewed Risk Programming Approaches in Farm Planning

In investigating the substitution capabilities of oilseeds in cropping patterns under risk conditions in Iran, Kakhki *et al.* (2009) compared the quadratic programming and MOTAD models. Although the authors reported that the result of both approaches suggested that the farmers should increase the cultivated area of oilseed crops, the result of the MOTAD model however prescribed more feasible optimal solutions than the quadratic programming model. Kobzar *et al.* (2002) had stated that quadratic programming failed to generate desired results on computational facilities which led to the development of the MOTAD model which allows for functions to be changed to linearity and solved on conventional linear programming computed codes. The MOTAD model as introduced by Hazell (1971) involves the dual criteria of maximizing net return and minimizing the variance of net return. In spite of this advantage of the MOTAD model over the quadratic programming model, Tauer (1983) argued that MOTAD solutions are not necessarily second degree stochastic dominance efficient. Stochastic dominance techniques are appealing, as their application requires very few restrictive assumptions about the decision maker's utility function.

The MOTAD model was modified by Tauer (1983) through his target – MOTAD (also called T-MOTAD) model approach. The author asserted that all solutions generated with a target MOTAD model (with the exception of the very rare case of plans with equal means and deviations) belong to the second degree stochastic dominance efficient set, thus implying that target MOTAD techniques are better than MOTAD. Watts *et al.* (1984) also compared MOTAD and target MOTAD models and concluded that the target MOTAD is better than MOTAD for risk analysis in farm planning models. The target MOTAD model has been successfully used in a number of studies and its use in the study of the Nigerian agricultural system is the most recent.

Empirical Studies on Application of Risk Programming Models to Farm Planning

In the Gwembe Valley of Zambia, Maleka (1993) used the T-MOTAD model to identify optimal cropping patterns. The researcher reported that the results of the T- MOTAD model prescribed an optimal cropping pattern of growing sorghum, rice and soybeans which is different from the existing cropping pattern of sorghum, sunflower, cotton and maize.

Gajanana and Sharma (1994) in Tumkur district of Karnataka formulated risk efficient farm plans through MOTAD approach for enhancing the development prospects of drought prone farmers being faced with weather-induced risk.. Input-output data from 130 farmers for the year 1987-88 and time series data for 18 years (1969-86) were used for the study. The results indicated relatively high risk attached with low returns in the existing plans. Among the risk efficient plans, crops, sericulture and dairy enterprise system was found more appropriate in adding stability to farm returns besides providing higher employment opportunities.

In a study by Alam *et al.* (1997), the parametric linear programming model which is a modified form of the MOTAD model was applied to small farm planning under risk in Jessore District of Bangladesh. The authors reported that the risk programming result revealed that higher gross margin, labour employment and tractor/power tiller utilization were associated with higher risk, while land utilization and capital investment increased

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along with the gross margin-risk frontier. The result also showed direction of efficient resource use for risk minimization at various levels of gross margins for the small farms. Similarly, Kehkha *et al.* (2005) applied a MOTAD risk-programming model to study the effects of risk on cropping pattern and farmers' income in Ramjerd and Sarpaniran Districts in Fars Province of Iran. The researchers reported that variability of crops gross margins has a significant effect on the cropping pattern but varies over different farmers and regions with various conditions. It was also reported that farm plans with more number of crops have a lower return but high degree of certainty.

In a study on risk preferences and resource allocation differentials of food crop farmers in Osun State, Nigeria, Salimonu and Falusi (2007) employed the LP and T-MOTAD models for data analysis. The researchers reported that the level of return from 13 crop enterprises in the existing plan was ₦31,959.81/ha. Furthermore, the result of the normative optimum plan revealed a return of ₦36,776.05/ha from six prescribed crop enterprises while the risk efficient plan prescribe five crop enterprises and a return of has ₦35,812.14/ha for the farmers. Derakhshan *et al.* (2007) also applied the conventional linear programming and the MOTAD and T-MOTAD models in an effort to develop a risk-including optimal cropping pattern of agricultural and horticultural crops in Neyriz, Fars Province of Iran. The authors reported that in MOTAD model result, the minimized risk increased with rising expected income, leading to replacement of low income bearing crops with high ones. Orange and tangerine due to high income bearing condition were preferred to apple, cotton and watermelon in higher levels of expected income. The results of T-MOTAD model revealed a reduced cropping area for cotton and watermelon indicating the effect of risky condition on mentioned crops. The cropping area of orange and tangerine were increased given that they were high income bearing crops.

In a study carried out in Akwa Ibom State, Nigeria by Umoh (2008), the T-MOTAD model was applied to determine the optimum farm plans under risk conditions in floodplains farming. The author reported that the most important risk factors in floodplains farming are flood and drought and that these risks were managed by the farmers through relay/sequential cropping, planting short gestation and flood tolerant crops. The result of the Target-MOTAD model shows that farmers were not operating at optimal level of production and a crop combination consisting of cassava, cocoyam, maize and fluted pumpkin was found to be the least risky and the most profitable while all vegetable crops combinations were the most risky. Similarly, Salimonu *et al.* (2008) applied T-MOTAD analysis on model efficient resource allocation patterns for food crop farmers in Nigeria. Their result revealed that the optimal value of profit maximization plan of ₦98,861.24/ha and the risk minimized plans of ₦54,919.73/ha and ₦36,776.05/ha respectively were higher than the net return value of the farmers' existing plan. The authors further argued that the alternative efficient allocation plans prescribed were of higher expected returns than the existing farmers' plan in the study area thus satisfying the increase income objective and that the profit maximization model was associated with higher risk than the suggested efficient plans.

In the recent past, Udo *et al.* (2015a) formulated optimum farm plans with child farm labour reduction in the face of risk and uncertainties for arable crop farmers in Akwa Ibom State using the LP and T-MOTAD models. Eleven cropping activities were identified in the existing plans in the study area with average net return of ₦275,247.03/ha for the State. The value of the normative optimum (single goal optimum net return) for an average farmer which prescribed the cultivation of four crop

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enterprises, that is, cassava/melon on 0.10ha, cassava/melon/cocoyam on 1.11 ha, yam/maize/pumpkin on 0.61ha and yam/maize/cocoyam on 0.34ha was ₦514,110.40/ha, indicating an increase of 86.78%, over the existing plans. The authors further reported that the net returns in the risk efficient plan was ₦467,506.20/ha which showed an increase of 69.84% above the existing plan and a decrease of 9.06% below the profit maximizing normative plan. The alternative risk efficient farm plan prescribed the cultivation of cassava/melon/cocoyam on 0.52ha, cassava/melon on 0.11 ha, cassava/maize/pumpkin on 0.83ha, yam/maize/pumpkin on 0.23ha, and yam/maize/cocoyam on 0.33ha. Similarly, Udo *et al.* (2015b) employed the LP and T-MOTAD models to develop an alternative farm plan involving risk constraint for arable crop farmers in Etinan, Abak and Eket agricultural zones of Akwa Ibom State using both primary and secondary data. The researchers reported an average annual net returns of ₦317,723.59/ha, ₦245,969.12/ha and ₦262,048.39/ha for Etinan Abak and Eket agricultural zones in the existing crop plans. The normative optimum net returns were ₦559,028.50/ha, ₦537,089.00/ha and ₦595,018.30/ha for Etinan, Abak and Eket zones respectively, indicating an increase of 75.94%, 118.35% and 127.06% respectively over the existing plan in each of the zones. The net returns of the risk efficient plan of ₦415,884.10/ha, ₦430,569.10/ha and ₦456,200.80/ha for Etinan, Abak and Eket zones respectively were higher than the farmer's existing plan but lower than the of normative optimum plan. The researchers argued that the profit maximizing model with very high returns was of higher variability of returns (risk) than the suggested efficient plan. The study concluded that capital was the only limiting resource in the study area and that farmers existing level of returns were not optimal.

Fathelrahman *et al.* (2017) applied the target MOTAD model to determine the optimum returns from greenhouse vegetables under water quality and risk constraints in the United Arab Emirates. The authors explored the tradeoffs between returns (gross margin) of selected vegetables (tomato, pepper, and cucumber), risk (deviation from gross margin means), and an environmental constraint (water salinity) using a unique target MOTAD approach to support the farmers' decision-making processes. The results confirmed that product diversification reduces overall risk. The optimal vegetable production mix revealed that reduction in tomato production should be offset by an increase in cucumber production while maintaining a constant level of pepper production. The authors implied that risk is reduced as cucumber production increases due to the high level of tomato and lettuce price volatility as the alternative to cucumber. The reported optimal solution was highly sensitive to changes in the crop water salinity constraint. The study concluded from results that the target MOTAD approach is a suitable optimization methodology.

CONCLUSION

The review revealed that some appreciable efforts have been made by researchers to incorporate risk into farm planning using various mathematical programming models. Critically looking at all the risk programming approaches reviewed and based on evidence from empirical studies, the T-MOTAD technique was concluded to be more appropriate and advantageous over other approaches in incorporating risk into farm planning models. Hence, it is recommended that the T-MOTAD technique be adopted by researchers for studies on farm planning under risk conditions. Also, it was found that most of the reviewed studies focused only on cropping enterprises, especially in Nigeria, researchers should therefore consider other farm enterprises such as the livestock and fisheries in the risk programming models in future farm planning studies.

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