ASSESSING OPTIONS FOR ENHANCING FOOD SECURITY BY PRINCIPAL COMPONENT ANALYSIS

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Abstract

This paper illustrates a possible statistical approach to policy option analysis. By using the principal component methodology for assessing options, the data of the farmers in terms of the number of family, distance to passable road and other natural food resources from Sikasso Region, Mali, West Africa were collected. This paper suggests that the farm size-family size, distance to passable road-choice of agricultural crop, distance to passable road-goat raising vis-a̓ -vis other ruminants and distance-family size-goat raising vis-a̓-vis other ruminants should be considered in assessing options for food security. Therefore, the principal components analysis of the characteristics of small-scale farmers yields insights that can be utilized for assessing options for enhancing food security. In underdeveloped or developing nations where agriculture forms the base of the economy, the provision of road infrastructure is a crucial element in the schema for ensuring sustainable development and food security.

Keywords: *food security, principal components analysis, eigenvectors, correlation Matrix, eigenanalysis*

1.0 Introduction

A 2020 vision was developed by the International Food Policy Research Institute (2012) that every individual has an economic and physical contact to sufficient nutrition. This is to endure a productive and healthy life, where undernourishment is absent, and where food commences from effective, efficient, and affordable food and farming systems that are suitable and with sustainable practice and supervision of natural resources. In assuring sustainable use of natural resources and food security, there are several challenges to consider: (i) prevalent poverty and insufficient human resource growth, which constrain people's ability to grow and/or acquire the required food; (ii) the number of populations in developing-country increases, particularly in urban regions, which will significantly expand food requirements; (iii) low investment in the entire agricultural research in developing nations, insufficiencies in accessibility of natural resources and admission to agricultural inputs– like water, fertilizer, pesticides, energy, research, and technology, which prevails slow increase of produce in most favorable areas and poor variable harvests in less-favored areas; (iv) deterioration of natural resources—such as soils, forests, marine fisheries, and water—which unstrengthen production capacity; and (vi) deficient national resource mobilization—savings and investment—and weakening worldwide support, which prevent economic progress and development. Assessing options for food security is a fundamental skill that must be elevated to the level of science if the 2020 vision is to be efficiently achieved. This paper illustrates a possible statistical approach to policy option analysis.

Philippine agricultural productivity is primarily estimated by sustenance or small-scale farmers (75%)

(Philippine Statistical Authority, 2016). For this reason, involvements designed to boost national agricultural productivity need to aim the subsistence of farmers if these interventions are to generate significant depressions in the agricultural area (Balicasan et. al., PIDS, 2006). The Agriculture and Fisheries Modernization Act (AFMA, 1998) specifically addresses this concern by authorizing the steps and procedures to modernize this segment in the Philippine economy. However, structural, systemic and other obstructions are, nonetheless, current in the Philippines that curtail the achievement of the objectives set along under this pioneering legislation. In contrast, most agriculturally progressive nations rely on individual farmers in terms of agricultural productivity. Bourguignon & Morrisson (2002), in a comparative study about the typical conditions of individual farmers in Europe and Asia, found the following significant differential characteristics obtaining in these two geographic situations: (a.) farm ownership, (b.) farm sizes, (c.) farm mechanization, (d.) state support, and (e.) knowledge in modern agriculture. In many Asian countries, most of the farmers possess their farms as tenants to absentee farm owners whereas in more progressive nations, the farmers own their farmlands and have complete control over their decisions in farming activities. Typical farm sizes in Asia range from 1 to 5 hectares while the farm sizes in Europe are almost quadruple these sizes. Typical European farmers make use of full farm mechanization while Asian farmers make use of the traditional "beasts of burden" e.g. water buffalos and cows for tilling their lands. European States support their farmers mainly opening credit lines for agricultural investments to these agricultural investors whereas Asian economies provide a host of support to farmers ranging from a provision of agricultural inputs to credit lines whose impact to the agricultural productivity of the farmers diminishes with time. Agriculture is considered a major science and field of study by itself in most developed nations but this field is largely ignored by local Asian farmers who rely mainly on traditions and age-old practices in agriculture for survival.

By carefully studying the status of subsistence or small-scale farmers, one may be able to deduce optimal options that can be undertaken to ensure food security. We illustrate this methodology in this paper.

2.0 The Principal Components Methodology for Assessing Options

Let X be a p – variate random vector of characteristics of farmers with mean μ and covariance matrix Σ. Principal Components Analysis (PCA) seeks to find linear combinations $Y=a^TX$ with maximum variance. More specifically,

$$\underset{a\neq\theta}{Max}\ var(Y)=var\,(a^T X)=a^T \Sigma a \qquad (1)$$
$$\text{Subject To: } a^T a\leq 1.$$

It is known that the solution a corresponds to the eigenvectors e of Σ. Since Σ is positive – definite, there exists an orthogonal matrix P such that:

$$\Sigma=p^T DP \qquad (2)$$

Where D = diag (λ_i) is a diagonal matrix of the eigenvalues of Σ and $P=[e_1 \vdots e_2 \vdots \ldots \vdots e_p]$ is the matrix whose columns are the corresponding eigenvectors. The eigenvectors $\{e_j\}$ are orthogonal:

$$\langle e_i / e_j \rangle = 0 \qquad (3)$$

Since $P^TP = PP^T = 1$. The i^{th} principal component is given by:

$$Y_i = e_i^T X \quad (4)$$

and:

$$var(Y_i) = e_i^T \Sigma e_i = e_i^T e_i \lambda_i = \lambda_i \quad (5)$$

The proportion of the total variance explained by the i^{th} principal component is provided by:

$$Proportion\ of\ Variance\ Explained\ by\ Y_i = \frac{\lambda_i}{\lambda_1+\lambda_2+\cdots+\lambda_p} \quad (6)$$

In the event that only subsets of the p characteristics are related, then the first m – principal component, $m<p$, will be needed:

$$\begin{matrix} Cumulative\ Proportion\ of\ the\ total \\ variance\ explained\ by\ the\ first\ m \\ principal\ components \end{matrix} = \frac{\sum_{j=1}^{m}\lambda_j}{\sum_{i=1}^{p}\lambda_i} > 90\% \quad (7)$$

Each of the m principal component represents a dimension that need to be assessed because each component can be an avenue where interventions may be required to enhance agricultural productivity.

3.0 Illustration Using a Survey from Farmers in Mali, West Africa

Survey data were collected as part of a study to assess options for enhancing food security through the sustainable use of natural resources in the Sikasso region, Mali , West Africa (Data collected by J. Angerer and can be downloaded from www.prenhall.com/statistics). The subset of the data used for this illustration is reproduced in Table 1:

Table 1: Survey Data from Sikasso Region, Mali, West Africa

Family	DistRD	Cotton	Maize	Sorg	Millet	Bull	Cattle	Goats
12	80	1.5	1	3	0.25	2	0	1
54	8	6	4	0	1	6	32	5
11	13	0.5	1	0	0	0	0	0
21	13	2	2.5	1	0	1	0	5
61	30	3	5	0	0	4	21	0
20	70	0	2	3	0	2	0	3
29	35	1.5	2	0	0	0	0	0
29	35	2	3	2	0	0	0	0
57	9	5	5	0	0	4	5	2
23	33	2	2	1	0	2	1	7
20	0	1.5	1	3	0	1	6	0
27	41	1.1	0.25	1.5	1.5	0	3	1
18	500	2	1	1.5	0.5	1	0	0
30	19	2	2	4	1	2	0	5
77	18	8	4	6	4	6	8	6
21	500	5	1	3	4	1	0	5
13	100	0.5	0.5	0	1	0	0	4
24	100	2	3	0	0.5	3	14	10
29	90	2	1.5	1.5	1.5	2	0	2
57	90	10	7	0	1.5	7	8	7

A principal component analysis was performed on the data set to see if certain dimensions can be extracted from them. Figure 1 shows the Scree Plot to determine the number of components to be extracted:

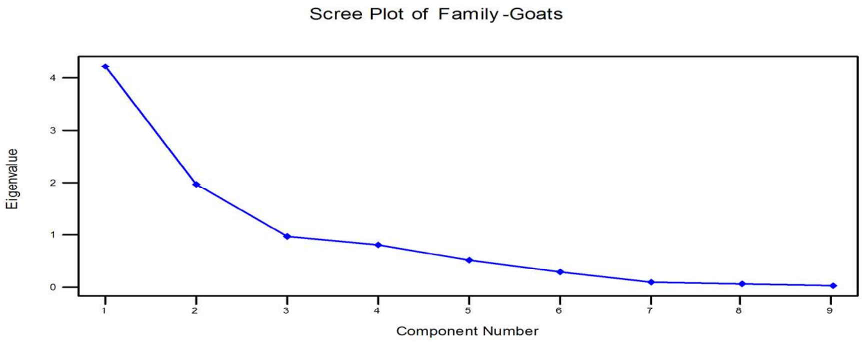

Figure 1. Scree Plot for the Mali, West Africa Data

The Scree Plot suggests taking the first four principal components. Table 2 shows the summary of the eigen-analysis performed:

Table 2: Eigenanalysis of the Correlation Matrix

Eigenvalue	4.2461	1.9802	0.9681	0.7951
Proportion	0.472	0.220	0.108	0.088
Cumulative	0.472	0.692	0.799	0.888

Variable	PC1	PC2	PC3	PC4
Family	0.440	-0.030	-0.267	0.243
DistRD	-0.092	0.447	0.603	0.450
Cotton	0.438	0.184	0.068	0.161
Maize	0.426	-0.210	0.007	0.093
Sorg	0.000	0.511	-0.629	-0.116
Millet	0.189	0.601	0.012	0.044
Bull	0.465	-0.015	-0.012	-0.033
Cattle	0.334	-0.259	0.155	0.101
Goats	0.245	0.176	0.374	-0.823

The first four principal components accounted for close to 90% of the total variance (or 88.8%). High positive loadings of the variables family size, number of hectares planted to cotton, number of hectares planted to maize, number of heads of bullocks and cattle, are noted on the first principal component. This component may represent the dimension of "family size-farm size" among small scale farmers. Moreover, the negative loading of the variable "distance from the nearest passable road" on the first principal component appears to contrast the dimension with distance i.e. family sizes determine the farm sizes and the agricultural production of these farm and they are mainly located close to a passable road.

The variables "distance from the nearest passable road", "number of hectares planted to sorghum", "number of hectares planted to millet" load high on the second principal component. The concordant signs indicate a "distance-agricultural crop" dimension i.e. farms located farther away from passable roads tend to cultivate larger farms with sorghum and millet.

The third principal component seems to indicate a "distance to nearest passable road – goat raising" dimension where farmers located farther away from the nearest possible road are more likely to raise goats.

The fourth principal component, on the other hand, demonstrates the contrast "family size-distance to passable road" on the "agricultural production of the farmers. In particular, farmers with larger family sizes and leaving farther away from the nearest passable road are more likely not to raise goats.

In summary, we conjecture that the following dimensions are important considerations in assessing options for food security among the farmers:

Dimension 1: Farm Size-Family Size
Dimension 2: Distance to Passable Road – Choice of Agricultural Crop
Dimension 3: Distance to Passable Road – Goat Raising vis-á-vis other ruminants
Dimension 4: Distance-Family Size-Goad Raising vis-á-vis other ruminants

In the Philippine setting, state support for small-scale farmers can be better targeted if these considerations are utilize in policies. A general framework of providing support for agricultural inputs without considering these dimensions are likely to fail. In the past, for instance, state support to farmers in the form of providing free fertilizers, giving of free seedlings, piglets, goats and others, have not significantly improved the agricultural productivity of these farmers. A more rationale policy framework which considers these four dimensions may, in the long run, succeed in improving the plight of the small-scale farmers in the Philippines.

Subsidiary Eigen-analysis of the Covariance Matrix.

A principal components analysis based on the covariance matrix can give a different picture of the dimensions already identified since such an analysis will tend to favor variables that have larger variances and where possible interventions can be effectively made. Figure 2 shows the Scree Plot for the Eigen-Analysis done on the covariance matrix of the survey data.

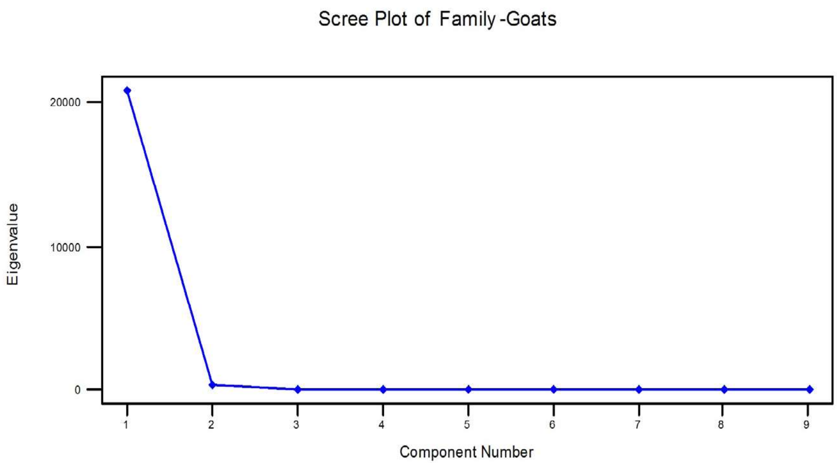

Figure 2: Scree Plot of the Principal Components from the Covariance Matrix

The Scree Plot suggests taking only one or two principal components. The summary of the eigen-analysis done is shown in Table 3:

Table 3: Eigenanalysis of the Covariance Matrix

Eigenvalue	20856	364
Proportion	0.980	0.017
Cumulative	0.980	0.997

Variable	PC1	PC2
Family	0.036	0.942
DistRD	-0.999	0.038
Cotton	-0.001	0.116
Maize	0.004	0.073
Sorg	-0.001	0.006
Millet	-0.003	0.030
Bull	0.003	0.095
Cattle	0.014	0.284
Goats	0.000	0.038

Tabular values show that the first principal component already accounted for 98% while the first two principal components account for almost 100% of the total variance (99.7%). The first principal component, which accounts for the greater bulk of the total variance, has something to do with the distance to the nearest passable road. This dimension may be aptly called "distance to nearest passable road – farm size" dimension. About the only crops that are cultivated far from nearest passable roads are sorghum and millet. The second principal component is the 'family size" dimension. Farmers with larger family sizes tend to cultivate any crops and raise all kinds of animals with specific leaning to cotton and maize for the crops and cattle for the animals.

Eigen-analysis of the covariance matrix appeared to have summarized the four dimensions obtained using the correlation matrix into two dimensions only. They essentially contain the same amount of policy information. In particular, the dimensions obtained from the covariance matrix are:

Dimension 1: Distance to Nearest Passable Road Determines Farm Sizes
Dimension 2: Family Size Contribution to Agricultural Production

Figure 4 clearly illustrates these dimensions:

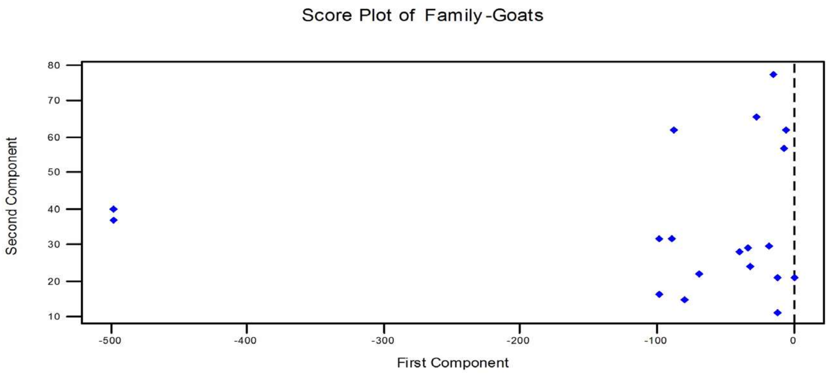

Figure 4: Score Plot for the Two Principal Components

The principal components analysis of the covariance matrix revealed some important considerations for assessing options for food security. First, the state needs to ensure that "farm to market roads" are made part of the annual infrastructure program of the government. Such roads are critical to the enhancement of agricultural productivity of farmers, particularly, the small-scale or subsistence farmers. Second, arable lands in the more remote areas can be made more productive with improved access to "farm to market roads" since farmers with larger family sizes tend to settle in areas where passable roads are in place.

A policy schema is shown in Figure 5 to guide in the assessment of options for enhanced food security based on the principal components analysis performed:

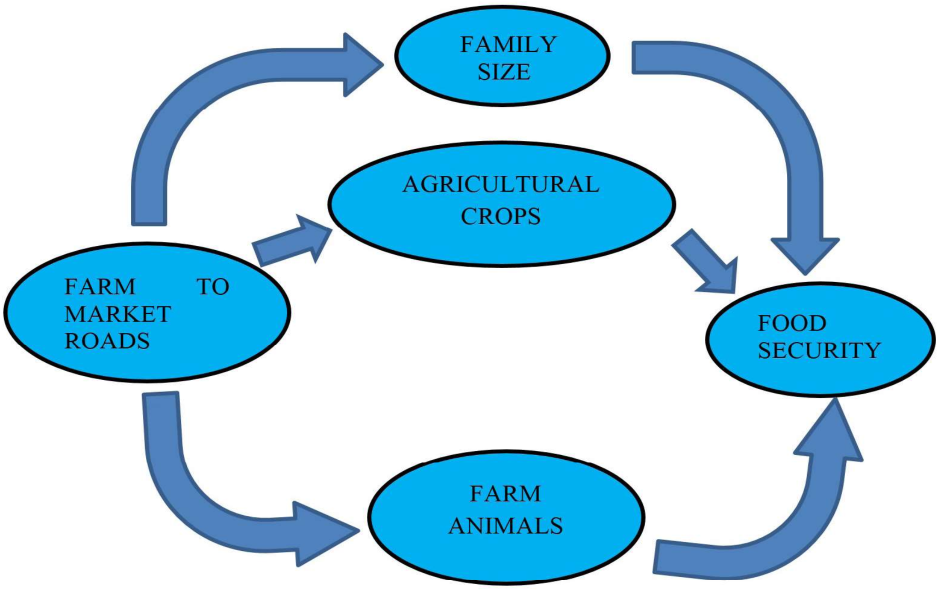

Figure 5. Policy Framework for Food Security

4.0 Conclusion

Principal components analysis of the characteristics of small-scale farmers yields insights that can be utilized for assessing options for enhancing food security. In underdeveloped or developing nations where agriculture forms the base of the economy, the provision of road infrastructure is a crucial element in the schema for ensuring sustainable development and food security.

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