Single versus Multiple Objective(s) Decision Making: An Application to Subsistence Farms in Northern Ethiopia

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Abstract

Single objective approach is most widely used whereas consideration of multiple objectives is the rule rather than an exception in many real life decision-making circumstances. This paper, therefore, investigates whether or not single and multiple criteria/objective approaches necessarily lead to differing conclusions. The central questions are could the single objective approach be a reasonable approximation for subsistence farm settings or does the multiple objectives approach has anything to add? Does the pattern of resource allocation change when priorities attached to the different objectives/ goals change? The study employs linear and goal programming techniques on a dataset from a stratified sample of 200 farm households drawn from Tigrai regional state, Northern Ethiopia, for 2001 and 2002 production years. Findings reveal that the two approaches might not necessarily lead to differing conclusions.

Keywords: Single versus Multiple Criteria/Objectives; Linear Programming, Goal Programming; Subsistence Farms; Northern Ethiopia.

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1. Introduction

It appears that, in reality, decision makers purse several objectives and therefore, the traditional paradigm of choice involving single-criterion might be inadequate for dealing with such situations or decision environments (Romero and Rehman, 2003). In fact, multiple objectives tend to be the rule rather than exception in many real life decision-making circumstances. For example, subsistence farmers might be interested in achieving security of family food supplies, maximizing cash income, increasing leisure, avoiding risk, etc. Moreover, most decisions might not only involve multiple-objectives (goals), but also hierarchy of objectives (goals) which might be potentially conflicting with each other and need to be reconciled (Harper and Eastman, 1980).

In the traditional 'single' objective approach, such as in the classic linear programming framework, one must assume that there is exactly one objective that is to be optimized subject to the absolute satisfaction of a number of 'constraints' (Ignizio, 1976). Often one of the objectives is optimized while the others are specified as constraints. For example, maximization of profit (or gross margin) or minimization of costs is considered the single most objective to be optimized. Proponents of multiple objective approaches argue that although logically sound, the single objective approach fails to faithfully reflect the real life decision situation for two reasons. Firstly, it assumes that the constraints that define the feasible set are so rigid that they cannot be violated. Secondly, decision-makers are usually not interested in ordering the feasible set according to just a single criterion but would rather find an optimal compromise involving several objectives. Moreover, a decision maker or a farmer, for instance, might be involved in diversity of occupations or activities such as farm and non-farm activities. Therefore, does the maximization of profit for the decision maker or a farmer refer to the farm, the non-farm or the two in conjunction also poses another dilemma. Particularly in the case of subsistence or family farms, the fact that the farm is a complete economic unit which exhibits interdependence between income and consumption casts some doubts upon the assumption of profit maximization as the only ultimate goal, which family farms strive to achieve. Indeed some of the motives might not be purely economic, although some are relevant than others for economic behaviour (Gasson, 1973). So, it would be of interest investigating the issue. Regardless of all these divergence of opinions, studies that applied multiple objective/criteria decision analysis to subsistence farm settings especially in the African context are very scanty. Barnett *et al.*, (1982) applied goal programming with multidimensional scaling to Senegalese subsistence farms. Bazaraa and Bouzaher (1981) applied linear goal programming model to Egypt's agricultural sector particularly at the regional level. Moreover, whereas subsistence farm settings tend to be well suited for multiple objective/criteria analysis, previous studies in Ethiopia and elsewhere in Africa have employed linear programming, implying addressing single objective only. For example, Belete *et al.* (1993) tried to explore the possibilities for improving production and income of small farmers through better allocation of resources under alternative cultivation (work oxen acquisition) practices using linear programming model. Heyer (1971) applied linear programming to maximize market value of output as the single objective given constraints on peasant farms in the case of Kenya. She found out that cotton and drought resistant maize alone might not necessarily provide substantial increase in income. Kassie *et al.* (1999) also used linear programming to analyze the benefits of integration of cereals and forage legumes with and without crossbred cows in mixed farms for highland Ethiopia. They found out that introduction of cereal-forage legume intercropping significantly increases gross margin and cash income. They also found that the introduction of crossbred cows further enhances these returns.

Studies that used multiple objectives approach include Barnett *et al.*, (1982), Bazaraa and Bouzaher (1981), Lee *et al.* (1995), Okoruwa *et al.* (1996), Hayashi (2000), Romero (2004), Manos *et al.* (2006), Krcmar and van Kooten (2008), Latinopaulos (2008), Sintori *et al.* (2009) and Rozakis *et al*. (2012). Barnett *et al.*, (1982) applied goal programming with multidimensional scaling to Senegalese subsistence farms. They found out that the multi-objective model did not exhibit superiority over a similarly structured profit maximizing model. Bazaraa and Bouzaher (1981) applied linear goal programming model to Egypt's agricultural sector particularly at the regional level, in relation to income distribution and regional employment goals. They concluded that a relatively higher degree of specialization and a relatively lower cotton production could be achieved through using improved farming techniques and labour-intensive means. Lee *et al.* (1995) applied multiple objectives programming to subsistence farming cropping decisions in Western Samoa. Their findings showed that the imputed non-market value of an important exportable crop is three to five times greater than the market price. Okoruwa *et al.* (1996) also used a multi-objective programming model to analyze crop-livestock competition in West African derived savannah. Their results indicated that farm and herd sizes will become smaller and the degree of crop-livestock integration will increase significantly, as population pressure and cropping intensity severely limit access to grazing land. Hayashi (2000) provides detailed review of multi-criteria analysis as applied to agricultural resource management. By way of assessing the criteria (i.e., attributes, objectives) used for modeling agricultural systems, it summarizes pros and cons involved applying the methodology. Manos *et al.* (2006) and Latinopaulos (2008) assess the impact of irrigation water pricing in Greece using multi-criteria decision analysis. Romero (2004) also provides a general structure, i.e., three alternative formulations of achievement function for a goal programming model, one of which is weighted goal programming. Krcmar and van Kooten examine whether the current policy of ensuring a stable timber supply is an effective rule-of-thumb for balancing environmental, employment and other objectives or is non-optimal, leading to unacceptable trade-offs? They develop multiple-objective programming that employs compromise and fuzzy programming for balancing conflicting objectives, and compares results from these approaches with those of the current policy of maintaining an even-flow of timber to mills. They find that outcomes obtained using multiple-objective programming greatly improve upon those associated with the rule-of-thumb policy of even-flow of timber.

The following outstanding issues turn out quite apparent from the review existing literature. Firstly, particularly in the case of subsistence or family farms, the fact that the farm is a complete economic unit which exhibits interdependence between income and consumption casts some doubts upon the assumption of profit maximization as the ultimate goal, which family farms strive to achieve. Indeed some of the motives might not be purely economic, although some are relevant than others for economic behaviour (Gasson, 1973; Lee *et al.*, 1995). Secondly, whereas subsistence farm settings might be viewed to be well suited for multiple objective/criteria analysis, previous studies particularly in the case of Ethiopia have employed linear programming, implying addressing single objective only. Therefore, it would be of interest understanding whether the multiple objectives approach has anything to add.

In this paper, we analyse single versus multiple criteria/objective approaches. Using linear and goal programming techniques, the paper tries to investigate whether the two approaches necessarily lead to differing conclusions. More specifically, the paper addresses such questions as: could the single objective approach be a reasonable approximation, particularly for subsistence farm settings or does the multiple objectives approach has anything to add? How does the pattern of resource allocation change when priorities attached to the different objectives/ goals change? If indeed the multiple objectives approach has something to add, then understanding the behaviour of economic agents in decision contexts involving multiple criteria would sharpen our prediction.

The remaining part of the paper is organized as follows. In section two provides definition of the subsistence farm household problem setting. Section three presents the model formulation and section four presents study area and data description. Section 5 deals with discussion of results, followed by concluding remarks in section 6.

2. Subsistence Farm Household: Definition of Problem Setting

The most defining feature of subsistence farmers is mainly the subsistence nature of their livelihoods. They are simultaneously engaged in both production and consumption and a larger proportion of the produce is directly consumed by the household (Ellis, 1993). They are distinguished from the landless laborers in that they have access to (own) certain amount of land, which by combining with other family resources such as labor and perhaps hiring in of land and/or labor produce farm output mainly for own (family) consumption.

We consider a representative farm household, which is assumed to have three objectives: attaining security of family food supplies, maximizing cash income and meeting fuel or energy needs of the household. This household faces a problem of making decisions on land and labor use by taking into account his/her objectives, available resources (constraints), institutional arrangements and access to markets/opportunities.

2.1 Activities

The typical subsistence farm household has on the one hand diversity of activities to which the scarce resources can be allocated and on the other hand available resource supplies or limits. These activities among others include production of various crop and livestock products. In this study we distinguish four broad categories of activities; crop or production activities, consumption activities, fuel gathering, and sales activities.

Crop or production activities: Crop choice or crop production can be subdivided into numerous activities. For simplicity we limit ourselves to four most important crops in order of their importance in production: barley, wheat, teff, and legumes. The decision problem facing the farm household is how much of land to allocate to the production of each of these crops given his objectives, resources and other constraints. Farmers in the area also maintain livestock for draft power and other purposes. The draft power aspect of livestock activities has been considered in this study. Looking after cattle is mainly the activity of children (Woldehanna, 2000). This implies that livestock doesn't compete for labor with other activities given that participation of children in other major activities is minimal.

Consumption activities: Subsistence farmers put emphasis on security of family subsistence or food supplies through own production. Consumption activities considered in this study include consumption of teff, wheat, barley and legumes. .

Fuel gathering: Fuel gathering essentially refers to the collection of fuelwood from the nearby sources for meeting fuel or energy needs of the representative household for baking, preparing meals and warming the house in cases of coldness.

Sales activities: When requirements for subsistence are met, subsistence farms often generate income by selling the available surplus output which, in turn, might be used to buy some items or products which they do not produce or cannot produce enough for subsistence. In the model, therefore, sales of teff, wheat, barley, and legumes were included as separate activities to balance production and utilization of these crops. Moreover, off-farm employment plays an important role in the farm household economy and counts up to 35 percent of total farm household income in the area (Woldehanna, 2000). Therefore, hiring out of labor has been considered as part of the sales activities.

2.2 Resource supplies and other constraints

The amount of scarce farm resources and other constraints such as subsistence/family food requirements, fuel requirements and cash needs determine the optimal allocation of resources to various activities. Average values in the dataset were taken/assumed resources currently available for the representative farm household and were used to derive the restrictions. Resources and other constraints specified in the model include labour, working capital, oxen-power, land, fuel/energy need, teff balance, wheat balance, barley balance, legumes balance, cereals, legumes, and cash needs or income.

Labour (hours): Total labour supply is approximated based on demographic characteristics of representative farm household and local circumstances such as number of nonworking or holidays. The representative farm household is assumed to have a family of 6 persons with 3 working persons (head, spouse and one other male member) and 3 dependants. The total labour supply is derived by aggregating total working time of each of the three working persons. Only one-third of the total working time for the spouse and the other male member of family have been considered in the total labour supply. Thus, the total labour supply is constrained to be less or equal to 2764 hours.

Working capital (Birr): Working capital is considered to be operating expenses of the farm in terms of purchasing farm inputs seed, fertilizer, pesticides, etc. The total amount of working capital requirement has been determined from the dataset and constrained to be less or equal to 529 Birr.

Ox-power: Per tsmdi or (pair day) ox-power requirement for the production of crops has been determined from the dataset. The representative farm household is assumed to have a pair of oxen. Taking into account local circumstances such as holidays and biological requirements of oxen, the total ox-power supply per year is assumed to be less or equal to 90 pair days.

Land (tsmdi): Households usually rent in land and total cultivated land constitute own land and rent in land. Total cultivated land minus rent in land is constrained to be less or equal to 6 tsmdi.

Fuel or energy needs: Fuelwood and dung are the most important fuel sources in the study area. Own sources such as own cattle barn and backyard account for major part of the dung used as fuel (see Appendix Table A.5). Most of the fuelwood is collected from adjacent woodlands and communal grazing areas. Therefore, fuelwood gathering is considered as an important activity competing for labour resource of the representative household. A total fuel or energy need of the household is determined from the dataset on the basis of fuel wood need and it is constrained to be greater or equal to 771 kilo grams.

Crop balances: As it could be shown from Table 1 below, four commodity balances namely teff, wheat, barley and legumes are specified assuming that production of each of these crops less consumption and sales should be greater or equal to 0.

Subsistence requirement of cereals: The representative farm household is assumed to be of 5.0 (persons) adult equivalents. Following Gryseels (1988) and Kassie *et al.* (1999), 200 kilo grams of cereals is considered to be the average annual subsistence requirement per adult equivalent. The minimum subsistence cereals requirement for our representative farm household is constrained to be greater or equal to 1000 kilo grams. It is assumed that the representative household consumes for subsistence requirements from one or more cereals among teff, wheat and barley depending on the optimal crop choice.

Legumes (kg): An average of 50 kilo grams of legumes or pulses was considered as the annual subsistence requirement per adult equivalent (Gryseels, 1988; Kassie *et al.*, 1999). Hence, subsistence legumes requirement is constrained to be greater or equal to 250 kilo grams.

Cash income or cash needs: Total cash income or cash needs of farm household includes working capital, expenses of marketable items such as salt, pepper and spices, coffee, tea and sugar and expenditures on non-food items such as soap, cosmetics, etc. Moreover, cash requirement to pay taxes and fees as well as cash needs to meet social obligations are also considered. The total cash income or cash need of household is constrained to be greater or equal to 1256 Birr. The total cash income is assumed to come from sales of teff, wheat, barley, and legumes as well as off-farm labour income. Average prices of the different products and of off-farm labour income observed during the survey period are considered in determining the amount.

3. Model Formulation

3.1 Classic Linear Programming Framework

Table 1 below presents a linear programming (LP) problem representation of the above problem. In this formulation, columns stand for activities or decision variables and rows stand for resource limits or supplies and other constraints. The first row in the table represents the objective function to be optimized. In such a classic LP model, a single most objective or goal, such as maximizing gross return or discounted value of net returns is often assumed. More technically speaking, in such an LP framework, the decision maker maximizes the objective function such as total gross margin subject to constraints (i)-(xii). Only one objective is optimized while the rest has to be treated as constraints. The coefficients of variables (x_i), for i=1,2,3, and 4, entering the objective function stand for gross margin (in Birr) per unit area (*tsmdi)* per annum of *teff*, wheat, barley, and legumes respectively. The coefficient of x_5 is the rental price/cost (in Birr) per unit area (*tsmdi)* of rent in land whereas the coefficient of x_{15} is return from a unit of off-farm labor.

In this setting, other objectives, for example, achieving food security or meeting fuel needs are considered as constraints and they are not by themselves taken as objective functions. However, such way of handling decision problems involving multiple objectives may not be satisfactory for various reasons. Firstly, representing goals by standard linear programming constraints is very rigid, whereas the decision-maker may have some flexibility say, for example, in the amount of cash income he/she wants to achieve. The amount need not necessarily be exactly constant. Imposing strict constancy is not only unrealistic but also easily leads to infeasibility of problems. Moreover, locating the constraint that might have caused the infeasibility could also be difficult in the case of large problems with many constraints. Secondly, since the objective function is optimized within the feasible region defined by the constraints, which could have been goals by themselves implies that priority of one over the other goal.

Goal programming tries to correct these limitations of linear programming while retaining its useful basic structure and numerical solution. Goal programming differs from the traditional single objective approach in two important respects. First, it stresses the satisfaction of multiple objectives instead of optimization of a single objective. Second, it realizes that it is highly unlikely that all of the constraints are truly absolute (Ignizio, 1976).

Table 1: Matrix of the Farm Household Problem in the classic LP (single objective) framework

Production activities					Consumption activities					Sales activities						
Teff (tsmdi)[1]	Wheat (tsmdi)	Barley (tsmdi)	Legumes (tsmdi)	Rent in Land (tsmdi)	Teff (kg)	Wheat (kg)	Barley (kg)	Legume (kg)	Fuel wood (kg)	Sales of Teff (kg)	Sales of Wheat (kg)	Sales of Barley (kg)	Sales of Legume (kg)	Off-farm work (hour)		
(x_1)	(x_2)	(x_3)	(x_4)	(x_5)	(x_6)	(x_7)	(x_8)	(x_9)	(x_{10})	(x_{11})	(x_{12})	(x_{13})	(x_{14})	(x_{15})		
241.33	298.05	279.34	104.92	-115.45										1.18	=	Z max (Birr)
167.94	76.42	71.05	70.64						0.11					-1	≤	2764 Labor (hours) (i)
34.70	87.46	77.13	48.24												≤	529 Working capital (Birr)[2] (ii)
4	3	3	2						0					0	≤	90 Ox-power (pair day) (iii)
1.0	1.0	1.0	1.0	-1.0					0					0	≤	6 Land (tsmdi) (iv)
									1						≥	771 Fuel need (kg) (v)
113.31					-1					-1					≥	0 *Teff*[3] balance (vi)
	146.73					-1					-1				≥	0 Wheat balance (vii)
		199.72					-1					-1			≥	0 Barley balance (viii)
			195.77					-1					-1		≥	0 Legumes balance (ix)
					1	1	1								≥	1000 MSRTPF[4] cereals (kg) (x)
								1							≥	250 MSR Legumes (kg) (xi)
				-115.45						2.13	2.03	1.40	0.54	1.18	≥	1256 Cash need (Birr) (xii)

[1] *Tsmdi* is local unit for land area -1 *tsmdi*=0.25 hectare
[2] Birr is Ethiopian currency 1USD = 12.7010 Birr (July, 2009)
[3] *Teff* is a staple crop it belongs to the grass family *Eragrostistef*
[4] MSR is an abbreviation for minimum subsistence requirement

3.2 Multi-objective or Goal Programming Model

In goal programming (GP), any problem involving multiple objectives is solved in such a way that the solution ensures the simultaneous satisfaction of many of the objectives. It attempts to include all pertinent objectives. However, not all objectives can or should be optimized and GP establishes aspired levels of achievement or goals for each of these objectives. Weighted goal programming (WGP), in particular, provides a way of striving towards all objectives simultaneously (Romero, 2004).

Mathematically, the goal programming problem in the general case could be specified as (Ignizio, 1976; Patrick and Blake, 1980; Barnett *et al*., 1982):

Minimize

$$\sum_i (W_i^+ \cdot p_i + W_i^- \cdot n_i) \quad \textbf{(1)}$$

subject to

$$\sum_j G_{ij} X_j + n_i - p_i = g_i \quad \textbf{(2)}$$

for all i,

$$\sum_j a_{kj} X_j \le b_k \quad \textbf{(3)}$$

for all k, and

$$X_j, p_i, n_i \ge 0 \quad \textbf{(4)}$$

for all j and i,

where p_i refers to the amount of positive deviation or overachievement from target level of the ith goal (g_i); n_i B refers the amount of negative deviation or underachievement of the ith goal; W_i^+, W_i^- are weights or relative importance attached to the deviation from targets, with the positive and negative superscripts respectively standing for overachievement and underachievement. G_{ij} are the coefficients of the goal constraints, i.e., the marginal achievement of goal i due to the production of X_j; a_{kj} is a matrix of technical coefficients for resources and other constraints; and b_k are the resource limits or right hand side.

To set up the GP model of our representative subsistence farm household, the set of inequalities (v) and (x)-(xii) in Table 1 are treated as goals, g_i, instead of constraints. This is done by introducing two associated variables, *n* and *p*, called the deviational variables, for each goal that convert inequalities to equalities (Romero and Rehman, 2003). Before we specify the WGP model for the subsistence farm household in question as in below, we present the formulation of the goals. Note that the four equations, i.e., equations (6)-(9) below represent the goal constraints, g_i, for i=1,…,4.

Goal g_1

The first constraint or goal (equation (6)) stands for household's consumption of cereals. The deviational variable n_1 measures the under-achievement of goal g_1 whilst p_1 captures the amount by which goal g_1 has surpassed its target. Because consumption of cereals should not be smaller than 1000 kilo grams, the deviational variable n_1 must be minimized.

Goals g_2, g_3 and g_4

Goals g_2 (equations (7)) stands for consumption of legumes; goals g_1 and g_2 in combination represent the food security objective of our representative subsistence farm household. Goal g_3 (equation (8)) stands for the goal of the representative farm household for fuel or energy needs. Consumption of legumes and fuel or energy needs should not be lower than 250 and 771 kilo grams respectively. Goal g_4 (equation (9)) represents the total cash income goal in Birr of the representative farm household. To achieve the desired level of g_2, g_3 and g_4 the respective values for n_2 n_3 *and* n_4 must be minimized.

It does not make sense minimizing absolute deviations especially when each goal is measured in different units. Hence, the variables of the objective function must represent percentage deviations from the targets. Therefore, the elements of the objective function have been standardized for the WGP model to give the objective function as in (equation (5)) below. Weights

(W_i, for i=1,…,4,) now express the relative importance of deviating by one percentage point from the respective goals. For example, if we assume that the farm household feels that it is indifferent from any of the four goals, then, this is equivalent to setting all weights equal to 1.

Therefore, the weighted goal programming (WGP) model for the representative farm household problem in consideration can now be specified as:

Minimize

$$0.1W_1n_1+W_2n_2+W_3n_3+0.08W_4n_4 \quad \textbf{(5)}$$

subject to

$$1.0x_6+1.0x_7+1.0x_8+n_1-p_1=1000\text{(cereals)} \quad \textbf{(6)}$$

$$1x_9+n_2-p_2=250\text{(legumes)} \quad \textbf{(7)}$$

$$1x_{10}+n_3-p_3=771\text{(fuelwood)} \quad \textbf{(8)}$$

$$2.13x_{11}+2.03x_{12}+1.4x_{13}+0.54x_{14}+1.18x_{15}+n_4-p_4=1256 \quad \textbf{(9)}$$

(cash income)

and

$$\boldsymbol{Ax} \underset{\geq}{\leq} \boldsymbol{b} \text{ (technical constraints from Table 1)}$$

$$\boldsymbol{x}\geq 0,\ \boldsymbol{n}\geq 0,\ \boldsymbol{p}\geq 0$$

Computer package (software) GAMS (General Algebraic Modelling System) was used to solve the weighted goal programming problem of our representative farm household.

4. Data and Study Area Description

The dataset used in this study come from Tigrai. Specifically, the farm dataset used in this paper was obtained from a stratified sample of 200 cross-sections of peasant farmers drawn from Enderta and Hintalo-Wajerat districts in the Southern zone of Tigrai region, for 2001 and 2002 production years. In addition, some findings of an earlier study by Woldehanna (2000) on same farm households were also used in the analysis. For instance, selection of most important crops was based on this earlier work. Our interest is to test and validate the models specified above whether these result in differing conclusions. Therefore, we use this dataset because we believe that the recentness of the dataset does not change the conclusions. Description of the data and summary statistics of the characteristics defining the representative subsistence farm household are provided in Tables A.2, A.3 and A.4 in the Appendices.

Tigrai is the most northern region of Ethiopia. It is situated between $12^0 15^1$ and $14^0 57^1$ N latitude and $36^0 27^1$ and $39^0 59^1$ E longitude. It is bordered to the North by Eritrea, to the West by the Sudan, to the South by Amhara and to the East by Afar Regional States of Ethiopia. The Tigrai region covers a total land area of about 50,000km^2 with a total population of 4.3 million (FDRE PCC, 2008). Of the total landmass of the region about 25 per cent is cultivated, and forest/grazing lands constitute about 37 per cent (Gebreegziabher, 2007). It belongs to the African drylands (African Sahel), which are often referred to as the Sudano-Sahelian Region (BoPED, 1998; Hunting, 1976). Administratively, the region is divided into six zones as Western, Northwestern, Central, Eastern, Southern zones and the Mekelle Metropolitan Zone. Included in these six zones are 45 districts of which 33 are rural and 12 are urban (see Figure 1). A tabia[26] is the lowest administrative unit below Woreda/district.

Agriculture and allied activities (crop, livestock and forestry) play an important role in the economy of the region. The average share of agriculture in the regional GDP (Gross Domestic Product) over the last four to five years, i.e., between 2005/06 to 2008/09 has been 38% in real terms. The service sector share accounted for about 39 percent and industry about 21 percent (BoFED, 2009).

[26]*Tabia* is the name for lowest local administration unit which constitutes about 1000 to 1500 households.

Figure 1: Location map of Tigrai

The specific study sites considered in the study are located in the range of 17 to 40 km south of Mekelle city (the regional capital) with an altitude ranging from 1760 to 2350 meters above sea level. The study area is characterized by erratic and low rainfall with an average of 460 mm per annum. This is considered as one of the limiting factors for crop production as most of the farming activities are performed under rain-fed condition.

Mixed crop-livestock is the dominant farming system in the area. In addition, about 36 percent of the peasant households were found involved in off-farm activities (Woldehanna, 2000). Besides barley, wheat, teff, and legumes as the four most important crops, farmers grow lentils, vetch, linseed, and vegetables.

Farm, off-farm and home activities might be distinguished as regards to labor allocation in the study area. Ploughing, sowing, weeding, harvesting as well as cattle keeping appear to be the major farm activities. Most of these major farm activities are carried out by the male members of the household, while female household members participate, mainly, in weeding and harvesting. Off-farm labor income accounts up to 35 percent of total farm household income and about 81 percent of the farm households are involved in off-farm activities (Woldehanna, 2000). Wage employment and self employment are the two types of off-farm activities in the area. Off-farm self employment constitute own-businesses such as petty trading, transporting by pack animals, fuel wood selling, charcoal making, selling fruits, pottery/ handicrafts, and stone-mining or quarrying. Home time activities include food preparation, child caring, and water and fuel wood fetching, which are generally undertaken by the wife or female members of the household.

5. Results and Discussion

Note that the purpose at hand is to investigate single versus multiple criteria/objective approaches. Specifically, we investigate whether the two approaches necessarily lead to differing conclusions using linear and goal programming techniques. The paper strives to answer key questions: could the single objective approach be a reasonable approximation, particularly for subsistence farm settings or does the multiple objectives approach has anything to add? Does the pattern of resource allocation change when priorities attached to the different objectives/ goals change? In what follows first we present the results of the linear programming model and then we present the results of the multi-objective or goal programming model.

5.1 Linear programming model

First we solved for the linear programming (single objective) model. Note that In the traditional 'single' objective approach one must assume that there is exactly one objective that is to be optimized subject to the absolute satisfaction of a number of 'constraints' (Ignizio, 1976). In our case, we assume maximization of gross margin (Z) as the single most objective to be optimized with all else treated as constraints. Then, we obtain the model solutions are:

x_1 = 2.677 *tsmdi*	x_6 = 30.280 kg	x_{11} = 0
x_2 = 0	x_7 = 0	x_{12} = 0
x_3 = 4.855 *tsmdi*	x_8 = 969.720 kg	x_{13} = 0
x_4 = 1.277 *tsmdi*	x_9 = 250.000 kg	x_{14} = 0
x_5 = 2.810 *tsmdi*	x_{10} = 771.000 kg	x_{15} = 1339.3

hours and the value of the objective function is Z=3397.7431 Birr.

Model results suggest that the farm household will allocate resources in such a way that production is mainly for own consumption and no sells of output. It also suggests that the cash income of the farm household solely comes from hiring out of labour for off-farm activities. It also shows that the subsistence farm household has to rent in about three tsmdi of land.

However, as already noted, the single objective approach fails to faithfully reflect the real life decision situation for two reasons. Firstly, it assumes that the constraints that define the feasible set are so rigid that they cannot be violated, whereas the decision-maker may have some flexibility. For example, the amount of cash income he/she wants to achieve need not necessarily be exactly constant. Hence, imposing such strict constancy is not only unrealistic but also easily leads to infeasibility of problems. Moreover, locating the constraint that might have caused the infeasibility could also be difficult in the case of large problems with many constraints. Secondly, decision-makers are usually not interested in ordering the feasible set according to just a single criterion but would rather find an optimal compromise involving several objectives. Moreover, especially in circumstances where the decision maker, say a farmer, is involved in diversity of occupations or activities such as farm and non-farm activities, it is not obvious whether the maximization of profit for the decision maker or a farmer refer to the farm, the non-farm, or the two in conjunction. In addition, since the objective function is optimized within the feasible region defined by the constraints (i.e., which could have been goals by themselves), it implies priority of one over the other goal that rendering inconsistency. Therefore, a more robust approach which addresses these failings of the traditional single objective approach would be needed.

5.2 Multi-objective or goal programming model

Goal programming model was used to test whether or if indeed the multiple objectives approach has something to add to our understanding of decision circumstances in subsistence farm settings. One way to solving a MOP (multiple-objective programming) optimization problem is to construct an aggregated objective function to be optimized (Krcmar and van Kooten, 2008). Romero (2004) provides alternative formulations of achievement function for a goal programming model of which weighted goal programming is one. This is done by combining the various objectives into a single objective expression, through attaching fixed weights to represent stakeholders' relative importance of various attributes in the utility function (Steuer 1986). Note that different solutions can be obtained by attaching different values to the weight (W) parameter. For example, in our case, first we run the initial algorithm in GAMS for $W_1 = W_2 = W_3 = W_4 = 1$, that we, where each of the goals given equal weight and generated optimal solutions (see first row, Table 3):

x_1 = 2.667 *tsmdi*	x_6 = 30.280 kg	x_{11} = 0
x_2 = 0	x_7 = 0	x_{12} = 0
x_3 = 4.855 *tsmdi*	x_8 = 969.720 kg	x_{13} = 0
x_4 = 1.277 *tsmdi*	x_9 = 250.000 kg	x_{14} = 0
x_5 = 2.810 *tsmdi*	x_{10} = 771.000 kg	x_{15} = 1339.3 hours

And the optimum values for the deviational variables were:

$n_1 = 0$	$p_1 = 0$
$n_2 = 0$	$p_2 = 0$
$n_3 = 0$	$p_3 = 0$
$n_4 = 0$	$p_4 = 0$

As could be clear from above, we found the initial solution permits full or complete achievement of all the farm household's goals. Solution suggests that the farm household will achieve family subsistence food supplies of 1000 kilo grams of cereals mainly from production of barley with teff contributing about 30 kilograms (4.4 percent). The household achieves the minimum subsistence requirement of legumes or pulses. The household also meets all of its fuel or energy needs. Besides, the household achieves the target level cash income Birr 1256. More importantly, the cash income was found to come solely from hiring out or supply of labour for off-farm activities. Moreover, the solution also suggest the farm household has to rent in land in order to be food secure.

Table 2: Sets of Weights used in the Sensitivity Analysis of WGP Solution

Run	W_1 (Cereals)	W_2 (Legumes)	W_3 (Fuelwood)	W_4 (Cash income)
1	1	1	1	1
2	2	2	1	1
3	1	1	1	2
4	3	3	1	1
5	1	1	1	3
6	4	4	1	1
7	1	1	1	4
8	5	5	1	1
9	1	1	1	5
10	10	10	1	1
11	1	1	1	10
12	100	100	1	1
13	1	1	1	100
14	1000	1000	1	1
15	1	1	1	1000

Sensitivity analysis was carried out to draw meaningful insights about the farm household's problem. Fifteen sets or iterations of weights (Table 2 above), were considered to test the sensitivity of the WGP solution to reordering of priority levels or weights. Table 3 presents results of sensitivity analysis of the WGP solution. In doing so, the intention was to obtain or generate proximate measure of the tradeoffs between goals. Specifically, the tradeoffs between two goals; achieving family food security and maximizing cash income of household were considered. This was done by altering the relative weights of these two goals while holding the relative weight or priority level for fuel or energy needs goal of household unchanged. Nonetheless, very surprisingly, all the iterations of reordering of priority levels or weights yielded exactly identical results.

Table 3: Results of sensitivity analysis of WGP solution

Run	Production activities				Consumption activities					Fuel wood	Sales activities					Goals			
	(x_1)	(x_2)	(x_3)	(x_4)	(x_5)	(x_6)	(x_7)	(x_8)	(x_9)	(x_{10})	(x_{11})	(x_{12})	(x_{13})	(x_{14})	(x_{15})	Cereals (kg)	Legumes (kg)	Feulwood (kg)	Cash income (Birr)
1	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
2	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
3	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
4	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
5	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
6	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
7	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
8	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
9	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
10	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
11	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
12	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
13	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
14	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256
15	2.677	0	4.855	1.277	2.810	30.280	0	969.720	250.0	771.0	0	0	0	0	1339.3	1000.0	250.0	771.0	1256

The fact that the multi-objective or goal programming model was insensitive to objective weighting might reveal that it has little, if not nothing, to add and that it might not be superior to the traditional paradigm of choice involving single-objective, particularly in the context of subsistence farm settings. It might suggests that the problem at hand is a classic case of decision-making environment that could be approximated, fairly reasonably, by a similarly structured model but with profit or gross margin maximization as the single most objective. The overall result of our model was also consistent with findings of Barnett *et al*. (1982) for Senegalese subsistence farms but inconsistent with findings in the European context. For example, Rozakis *et al.* (2012) conclude that the structure and management of sheep farms in western Greece are better approximated through the use of the multicriteria model thereby questioning the relevance of the traditional single objective model as a policy tool, as this significantly deviates from the actual behaviour of the farmers. Sintori *et al.* (2009) also argue that the multicriteria model is superior to the singlecriteria model and the superior quality of the multicriteria model relative to the single-objective (gross margin) maximization model is more easily vivid in the case of the small family farms. This might suggest that context matters

We argue the fact that the multi-objective or goal programming model result was insensitive to objective weighting cannot and need not be attributed model assumption, given the premise that assumption that simplify calculations do not alter the qualitative conclusions Milgrom (1994).

6. Conclusions

Using linear and goal programming techniques, this paper tried to investigate whether single and multiple criteria/objective approaches necessarily lead to differing conclusions based on farm dataset from a stratified sample of 200 farm households from Tigrai regional state, Northern Ethiopia. The key questions considered were: could the single objective approach be a reasonable approximation or does the multiple objectives approach has anything to add? How does the pattern of resource allocation change when priorities attached to the different objectives/ goals change? The multiple criteria or goal programming technique, in particular, was applied to investigate the tradeoffs between two objectives; (i) achieving family food security, and (ii) maximizing cash income or cash needs of subsistence farms in the allocation of scarce resources. The following concluding remarks could be drawn.

The result reveals unique solution that permits full or complete achievement of all the farm household’s goals. It also suggests that cash income of household comes solely from hiring out or supplying labour for off-farm activities. Moreover, the result also suggests the farm household has to rent in land in order to be food secure. The initial solution permits full or a complete achievement of all the goals of the farm household..

Sensitivity analysis was carried out to draw meaningful insights about the farm household’s problem. Fifteen sets or iterations of weights were considered to test the sensitivity of the WGP solution to reordering of priority levels or the tradeoffs between goals of achieving family food security and maximizing cash income of households. Surprisingly, model solution was also found insensitive to reordering of priority levels or weights of the goals in question.

The fact that the multi-objective or goal programming model was insensitive to objective weighting might reveal that it has little, if not nothing, to add and that it might not be superior to the traditional paradigm of choice involving single-criterion. It might suggests that the problem at hand is a classic case of decision-making environment that could be approximated, fairly reasonably, by a similarly structured model but with profit or gross margin maximization as the single most objective. However, our study is a first attempt to build a multicriteria model at least in the Ethiopian context to explain the behaviour of subsistence farm households. Therefore, further research is called for to be more conclusive.

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Appendices

Table A.1: Cropping pattern: Percent of farm households growing crops

Crop type	Enderta	Adigudem	Total
Teff	63.5	65.4	64.4
Wheat	71.0	64.4	67.7
Barley	78.5	82.7	80.6
Sorghum and finger millet	6.0	22.3	14.2
Legumes	42.5	39.1	40.8
Oil crops	7.5	10.9	9.2
Vegetables	9.5	4.9	7.2

Source: Woldehanna (2000)

Table A.2: Inputs allocation and output per tsmdi by crop type of a representative/average farm household (1 tsmdi=one-fourth of hectare)

Crop type	Oxen-power (Oxen day/tsmdi)	Labor input (hours/tsmdi)	Capital inputs (Birr/tsmdi)	Yield (kg/tsmdi)	Yield (Birr/tsmdi)
Teff	4	167.94	34.70	113.31	241.33
Wheat	3	76.42	87.46	146.73	298.05
Barley	3	71.05	77.13	199.72	279.34
Legumes	2	70.64	48.24	195.77	104.92

Source: Own Calculation (Dataset of 2001 and 2002) and Woldehanna (2000)

Table A.3: Summary statistics of characteristics defining the representative farm household (n=402)

	Mean	Std. Dev.	Min	Max
Family size	6	2	1	11
Number of dependents	3	2	0	7
Age of the household head	48	11.83	25	76
Area of land cultivated (tsmdi)	7.06	4.7	0	24
Number of plots cultivated	3.65	2.11	0	14
Area of land owned (tsmdi)	5.88	2.42	1	15
Number of plots owned	3.06	0.95	1	7
Market wage rate (Birr/ hour)	1.18	1.61	0.10	14.73

Source: Woldehanna (2000)

Table A.4: Summary statistics of other characteristics considered in the analysis

Variable name	n	Mean	Std. Dev.	Min	Max
Quantity of dung consumed in kg	199	1364.588	790.707	0	3951.36
Quantity of wood consumed in kg	199	624.26	743.994	0	4129.92
(Time spent collecting dung in hour)	199	22.5	26.26	0	221.10
(Time spent collecting wood in hour)	199	5.27	19.997	0	163.35
Variable farm inputs in birr (barley)	398	234.228	282.558	30	2080
Variable farm inputs in birr (teff)	398	46.603	59.768	6	375
Variable farm inputs in birr (wheat)	398	219.614	281.563	24	2989
Variable farm inputs in birr (legumes)	398	28.53	80.246	0	500
Number of cattle	398	5	5	0	32

Source: Own Calculation (Dataset of 2001 and 2002)

Table A.5: Distribution of sample households by mode of fuel acquisition by fuel type (in %) (n=199)

Mode of acquisition	Fuel type	
	Fuel wood	Dung
Free collection	61.4	30.9
Buying	13.2	0.0
Own source (tree/cattle manure)	3.6	51.3
Free collection + own source		17.8
Do not use fuel wood	17.8	
Total	100.0	100.0