MODELING THE MOTIVATION FOR DIVERSIFICATION ON SUBSISTENCE FARMS IN THE ETHIOPIAN HIGHLANDS

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Abstract

Mathematical programming analysis has been quite effective for commercial farm planning in developed countries, but less so for subsistence farms in developing countries. In particular, it is difficult to reproduce the level of diversification observed on subsistence farms using a simple profit maximization framework. This paper proposes an alternative to the minimum consumption requirement approach for modeling subsistence farming households by treating consumption explicitly through a demand system motivated by Cobb-Douglas utility. A typical, linear programming-based production system is incorporated, allowing for the production of crops and livestock subject to constraints on resource availability.

The approach successfully predicts consumption behavior of subsistence households in Holetta area of the Ethiopian highlands, but diversification of the cropping plan occurs only when marketing behavior is incorporated in terms of restriction on purchases of major consumption goods. The results suggest that integrating markets economy to improve their performance may improve the welfare of poor households in developing countries. This requires improvement of both input and output markets.

Keywords: Calibration, household model, subsistence

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Mathematical programming analysis has been quite effective for commercial farm planning in developed countries (McCarl, et al.), but less so for subsistence farms in developing countries. In particular, it is difficult to reproduce the level of diversification observed on subsistence farms using a simple profit maximization framework. This has lead modelers to a number of modifications to attempt to get more diversification.

The first of these modifications is to force production of at least minimum quantities of selected crops in the name of "safety-first" for subsistence. This is in contrast to the usual versions of the Safety First model that focuses on obtaining a minimum level of income (see Roy and Low). The second is the inclusion of risk aversion through a variety of means that are all fundamentally motivated by von Neuman-Morgenstern expected utility theory. The third approach is through disaggregation of the resource base. For example, Baker and McCarl find that disaggregation of resources over time can have a significant impact on the diversification of the crop portfolio. Alternatively, Roth disaggregates land resources into categories that are more or less productive for different crops.

None of these approaches are completely satisfying. The approach of minimum production constraints does not allow for any substitution between the minimums in response to changes in expected prices. For small changes, this is likely to be a good approximation, but for large changes, especially over time, there may be impacts on these minimums. One problem is that these expected price changes might be due to policies or environmental changes, and the assessment of those impacts may be the goal of the modeling exercise. The expected utility approach is unsatisfying for a much different reason. This approach is very useful for explaining diversification in financial markets. However in financial markets, offerings with non-viable risk/reward combinations are culled through the machinations of the market. When examining data on cropping patterns for subsistence farms, it frequently appears that crops that are dominated from a risk/reward perspective are produced. Similarly, disaggregation of resources is often not sufficient to obtain observed diversification of the production plan. Why does this happen?

One explanation is that by looking at the subsistence farm as a "producing unit", an important aspect of farm behavior is ignored. In addition, most of the models cited above make the assumption of perfect markets. An alternative perspective is that subsistence farms are producing for the purpose of satisfying their own consumption needs with limited access to markets. Sanders notes that in years when yields are low, market prices tend to skyrocket, making purchases for consumption limited by budget constraints, while in years when yields are high, prices often collapse, greatly reducing the effectiveness of households' decisions to make sales to finance the purchase of other goods. By ignoring the consumption motivation for the farm and the limited usefulness of markets, we ignore an important determinant of production behavior. De Janvry et al. also cite the importance of including both production and consumption decisions in modeling decisions of a household when markets are incomplete. Note that the minimum production approach is also focused on the consumption aspect. Here, we propose an alternative treatment of consumption preferences that does not employ hard minimums and allows substitution in response to changes in policy or the environment combined with limits on market transactions.

In this paper, we construct a household model for a typical farm in the Holleta region of the Ethiopian highlands. Consumption is treated explicitly through a demand system motivated by Cobb-Douglas utility. A linear programming-based production system is incorporated, allowing for the production of crops and livestock subject to constraints on resource availability.

Using this formulation, we demonstrate that observed consumption patterns are roughly reproduced. In addition, we demonstrate that if purchases of crops are restricted not to exceed observed average purchases, substantial diversification of production occurs. These restrictions are motivated by the observation that marketing costs are high, and there is a high negative correlation between prices and yields that gives farmers a large incentive to be close to self-sufficient in food production.

Ethiopia offers a very good "laboratory" for addressing these questions because there is a high level of poverty. Cereal yields average less than one ton per hectare in most of the highlands, and milk yield is only about one-fourth of the average of all developing world. Such low productivity combined with a small farm size (less than two hectares on average) implies extreme poverty and food insecurity. (Pender et al. 2001)

Model

The crop-livestock, household model developed here is based on the bio-economic conceptual framework. In this framework, the household has two integrated enterprises: crop and livestock production. Crops provide feed for livestock while livestock is the principal supplier of traction power to till cropland, and manure for improving soil fertility. Therefore, in selecting a crop plan, the farmer considers, among other things, the available traction capacity, the expected quantity of feed for livestock, available manure resource for fertilizing the land and the expected produce to feed the humans and livestock in the household. The productivity of both enterprises is determined by biophysical environmental factors such as rainfall and soil fertility, and by the available technology such as improved seeds, inorganic fertilizer, and soil fertility management and erosion control.

The household supplies feed and labor to the livestock herd and labor and crop inputs to the farm. In return, the household receives livestock services and livestock and crop products for own consumption and sale as well as manure for either burning as a fuel, improving soil fertility, or sale. Through the market, the farm surplus is exchanged for food, feed, fuel, other consumption goods, and savings.

The model consists of activities broadly relevant to crop production, livestock production, resources management and consumption. The household objective function is a direct function of consumption. A Cobb-Douglas utility function whose arguments are the monthly consumption levels of all goods is used to reflect household preferences. That is,

$$u(c_{it}) = \prod_{t=1}^{12}\left(\prod_{i=1}^{j} c_{it}^{\alpha_{it}}\right)$$

where c_{it} is the level of consumption of the i^{th} good in period (month) t, and α_{it} is the expenditure share of the i^{th} good (i=1,…,j) in period t.

Data

The data used in the modeling exercise is derived from the Holetta dairy/draft project database. One major objective of the project is to develop technologies to enable resource-poor smallholder mixed crop-livestock farmers to participate in market-oriented dairying. Another major objective is testing the use of crossbred dairy cows (CBC) for traction, as well as milk production.

In this project, pairs of crossbred dairy cows were introduced initially on 14 farms in Holetta in 1993, half for milk production only, and half for traction, as well as milk production. In 1995 and early 1996, 120 more crossbred cows were introduced into an additional 60 households that were all using the cows for traction, in addition to milk production and reproduction. Willingness and ability to pay the initial fixed cost and costs maintaining the CBCs were the major criteria used for selection of the participating households. Although the initial 14 farmers were relatively rich, the latter sixty farmers were selected from a list of farmers in three wealth groups, namely poor, medium wealth, and rich farmers. This wealth classification is based on livestock holdings, available crop and pasture land and available household. Sixty control households using traditional practices of local Zebu cows for milk production and oxen for traction were included in the household surveys beginning in mid-1995. The number of control farmers in each wealth group is roughly equal to the number of CBC owners in the same wealth group. Within each wealth group, participating and control households were comparable, selected on the basis of the same criteria.

The Holetta area is located 40 to 70 km west of Addis Ababa, the capital of Ethiopia, in the vicinity of two small towns: Holetta and Addis Alem. The altitude of the area is around 2,600 meters and receives an average annual rainfall of 1,100 mm. Average minimum and maximum temperature are, respectively, 11.6° and 15.3° C. The main rainy season, *mehr*, extends from June to September when more than seventy percent of the rain falls. The short rains season, *belg*, extends from late February to May and is mainly used to break and prepare the soil for the main crop season. Farmers in this area exclusively depend on rain-fed agriculture and most crops are grown in the main rainy season.

The Holetta area is characterized by variable soils with a predominance of red brown soils, with a low water holding capacity on the slopes and poorly drained heavy dark clay soils (vertisols) mostly in the valleys. Three types of soils can be identified on household plots: vertisols, light and mixed upland soils, and heavy upland soils with vertisol properties. The farming system in this area is typically a mixed, crop-livestock system. Farmers produce a wide range of cereal and legume crops on small parcels of land. Production is geared towards satisfying the household food requirements as well as provision of feed in the form of straw and hay for livestock.

Total crop area and land allocation to crops vary substantial with the wealth. Table 1 summarizes the average cropping plan for poor, medium and rich households. The household grows as many as ten crops, mostly in small parcels of land. The main crops are teff, wheat, and barley according to area allocation. Teff and wheat are the main staples. Other crops include field peas, oats, sorghum (*Sorghum bicolor*), linseed, and rape seed, the latter two being the main cash crops. Although on-farm forage production, such as an oat-vetch intercrop, is recommended when crossbred cows (CBC) are introduced, growing fodder is limited (Table 1).

Besides crops, the household keeps a herd of animals, mainly consisting of dairy cows, oxen for plowing, heifers, bulls, goats, sheep, and chicken. Because of the dependency on animal traction for crop production, keeping at least a pair of oxen and a follower herd (heifers and bulls) for replacement is necessary despite the feed shortage.

The subsistence nature of the farming system is reflected in the limited dependency on the market for food supply. Medium and rich households, for example, purchase less than 2% of their teff and wheat consumption while poor households purchase a greater fraction of their teff and barley consumption but produce most of the wheat that they consume (Table 2). This indicates the thinness of the market for staple grains. The implication of this on modeling household behavior is that the usual assumption of perfect and complete markets is inappropriate. In the next section, we compare the modeling results of two scenarios to observed behavior. In the first scenario, a perfect market for food is assumed and households are allowed to purchase food without restrictions. In the second, household purchases are limited to a fraction of their observed consumption as shown in Table 2.

Results

The unrestricted purchases scenario reflects the case of perfect and complete markets. Though the household is assumed to maximize its utility of consumption subject to minimum daily requirements for energy and protein intake, land allocation decisions in this case maximize income subject to resource constraints. (Because markets are treated as perfect, high production profits are consistent with high consumption and utility.) As such, most of the land is allocated to one of the few cash crops, namely linseeds, with the remaining cropland allocated to teff and sorghum by the model. In reality, cash crops (linseeds and rape seeds) are only allocated to a limited parcel of land of 0.015 –0.10 ha (Table 3, 5 and 7). These results are consistent across the three types of households of different levels of wealth, and land, labor, and livestock endowments. In this case, the diversified cropping plan usually observed in the area is avoided. All households make substantial purchases of food from the market.

However, as mentioned above, subsistence households do not depend heavily on the market for their food needs and their market transactions are rather limited. This forces the household to diversify its cropping plan to meet its consumption requirements[2]. When purchases of the major consumption goods are restricted to reflect observed behavior, the household allocates its available cropland to 6-8 cropping activities. For all households, the largest land area is allocated to teff, the principal staple, followed by wheat and barley (Tables 3, 5, and 7). The crop area allocation predicted by the model in this case is reasonably consistent with the observed allocation. However, some discrepancies remain. First, oats and rape seed, which are

[2] Risk is another explanation for diversification to spread the risk across many activities. However, in this model risk is only included through the limitation of market transactions.

minor crops in terms of area, are not grown by any household. Second, linseed, which is usually not grown by poor households, replaces the oat-vetch intercrop recommended as a forage crop to meet CBCs' feed requirements. Though allocation of 0.5-1 ha of land to oat-vetch intercrop is recommended, the households with a pair of CBCs only allocate 0.024-0.170 ha to this activity. Our model predicts that rich and medium households should allocate about 0.8 ha to oat-vetch. Among the three households, the observed allocation of medium households compares very closely to the model predictions.

Under the assumption of perfect markets and unrestricted purchases, the model predictions of land allocation diverges substantially from observed behavior. The prediction of consumption patterns is generally better in the unrestricted case (Tables 4, 6 and 8) compared to the case of restricted purchases. The exception is the medium household, for which the predicted consumption is quite close in both cases. This reflects the tradeoff between accuracy of the production and consumption portions of the model. While further work is needed to improve the balance, the present model represents a large improvement over the unrestricted case.

An important implication of the market imperfection is reflected in household consumption of milk and dairy products. All households consume much less milk compared to observed quantities, according to model results. Since the model does not limit the quantity of milk consumed, processed or marketed, it appears the households are unable to dispose of (market) their surplus milk. This may be due to high transaction costs of milk marketing or another barrier (not reflected in the model). Thus, households are observed to consume more milk. Improving livestock marketing channels and reduction of transaction costs such as long walking distances to collection points is a critical requirement for encouraging adoption of livestock technology.

The most important implication of market uncertainty and the limited participation in marketing is also reflected in the lower value of consumption by poor and rich households when purchases are restricted (Tables 4 and 8). In this case, the household is forced to adopt a less profitable land allocation. From a policy perspective, this implies that market integration may improve the welfare of these households substantially. However, this requires improving marketing infrastructure and availability of alternative cash income opportunities for the households. One of the main options in this area is the expansion of household dairy production activities through adoption of improved livestock technologies.

Conclusions

This paper presents a novel approach to modeling the economic motivation for diversification on subsistence farms. The thesis is that a desire for a diverse diet combined with market instabilities due to the strong negative correlation between yields and market prices results in a substantial motivation for near self-sufficiency of the household. A deterministic household model is constructed to reflect these facts, and the model is calibrated for several households in the Holetta region of Ethiopia.

Results of the household model highlight the importance of reflecting the market constraints imposed on subsistence households for predicting their resource allocation decisions. When the observed limited purchases of major food commodities are imposed, the model predicts the more diversified land allocation behavior observed for subsistence households. However, these restrictions appear to reduce household welfare by reducing its income and its ability to satisfy consumption needs through market purchases.

This type of model shows promise for reflecting the impacts of policy on crop mix, livestock management, production practices, and other household activities. In particular, due to the bioeconomic linkages in the model, it may be useful for investigating the effectiveness of alternative policies designed to foster improved land and water management issues as are presently a concern in the East African Highlands.

Four "next steps" suggest themselves for this research. First, application of the existing model to analyses of alternative credit systems and disaster relief policies will provide short-run beneficial analyses. Second, inclusion of risk in the model will allow the elimination of the artificial upper bounds on purchase and sales activities and give households incentive to hold stocks as is observed. This model will be used to develop a better understanding of the limits of the market for making up consumption shortfalls and for absorbing excess production, providing an empirical basis for improved bounds on purchases and sales for an improved deterministic model. Third, expansion of the time dimension of the model to include multiple years will allow the tracking of soil quality over time. This model will be used to evaluate alternative policies focusing on improving soil resource conservation and sustainability of the production system. Fourth, expansion of the model to include multiple households within a village and their interactions through formal and informal inter-household transactions, resource use externalities, and competition for the use of commons will be made. The expanded model will allow the assessment of the effectiveness of policy on a more comprehensive basis.

Table 1: Crop land allocation for three types of households in Holetta

	Poor	Medium	Rich
Barley	0.170	0.420	0.348
Wheat	0.270	0.590	0.820
Teff	0.410	0.830	0.830
Sorghum	0.030	0.070	0.047
Horse beans	0.011	0.190	0.211
Oats	0.017	0.010	0.015
Rape	0.015	0.050	0.040
Linseed	0.000	0.050	0.015
Field peas	0.000	0.140	0.040
Oat-vetch	0.024	0.170	0.120
Total	1.046	2.520	2.486

Source: Model results and ILRI/EARO dairy-draft database.

Table 2: Food purchases as a percentage of observed consumption for three types of households

Crop	Poor	Medium	Rich
Maize	100	21	100
Wheat	7	2	1
Teff	19	2	2
Oats	17	0	5
Barley	33	2	2
Sorghum	100	8	6
Field peas	18	3	3
Horse beans	100	7	11

Source: Model results and ILRI/EARO dairy-draft database.

Table 3: Observed and predicted area allocation (ha) for for poor households with CBCs

Crop	Observed (ha)	Unrestricted purch.	Restricted purchases
Barley	0.170		0.100
Wheat	0.270		0.147
Teff	0.410	0.221	0.488
Sorghum	0.030	0.019	0.053
Horse beans	0.011		0.027
Oats	0.017		
Rape	0.015		
Linseed	0.000	0.800	0.225
Field peas	0.000		
Oat-vetch	0.024		
Total	1.046	1.046	1.040

Source: Model results and ILRI/EARO dairy-draft database.

Table 4: Observed and predicted consumption levels with for alternative scenarios for poor households with CBC

	Observed Consumption	Unrestricted purchases		Restricted purchases	
		Consumption	% difference	Consumption	% difference
Cereal (kg)	1003	1266	-26.2	1324	-32.0
Pulses (kg)	63	75	-19.9	54	13.9
Meat (kg)	41	32	20.8	17	58.7
Milk (*l*)	125	83	33.4	52	58.0
Eggs (no)	182	154	15.5	99	45.3
Butter (kg)	20	18	10.1	10	50.0
Cheese (kg)	14	12	15.5	7	47.7
Others (Birr)	564	435	22.3	214	62.1
Value of Consump. (birr)	3802	3883		3274	

Source: Model results and ILRI/EARO dairy-draft database.

Table 5: Observed/predicted crop area allocation for two alternative scenarios for medium households with CBCs.

Crop	Observed (ha)	Unrestricted purchases	Restricted purchases
Barley	0.420		0.135
Wheat	0.590		0.133
Teff	0.830	0.393	1.127
Sorghum	0.070	0.127	0.179
Horse beans	0.190		0.420
Oats	0.010		
Rape seed	0.050		
Lin seed	0.050	2.000	0.001
Field peas	0.140		0.073
Oat-vetch	0.170		0.830
Total	2.520	2.520	2.520

Source: Model results and ILRI/EARO dairy-draft database.

Table 6: Observed/predicted consumption levels for two alternative scenarios for medium households with CBC

	Observed Consumption	Unrestricted purchases		Restricted purchases	
		Consumption	% difference	Consumption	% difference
Cereal (kg)	1240	1296	4.5	1283	3.5
Pulses (kg)	103	103	0.0	91	11.8
Meat (kg)	59	56	4.6	57	3.2
Milk (*l*)	198	150	24.2	182	7.9
Eggs (no)	119	11	3.9	12	1.7
Butter (kg)	19	19	-5.6	20	-8.2
Cheese (kg)	30	29	2.7	30	0.0
Others (Birr)	1151	1110	3.6	1145	0.5
Value of Consump. (birr)	5374	5333		5399	

Source: Model results and ILRI/EARO dairy-draft database.

Table 7: Observed/predicted crop area allocation for two alternative scenarios for rich households with CBCs.

Crop	Observed (ha)	Unrestricted purch.	Restricted purchases
Barley	0.348		0.198
Wheat	0.820		0.178
Teff	0.830	0.903	1.236
Sorghum	0.047	0.020	0.033
Horse beans	0.211		0.040
Oats	0.015		
Rape seed	0.040		
Lin seed	0.015	1.563	0.000
Field peas	0.040		0.002
Oat-vetch	0.120		0.798
Total	2.486	2.486	2.486

Source: Model results and ILRI/EARO dairy-draft database.

Table 8: Observed and predicted consumption levels with for alternative scenarios for rich households with CBC

	Observed consumption	Unrestricted purchases		Restricted purchases	
		Consumption	% difference	Consumption	% difference
Cereal (kg)	1343	1467	-9.2	1528	-13.8
Pulses (kg)	80	87	-8.8	75	6.6
Meat (kg)	75	69	42.5	43	43.2
Milk (*l*)	294	218	25.8	146	50.4
Eggs (no)	18	17	7.3	11	36.7
Butter (kg)	28	29	2.7	19	34.1
Cheese (kg)	36	34	5.7	23	37.2
Others (Birr)	546	502	8.0	300	45.1
Value of consump. (birr)	5511	5497		4558	

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