Production structure and derived demand for factor inputs in smallholder dairying in Kenya

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Abstract

This study examined the production structure of smallholder dairy farms in Kenya's marginal zones, using duality theory in production and costs. The restricted translog cost function was used to derive a system of six input share equations, which were estimated simultaneously with the cost equation by the iterative Zellner procedure. The Morishima elasticities of inputs and the price elasticities of factor demands were computed, and economies of scale were determined. The results indicated that the production structure is a fairly well integrated system of activities, despite scale diseconomies. The Morishima elasticities indicated that factor inputs are substitutable. For example, as prices of formal feeds remain relatively high, informal feeds may be substituted for expensive formal feeds. Policy makers can use these findings to suggest ways of rationalizing feed quality and markets. This would enhance extension and research on balancing protein needs with the current use of roughage on the farms.

Keywords: production structure; translog cost function; marginal zones; elasticities; scale economies

Cette étude a examiné la structure de la production des petits propriétaires de laiterie dans les zones marginales du Kenya, en utilisant la théorie de la dualité dans la production et les coûts. On a utilisé la fonction translog de coût pour obtenir un système d'équations basé sur six entrées qui a été évalué en même temps que l'équation du coût par la méthode itérative de Zellner. L'élasticité de Morishima des entrées et de l'élasticité des prix des entrées ont été calculées, et les économies d'échelles ont été déterminées. Les résultats ont indiqué que la structure de la production est un système d'activités plutôt bien intégré, malgré les déséconomies d'échelle. L'élasticité de

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Morishima a indiqué que les entrées sont remplaçables. A titre d'exemple, puisque les prix des aliments formels demeurent relativement élevés, les aliments informels pourraient remplacer les aliments formels, qui sont chers. Les décideurs peuvent utiliser ces conclusions pour suggérer des stratégies de rationalisation concernant la qualité des aliments et les marchés. Ceci améliorerait la vulgarisation en gestion agricole et la recherche sur la façon d'équilibrer les besoins en protéines par rapport à l'utilisation actuelle des fourrages grossiers dans les fermes.

Mots clés : *structure de la production ; fonction translog de coût ; zones marginales ; élasticité ; économies d'échelle ; Kenya*

1. Introduction

Exotic dairy cattle were first introduced to Kenya from Europe by white settlers in 1920 and established in the high potential Kenyan highlands, which has a temperate climate similar to Europe's and is thus ideal for these cattle (Conelly, 1998; Omore et al., 1999). Dairy experts in Kenya in those days argued that the dry marginal zones were unsuitable for these high performing exotic breeds and could not meet their requirements (Meyn & Wilkins, 1973; Kimenye & Russell, 1975). For the marginal and semi-arid areas they recommended that upgraded zebu breeds, which have lower nutritive requirements and are more adaptable to marginal conditions, would be more suitable, though a disadvantage is that they supply relatively little milk. However, since the mid-1980s exotic dairy production has been established in the marginal areas. This has happened through a slow process of technology diffusion from the high potential zones. There has been minimal involvement of the national livestock extension services, however, so the majority of smallholder producers have organized themselves into dairy cooperatives to improve rural milk marketing.

The marginal and transitional zones, at altitudes from 1,000 to 1,900 m above sea level, have a warm and dry climate with a bi-modal rainfall pattern and a mean annual rainfall of 625 to 850 mm. Rainfall reliability is low and frequently results in drought and crop failure, worsening the food security situation in the region (Mbithi, 1999). Agriculture provides employment to the majority of the people in the marginal districts (GoK, 2002), but it is unreliable and there are frequent food deficits. Crop farming is mainly for subsistence purposes, with occasional sales when there is a surplus. The major food crops are maize, beans, pigeonpea and cowpea. The marginal zones have no established cash crops, unlike the high potential highland areas that grow industrial cash crops such as tea, coffee and pyrethrum, and they have no off-farm employment such as tourism and fisheries, unlike the coastal areas. Household incomes in the marginal zones are therefore low (GoK, 2002) – over 60% of the population here live below the poverty line (GoK, 2000).[1] Reduction of poverty remains one of the greatest challenges in the marginal zones.

[1] People who earn below Kshs.1238.86 ($17.21) per month (GoK, 2000).

The importance of the dairy industry in Kenya's marginal and semi-arid lands cannot be overemphasized. There is a need for alternative new agricultural activities that offer higher returns to land and labor and the expectation of future growth and are suitable for the resource-poor smallholder farmers who continue to dominate agricultural production (Nicholson et al., 2004). Smallholder farmers in the marginal zones have been compelled by changes in policy and markets to diversify from traditional subsistence staple food crops, where the outlook for growth remains uncertain, to small-scale dairy production for a cash market. The challenge for the transition to the next stage is to intensify dairy production using the new dairy technologies and achieve the greatest possible output, given the available resources.

Dairy production can be intensified by introducing exotic breeds of cattle with a higher genetic potential for milk production and using complementary inputs (Nicholson et al., 2004). In a number of regions there is good potential for increased demand and higher real prices for milk and other dairy products, especially in the urban and rural townships in the marginal zones. This can mean increased incomes for smallholders, and income from milk and dairy products is distributed more evenly throughout the year than income from crops. Where there is regular payment from milk societies, cash receipts constitute a monthly salary in an area where there are no cash crops. In addition, because dairy production tends to be labor intensive it can increase the intensity of household labor use and generate hired employment. This may stimulate the demand for labor, providing benefits to unskilled laborers and distributing the gains from dairy production more broadly and progressively (Nicholson et al., 2004). Thus, smallholder dairy production is a catalyst for agricultural development. It can generate income and employment, and improve food security and livelihoods (Winrock International, 1992).

Staal (2002) carried out a case study on extensive and intensive dairy systems in the high potential zones of Kenya to determine the farm enterprise competitiveness of dairy. The results showed that intensive smallholder dairy had above normal profits, indicating that it is a fairly competitive farming enterprise. The challenge now is to intensify dairy production and make it competitive in the marginal zones as well. However, small-scale dairy farmers in the marginal zones and the transitional semi-arid lands are often neglected by policy makers and planners of extension and dairy development programs, who pay more attention to the high potential areas. Even the professionals rarely investigate or understand the competitiveness and potential productiveness of exotic dairy cattle in the marginal zones.

Given the paucity of information about dairy production using exotic breeds in the region, we surveyed producers in the marginal zone directly (Kavoi, 2007). The diversity of production methods used by these producers provides a natural experiment in production structure. In the analysis, a flexible form cost function that includes both market and on-farm dairy feed inputs along with labor is estimated to describe the structure of smallholder dairy production in the marginal zones. More specifically, a restricted translog cost function is estimated simultaneously with the dairy input demand cost share equations in a systems approach using the iterative Zellner method. Our objective is to determine the different impacts that exogenous variables have within and across dairy input demands for this neglected, but important, market sector. The price elasticities of factor demands are computed as well as the Morishima elasticity of substitution among pairs of inputs. Finally, the scale elasticity of dairy production is computed and discussed.

2. Methodology

2.1 Theoretical framework

An industry's production structure can be studied empirically using either a production function or a cost function. However, the choice should be made on statistical grounds (Kant & Nautiyal, 1997). Direct estimation of the production function is more convincing in the case of endogenously determined output levels; in the case of exogenous output levels, cost function estimation is preferable (Christensen & Greene, 1976). In most cases the dairy sector competes with other enterprises for factors of production, and this makes factor prices exogenous. Since the arguments of the cost function are the output and the factor prices, its estimation is statistically more logical than that of the production function. On the other hand, duality theory allows us to recover from the cost function all information regarding the production structure. We chose the translog cost function (Christensen et al., 1971, 1973) for this analysis because of its very specific features, i.e. no a priori restrictions on the substitution possibilities and variation of scale economies with the level of output (which is essential to enable the unit cost curve to attain the classic U-shape).

2.2 Specification of the empirical model

A general form of the translog cost function for the six variable dairy inputs (protein feed, roughage feed, animal treatment, tick control, labor, own feeds) and one fixed input (grazing area) can be expressed as:

$$\ln C_i = \alpha + \alpha_q \ln Q_i + \sum_i^n \alpha_i \ln P_i + \frac{1}{2}\beta_{qq}(\ln Q_i)^2 + \frac{1}{2}\sum_i^n \beta_{ii} \ln P_i \ln P_i + \sum_i^n \beta_{ij} \ln P_i \ln P_j$$
$$+ \sum_{i=1}^n \beta_{qi} \ln Q_i \ln P_i + \gamma_m \ln Z_m + \frac{1}{2}\gamma_{mm}(\ln Z_m)^2 + \sum_{m,i}^n \gamma_{mi} \ln Z_m \ln P_i + \sum_{m,q}^n \gamma_{mq} \ln Z_m \ln Q_i \quad (1)$$

where $\beta_{ij} = \beta_{ji}$ for all i, j and the function is homogeneous of degree one in prices of all variable inputs and output. The definitions of the variables and the notation used are as follows:

Q = total annual milk production (liters) produced in the period under study; C_i = total variable cost of production normalized by the labor wage (w_i); P_i' = price of the ith input (P_i) normalized by the labor wage (w_i); i = 1, protein feed, 2, roughage feed, 3, animal treatment, 4, tick control, 5, own feed; Z_m = grazing area as the only fixed input; and $\alpha's, \beta's$ and $\gamma's$ are the parameters to be estimated.

The total variable cost of production (C_i) normalized by wage (w_i) depends on the level of total annual milk output in the period under study (Q), the prices of inputs P_i normalized by the labor wage (w_i) where i are the various dairy inputs, the fixed inputs and both squared and cross terms of the model, as discussed above. Therefore, the a priori expectations are that annual milk output and the normalized prices of protein feed, roughage feed, animal treatment, tick administration and own produced feeds would have a positive impact on the total variable cost of production. However, no clear-cut signs could be assigned a priori to the fixed inputs and both squared and cross terms of the translog cost function.

To correspond to a well-behaved production function, a cost function must be homogeneous of degree one in the input prices, which requires the following conditions to be satisfied:

$$\sum_i \alpha_i = 1 \tag{2}$$

$$\sum_i \beta_{qi} = 0 \tag{3}$$

$$\sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \sum_j \beta_{ij} = 0 \tag{4}$$

The restriction of linear homogeneity in the input prices is imposed by normalizing cost and the other prices by the labor wage rate (Greene, 2002). The translog cost function can be estimated directly or in its first derivatives which, by Shephard's lemma, gives the factor shares. Thus, logarithmically differentiating equation (1) with respect to input prices yields:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C_i} = S_i \tag{5}$$

where S_i indicates the cost share of the ith input factor. The translog cost function thus yields the cost share equations:

$$S_i = \alpha_i + \beta_{qi} \ln Q + \sum_i \beta_{ij} \ln P_j + \gamma_{ij} \ln Z_m \qquad (6)$$

and $i = 1$ for protein feed share, 2 for roughage feed share, 3 for animal treatment share, 4 for tick control share, 5 for labor share and 6 for own feed share, and 7 is the fixed input (grazing area). Both sets of estimation equations are linear in logarithms and have proper exogenous variables on the right-hand side if the analysis pertains to firms or farms or an industry (Binswanger, 1974). The necessary cross equation constraints are imposed in the translog cost function and the input demand system. Within the factor demands, symmetry of the input demand equations (i.e. $\beta_{ij} = \beta_{ji}$) is imposed. It is generally observed that very large gains in efficiency often follow when the cross equation restrictions are imposed (Greene, 2002). The β_{ij} parameters have little economic meaning of their own. However, they are related to the variable elasticities of substitution and of factor demands (Binswanger, 1974).

2.2.1 Estimation procedure

It is possible to estimate the parameters of the cost function using ordinary least squares (OLS), but that neglects the information contained in the cost share equations. An alternative procedure is to estimate the cost shares as a multivariate regression system (Berndt & Wood, 1975). However, in this approach the parameters associated with output and output cross terms, which are found only in the cost function, cannot be estimated. The optimal procedure is to estimate the cost function simultaneously with the cost share equations as a multivariate regression system. If we include the cost share equations in the estimation, this gives us more degrees of freedom without adding any unrestricted regression coefficients and produces more efficient parameter estimates.

Additive disturbances are assumed for the cost function as well as for each of the share equations. Following Zellner (1962), it is also assumed that the error in each equation is homoscedastic but that there is a non-zero correlation between contemporaneous disturbance terms across equations. In view of the adding-up requirement of the input shares, one equation, labor input demand share, is excluded from the system. By thus deleting one of the share equations from the system and using the iterative Zellner estimation procedure until convergence, we realize maximum-likelihood estimates. The iterative Zellner procedure is a computationally efficient method for obtaining maximum-likelihood estimates and has been used by researchers for estimating translog cost function (Christensen & Greene, 1976; Meil & Nautiyal, 1988; Kant & Nautiyal, 1997). The systems analysis is implemented by using LimDep software (Greene, 2002).

2.2.2 Hypothesis testing

The hypotheses of joint estimation of the cost function and the system of input share demands can be tested by the likelihood ratio test. The likelihood ratio (see equation (7)) is equal to double the difference between the logarithmic values of likelihood functions of the unrestricted and the restricted models. This ratio has a χ^2 (chi-square) distribution with degrees of freedom equal to the number of independent restrictions imposed, i.e.:

$$LR=-2\{\ln[L(H0)/L(H1)]\} \quad (7)$$

where L(H0) and L(H1) are the values of the likelihood function under the null and alternative hypotheses, H0 and H1 respectively. The generalized likelihood-ratio statistic is assumed to have asymptotic chi-square distribution (mixed chi-square) if the appropriate null hypothesis, H0, is true.

The generalized log-likelihood ratio test is used to test several hypotheses related to the system of dairy production structure in the marginal zones. The hypotheses attempt to establish whether the translog cost function is a simultaneous system with the input demands in the production structure. The hypotheses test the cross equation parameter restrictions in the share equations by estimating them as a system without the cost equation, and with and without the cross equation equality restrictions. They are joint hypotheses on the validity of the symmetry and parametric constraints across the cost and input demand equations. A chi-square test statistic with good asymptotic properties is conducted to test this hypothesis. The first hypothesis is that the estimation of the input demand system with cross equation equality restrictions is not different from the simultaneous estimation of the translog cost function/input demand system. The second hypothesis is that the estimation of the input demand system *without* cross equation equality restrictions is not different from the simultaneous estimation of the translog cost function/input demand system. And the third hypothesis is that the estimation of the input demand system with *and* without cross equation equality symmetry restrictions is not different. These tests attempted to establish whether dairy technology and input demands are integrated as a system.

2.3 Estimation of input demand and substitution elasticities

The parameter estimates of equation (1) are used to estimate the elasticities related to variable input demands, and the cost function. These elasticity estimates represent the structure of the production system for the dairy farms in the marginal areas. They are policy variables which indicate different impacts that exogenous price variables have within and across input demands. They are evaluated at averages of the S_i and are linear transformations of the β_{ij} parameter estimates of the cost function and input demand shares.

Fuller et al. (1999) have shown that the price elasticities of demand for the inputs can be calculated as:

$$\eta_{ii} = \frac{\beta_{ij}}{S_i} + S_i - 1 \tag{8}$$

$$\eta_{ij} = \frac{\beta_{ij}}{S_j} - S_j \tag{9}$$

where η_{ii} and η_{ij} are own and cross price elasticities respectively. The price elasticities of input demands for dairy production will be computed using the given derivations.

Previously, the elasticity of substitution was used extensively to measure elasticity of substitution between input factors (Binswanger, 1974; Ray, 1982; Kant & Nautiyal, 1997; Fuller et al., 1999; Yanikkaya, 2004). However, it has been argued that it does not explain factor substitution explicitly (Blackorby & Russell, 1989; Christev & Featherstone, 2005). Since it does not provide information about the comparative statics of factor shares, it cannot be interpreted as the marginal rate of substitution. An alternative measure of factor substitution is the Morishima elasticity of substitution (1967). Blackorby and Russell (1989) argue that the MES is an exact measure of curvature or ease of substitution and that it provides complete comparative static information about relative factor shares. It preserves the salient features of the Hicksian concept in the multifactor context. It is therefore a sufficient statistic for assessing the effects of changes in price or quantity ratios on relative factor shares. In addition, the MES is a logarithmic derivative of a quantity ratio with respect to a marginal rate of substitution or a price ratio. According to Blackorby and Russell (1989), the MES can be calculated as $M_{ij} = \varepsilon_{ij} - \varepsilon_{ii}$. In this analysis, the Morishima elasticities will be computed to assess input substitution in dairy production.

2.4 Scale economies in dairy production

Economies of scale are usually defined in terms of the relative increase in output resulting from a proportional increase in all inputs (Christensen & Greene, 1976). However, it is more appropriate to represent scale economies by the relationship between total cost and output along the expansion path, where input prices are constant and costs are minimized at every level of output. A natural way to express the extent of scale economies is as the proportional increase in cost resulting from a small proportional increase in the level of output, or the elasticity of total cost with respect to output. We will define scale economies (SCE) as unity minus this elasticity:

$$\text{SCE} = 1 - \partial \ln C / \partial \ln Y \tag{10}$$

This results in positive numbers for positive scale economies and negative numbers for scale diseconomies. Another way to measure scale economies is by the relation between total variable cost and output along the expansion path (Yanikkaya, 2004). Hence, the elasticity of scale (ε) is measured by the reciprocal of the elasticity of cost with respect to output. Using equation (10), the elasticity of scale can be computed as:

$$\varepsilon = (\partial \ln C / \partial \ln Y)^{-1} = \frac{1}{\alpha_q} \tag{11}$$

where α_q is elasticity of cost with respect to output. Furthermore, SCE has a natural interpretation in percentage terms. Thus, elasticity of scale is the percentage change in total variable cost resulting from a 1% change in output. It is the responsiveness of total variable cost to a 1% change in output. This study will compute scale elasticity for dairy production.

3. Data, variable definition and computation

Stratified random sampling was adopted in this study. Primary data for the study was collected in an intensive farm survey of smallholder dairy producers conducted during June–September 2006 in five dairy cooperative societies in the marginal zones of Machakos and Makueni Districts in Kenya. Five dairy societies were randomly selected for the study from six societies in the region. From each dairy cooperative stratum, a proportionate number of smallholder dairy farmers were randomly selected. In this way, a sample of 285 farmers out of a total of a population of 895 was selected for the study. Next, a structured questionnaire instrument was used for data collection. Information gathered included both quantitative and qualitative data from dairy farms. The variables used to analyze production structure were created from this survey data.

The dependent variable is the natural logarithm of the normalized total variable costs (LNCOST) of milk production for the period July 2005 to June 2006. The normalized total variable cost is the sum of expenditures on concentrates, mineral salts, milking salve, hay, locally purchased feeds (i.e. Napier grass, maize stover and other grasses), tick control, cattle treatment, labor and imputed expenditure on own produced feeds divided by labor wage rate. The independent variables are calculated as follows.

Milk quantity (Q): This is the total annual milk production (liters) produced in the period under study. It is the sum of monthly milk production for one year for each household.

Price of protein feed: This is a natural logarithm of the protein feed price. Protein feeds are dairy inputs purchased from formal markets. To get the price for each, the annual expenditure is divided by the respective annual quantity purchased. The prices are summed to get the price of one bundle of protein feed. This price is normalized by the labor wage rate to get the relative protein feed price. Next, the natural logarithm of the relative protein feed price is the variable for price of protein feeds.

Price of roughage feed: This is a natural logarithm of the roughage feed price. Roughage feeds are hay and locally purchased feeds (i.e. Napier grass, maize stover and grasses). The price for each feed is obtained by dividing the annual expenditure by the annual quantity purchased. The prices are summed to get the price of a bundle of roughage feeds made up of hay and locally purchased feed. This is then normalized by the labor wage rate to get relative roughage feed prices. The natural logarithm of the relative price is then computed as the variable for the price of roughage feeds.

Price of animal treatment: This is a natural logarithm of the normalized average price of animal treatment per year. It is obtained by dividing annual treatment expenditure by the number of treatments per year. This is normalized by the labor wage rate to get the relative price of animal treatment. The natural logarithm is then computed as the variable for the price of animal health treatment.

Price of tick control: This is a natural logarithm of the normalized average price of tick control per year. It is obtained by dividing annual tick control expenditure by the number of tick control administrations per year. This price is normalized by the labor wage rate to get the relative price of tick control. The natural logarithm is then computed as the variable for price of tick control.

Labor wage rate: This is the price of labor per man-hour in each household. It is obtained by dividing annual expenditures on labor by the annual number of man-hours worked per household. The wage rate variable is used to normalize total variable cost and all the independent price variables to get the relative prices of the variable inputs.

Price of own feed: This is a natural logarithm of the imputed normalized price of producing own feeds per year. The imputed expenditure on own feeds is simply how much it would cost the farmer if the feeds produced on the farm were to be purchased from the local markets within the neighborhood. To obtain the imputed price, imputed expenditures are divided by the estimated weight of own produced feed. This price is then normalized by the labor wage rate to get the relative price of own produced feed. The natural logarithm is then computed as the variable for price of own feed.

Area for grazing: Area for dairy grazing is the only fixed input. It is entered as a natural logarithm of the area for dairy grazing.

Input shares: The input shares are calculated by dividing the input expenditures by the total variable costs. The descriptive statistics of the created variables used in this analysis are shown in Table 1.

The average annual total variable cost per cow is Kshs 8,1385.81. The average annual milk output is 4,027.672 liters per household. A bundle of protein feed on average costs Kshs 419.5397 – this is the most expensive feed. The cheapest feed input is the own produced feed, at an average of Kshs 2.4016. The average wage rate is Kshs 7.7010. Labor input has the largest share of all input expenditures – 0.3620 (36.2%). Tick control and animal treatment expenditure shares are the lowest with approximately 3% of total expenditure. Of all the feeds, protein feeds have the lowest share of expenditure (15.85%).[2]

Table 1: Descriptive statistics of production structure variables

	Measuring units	Mean	Std. deviation	Coefficient of variation (%)
Total variable cost	Kenyan shillings (Kshs)	81385.81	129527.2	134.5778
Annual milk production per farm	Liters	4027.672	6079.603	126.1176
Protein feed price	Kshs/bundle of 3 kgs	419.5397	235.1678	56.0538
Roughage feed price	Kshs/bundle of 2 kgs	10.3564	9.2502	89.3187
Animal treatment price	Kshs/case treated	224.2733	328.2663	146.3688
Tick control price	Kshs/administration	294.2185	393.0733	133.5991
Labor rate	Kshs/man-hour	7.7010	2.7996	36.3537
Own feed price	Kshs/kg	2.4016	1.1055	46.0318
Input shares				
Protein feed share	Ratio	0.1585	0.1478	93.2492
Roughage feed share	Ratio	0.2225	0.1720	77.3034
Animal treatment share	Ratio	0.0359	0.0398	110.8635
Tick control share	Ratio	0.0335	0.0299	89.2537
Labor share	Ratio	0.3620	0.1944	53.7017
Own feed share	Ratio	0.2522	0.1873	74.2665

Source: Sample survey of dairy households in the marginal zones of Kenya, June–September, 2006

4. Systems model results

The cost function model consisting of the translog cost function with cross equation restrictions of homogeneity in input prices, symmetry and adding up property was estimated to provide information about input demand. The restriction of linear homogeneity in the input prices is imposed by normalizing cost and the other prices by the labor wage rate (Greene, 2002). In the estimation of the model, the cost share equation for labor is deleted to sustain the linear independence of the remaining equations. The estimated parameters of the system and the associated asymptotic z-values are shown in Table 2. Most of the coefficients of the model are statistically significant and have the expected signs, except for the coefficient for protein feeds, which has a negative sign.

[2] 1 US$ = 75 Kshs at the time of the study.

A well-behaved cost function is concave in the input prices, and its input demand functions are strictly positive. However, the translog cost function does not satisfy these restrictions globally (Berndt & Wood, 1975). The positivity condition is satisfied if the fitted cost shares of all the inputs are positive; this was checked and found to be true for each household, with the exception of a few in roughage and tick control demand functions. The concavity condition is satisfied if the Hessian matrix of the second order partial derivatives is symmetric and negative semi-definite (Varian, 1992). The Hessian is symmetric by assumption (Kant & Nautiyal, 1997). The concavity condition is satisfied if the Hessian matrix of the second order partial derivatives is symmetric and negative semi-definite (Varian, 1992). The Hessian is symmetric by assumption (Kant & Nautiyal, 1997). The parameter estimates of the input share demand equations are equal to those in the cost function-input demand system due to simultaneity. These parameters have little economic meaning of their own (Binswanger, 1974). They are best evaluated by the values they imply for the elasticities of substitution and elasticities of factor demand discussed in Section 4.1 below.

The generalized log-likelihood ratio test was used to test several hypotheses relating to the dairy production structure. The first hypothesis attempted to establish whether the translog cost function was a simultaneous system with the input demands in the production structure. The null hypothesis was that there is no difference between estimating the input demand system with cross equations restrictions and estimating the translog cost/input demand system of equations simultaneously. The null hypothesis was rejected in favor of the translog cost/input demand equations as a simultaneous system of production structure. The second hypothesis specified that estimating the input demand system of equations without the cross equation restrictions was not different from estimating the translog cost/input demand system. This hypothesis was also rejected. The third null hypothesis specified that estimating the input demand system of equations *without* cross equation equality symmetry restrictions was not different from estimating the input demand system of equations *with* cross equation equality symmetry restrictions. This hypothesis was also rejected in favor of imposing symmetry in the input demand system of equations. These results imply that imposing symmetry and cross equation equality restrictions in the input demand system and estimating them simultaneously with the translog cost function is an economically true representation of the production structure of dairy in the marginal zones. It is observed that very large gains in estimation efficiency of the system follow when the cross equation restrictions are imposed. Thus, milk supply, costs and input demands are an integrated simultaneous system of activities in dairy production.

Table 2: Estimated coefficients of the translog cost function

Variable description	Parameters	Parameter	Standard error	|b/St. Er.|	P[|Z|>z] |
Constant	α_0	-38.318488	36.0233	-3.8400	0.0001
Milk output	α_Q	3.717104	8.6980	0.4270	0.6691
Protein feed price	α_P	-0.030767	0.0115	-2.6740	0.0075
Roughage feed price	α_R	0.755854	0.0553	13.6720	0.0000
Animal treatment price	α_H	0.039231	0.0098	3.9880	0.0001

Tick control price	α_T	0.582107	0.0278	20.9730	0.0000
Own feed price	α_O	0.139173	0.0190	7.3140	0.0000
Output*Output	β_{QQ}	3.730359	1.0845	3.4400	0.0006
Protein price*protein price	β_{PP}	0.000161	0.0000	5.5900	0.0000
Roughage price*Roughage price	β_{RR}	0.078409	0.0067	11.7890	0.0000
Treatment price*Treatment price	β_{HH}	0.000032	0.0000	3.0310	0.0024
Tick price*Tick price	β_{TT}	0.000828	0.0001	15.3470	0.0000
Own feed price*Own feed price	β_{OO}	0.000082	0.0001	1.1760	0.2396
Output*Protein price	β_{QP}	0.025507	0.0019	13.3690	0.0000
Output*Roughage feed price	β_{QR}	-0.071647	0.0067	-10.6610	0.0000
Output*Treatment price	β_{QT}	-0.000261	0.0013	-0.2070	0.8358
Output*Tick price	β_{QT}	-0.069282	0.0035	-19.8640	0.0000
Output*Own feed price	β_{QO}	0.012132	0.0029	4.1550	0.0000
Protein price*Roughage feed price	β_{PR}	0.000058	0.0000	1.2470	0.2124
Protein price*Treatment price	β_{PH}	0.000002	0.0000	0.2000	0.8414
Protein price*Tick price	β_{PT}	-0.000007	0.0000	-0.3350	0.7377
Protein price*Own feed price	β_{PO}	-0.000052	0.0000	-1.5930	0.1111
Roughage feed price*Treatment price	β_{RH}	-0.000099	0.0000	-1.9770	0.0481
Roughage feed price*Tick price	β_{RT}	0.001674	0.0001	11.3490	0.0000
Roughage feed price*Own feed price	β_{RO}	-0.000544	0.0001	-6.2980	0.0000
Treatment price*Tick price	β_{HT}	-0.000052	0.0000	-2.9780	0.0029
Treatment price*Own feed price	β_{HO}	0.000022	0.0000	1.4300	0.1526
Tick price*Own feed price	β_{TO}	-0.000266	0.0000	-7.8360	0.0000
Output*Acres	β_{OA}	-0.100364	0.1139	-0.8810	0.3782
Protein feed price*Acres	β_{PA}	0.000059	0.0000	2.1330	0.0329
Roughage feed price*Acres	β_{RA}	0.000058	0.0000	1.3580	0.1745
Treatment price*Acres	β_{HA}	0.000003	0.0000	0.3820	0.7026
Tick price*Acres	β_{TA}	0.000044	0.0000	2.2900	0.0220
Own feed price*Acres	β_{OA}	-0.000071	0.0000	-1.8310	0.0671
Dairy acres	β_A	-1.160007	0.5610	-2.0680	0.0387
Dairy acres*Dairy acres	β_{AA}	1.238200	0.6218	1.9910	0.0465

Source: Sample survey of dairy households in the marginal zones of Kenya, June–September, 2006

4.1 Input demand price elasticities

The parameters of input demand shares have little economic meaning of their own (Binswanger, 1974). However, they are used to determine the variable elasticities of substitution and the factor demand of the inputs. The price elasticities are a function of the input share parameter estimates and the input share variables themselves. The price elasticities for dairy input demands are shown in Table 3. The parameters estimates of own price elasticities of all the six inputs are negative, as they must be in keeping with the a priori theoretical expectations. The t-values of the coefficient estimates are shown in parentheses. These elasticities are statistically significant at 1% level. The own price elasticities are elastic, ranging from -2.328412 for protein feed to -1.151118 for roughage feed. The results imply that increasing the price of any of the dairy inputs by 1% would reduce input use by more than 1%. For example, for a 1% increase in the input prices, farmers reduce protein feeds by 10.27 kilograms per cow, roughage feeds by 16.54 kilograms per cow, labor by 36.38 man-hours per cow per year and own produced feeds by 59.66 kilograms per cow per year. Similar observations are made for tick control and animal treatment if prices increase. These results imply that with input market liberalization farmers are now quite responsive to price changes. Protein feeds have the highest response to a 1% change in the price of the inputs.

The cross price elasticity of all the input demands with respect to protein feed price are negative except for roughage feed and own feed. This means that protein feed and the other inputs other than roughage feed and own produced feed are complements. On the other hand, protein feed-roughage feed and protein feed-own feed are substitutes. However, all the coefficients are insignificant, which means that if the price of protein feed changes it usually has no impact on the use of the other animal feeds on the farm. These results seem to be plausible because protein feeds are usually purchased in small quantities and mixed with prepared Napier grass (either purchased roughage or own feed) and fed to the cows when milking. Therefore, if the price of protein feed goes up by 1%, there is no significant change in demand for the other dairy inputs, most of which are produced on farm.

Table 3: Estimated price elasticities of the translog cost function

Input items:	Protein feed demand	Roughage feed demand	Animal treatment demand	Tick control demand	Labor demand	Own feed demand
Protein feed	**-2.328412*** (0.023576)**	2.502541 (3.599495)	-2.111929 (7.704242)	-4.285899 (4.859472)	-4.318605 (18.898211)	2.850351 (8.870101)
Roughage feed	-2.593648 (3.395439)	**-1.151118*** (0.615729)**	-2.523465 (5.45141)	-1.585368 (8.416966)	-3.807824 (10.19960)	0.151054 (5.104626)
Animal treatment	-4.041275 (7.580561)	-0.494424 (9.071102)	**-1.765213 *** (0.642758)**	3.189816*** (0.011132)	-8.595361 (5.619736)	-3.081924*** (0.009220)
Tick control	-3.760632*** (0.0100265)	-1.202651*** (0.0097723)	3.253751 *** (0.011118)	**-2.208417*** (0.0209993)**	-8.278418*** (0.798226)	-4.084581*** (0.044306)
Labor	-6.071546 (14.576002)	-1.323139 (7.496768)	-1.956414 (4.589133)	-2.851511 (4.589143)	**-2.275161*** (7.334627)**	-4.525273 (5.735175)
Own feed	-3.507752*** (0.048182)	0.706697** (0.311899)	-3.426819*** (0.534294)	-3.472315*** (0.011132)	-4.071378*** (0.0403235)	**-1.714289*** (0.005386)**

Source: Sample survey of dairy households in the marginal zones of Kenya, June–September, 2006
*** Significance at 1% level
** Significance at 5% level

The cross price elasticity of the input demands with respect to roughage feed price is negative for protein feed, animal treatment, tick control and labor demand. They are thus complements. Usually, roughage feed once purchased in the neighborhood requires labor to gather, collect and store on the farms. Also, the high incidence of ticks in the marginal areas means that roughage feeds, which are usually grasses or maize stover, tend to harbor ticks, so the demand for tick control and animal treatment increases. However, roughage and own produced feeds are substitutes. But the coefficient is insignificant.

The cross price elasticity of input demands with respect to treatment price is negative except for tick control. This implies that animal treatment complements all the other dairy inputs in production. However, the results indicate that animal treatment and tick control are significant substitutes. This is an unexpected result and the only possible explanation for this is that when the price of animal treatment increases, management of tick control is intensified. This protects the cows from diseases that are mostly caused by ticks, such as East Coast fever (theileriosis). As health costs increase, farmers concentrate more on preventing tick-borne diseases. Hence they are substitutes. The cross-price elasticities of input demands with respect to tick control price are all negative except for animal treatment. Thus tick control and the other inputs are complements, but substitutes of treatment, as explained previously. The price elasticities of input demands with respect to labor are negative and insignificant for all the cases. Thus, labor and the other inputs are insignificant complements.

Own produced feed and roughage feed are substitutes. Both of them are roughages but from different sources: own feeds are produced on the farm whereas roughage feeds are purchased from informal markets. The elasticity coefficient is significant at the 5% level. On the other hand own produced feeds and the other dairy inputs are complements. Own produced feeds are mixed with protein feeds and fed to cows when milking. The greater the demand for own produced feeds, the higher the demand for labor. The demand for own produced feeds and the health of dairy cows also go together.

4.2 Elasticity of dairy input substitution

The elasticities of substitution vary with input share levels. Hence, they are calculated at the mean level of input shares. The Morishima elasticities of substitution (MES) are presented in Table 4. The MES measures the percentage change in the ratio of a pair of factors with respect to a change in the ratio of their respective prices. It can be observed that the Morishima elasticities are asymmetric. Most of the variable price input elasticity coefficients are negative. Hence they are Morishima complements. However, protein feed-roughage feed, protein feed-own feed, roughage feed-own feed and animal treatment-tick control are Morishima substitutes. In the current dairy production structure, all the Morishima elasticity coefficients are elastic.

The results seem to indicate that if the price of protein feeds goes up, farmers turn to purchasing roughage feeds (mostly Napier grass, which is usually used when milking) and using own feeds. Thus, if there is a 1% change in the ratio of roughage-protein feed prices, the roughage-protein quantity ratio responds by 3.65%. If the price change is the result of an increase in the protein feed price, then more roughage is substituted for protein feed. Thus, if the price of protein feeds increases, the change in percentage ratio of the inputs leads to more use of roughage and own produced feed in the feed mix. The Morishima elasticity coefficients seem to augment the price elasticity coefficients, where a 1% increase in the price of protein feeds causes a 2.5% increase in roughage feeds and 2.85% increase in own produced feeds. However, a 1% increase in the price of roughage and own produced feeds causes protein feeds to decrease by -2.59% and -3.51% respectively. These values indicate that in the existing dairy technology it is easy for roughage feeds and own produced feed to substitute for protein feeds. On the other hand, protein feeds seem to be purchased to complement roughage feeds and own produced feeds. This result seems plausible in the light of the current production structure which is based on own produced feeds and informal market feed sources with relatively little dependence on formal market feeds.

Table 4: Morishima elasticities of substitution between inputs

Input demand for:	Protein feed	Roughage feed	Animal treatment	Tick control	Labor	Own feed
Protein	0.000000	3.653660	-2.416174	-4.144257	-2.043444	4.564641
		(3.403474)	(5.997019)	(9.76605)	(2.171492)	(12.08077)
Roughage	-2.627246	0.000000	-2.827709	-1.443726	-1.532663	1.208730
	(4.2869678)		(9.0245)	(6.45409)	(8.546130)	(2.22717)
Animal treatment	-3.744766	-1.697811	0.000000	3.331458	-6.320201	-1.367634
	(7.584213)	(9.99510)		(6.45409)	(6.580149)	(3.729386)
Tick control	-2.897893	-2.406037	-3.491221	0.000000	-6.003257	-2.370291
	(9.669783)	(3.403474)	(4.085834)		(7.456149)	(3.729386)
Labor	-2.452006	-0.496689	-3.731063	-7.347838	0.000000	-2.810983
	(2.35619)	(9.99510)	(4.085834)	(8.45409)		(3.735649)
Own feed	-3.374905	-5.85186	-2.306262	-2.709868	-1.796217	0.000000
	(8.252961)	(5.38439)	(4.093386)	(4.607802)	(6.342800)	

Source: Sample survey of dairy households in the marginal zones of Kenya, June–September, 2006

The results of this study of the dairy production structure in Kenya are seemingly different from those of a study on farm level feed demand in Turkey (Fuller et al., 1999), although the two country's production and animal feeding technologies and the feeds they use are of course different in the two countries. In the marginal zones of Kenya, the own-price elasticities are quite elastic, whereas in Turkey the feed prices are inelastic. In Kenya, farmers mostly depend on own produced feeds or purchase roughage feeds from informal markets supplemented by relatively small amounts of protein feeds purchased from the formal input markets. The protein feed price is therefore relatively elastic. In Turkey, however, farmers depend on formal feed markets for their dairy production. For Turkish dairy producers, therefore, the own-price elasticity of formula feeds (i.e. protein feeds) demand is the most inelastic. This is not surprising, because formula feeds contain the highest levels and the best balance of protein and energy (Fuller et al., 1999). Turkish dairy producers rely on formula feeds to provide a substantial portion of the animal's daily nutritional requirements, supplementing formula feeds with less expensive grain, oilseed meals and by-product feeds. Forages account for 55% of dairy cattle rations and formula feeds 45%. Thus, dairy producers in Turkey feed significantly more protein feeds than Kenyan farmers do. Their price elasticities for dairy inputs are inelastic. The Morishima elasticities of substitution indicate that formula feed is easily substituted by forage, by-product meal and grain. But it is harder for formula feed to substitute for forage, by-product meal and grain. On the other hand, protein feeds are purchased mostly to complement roughage feeds and own produced feeds and not as a substitute in Kenya.

4.3 Scale economies in dairy production

As mentioned in Section 2.4 above, Christensen and Greene (1976) defined scale economies (SCE) as unity minus elasticity of cost with respect to output i.e. SCE=1-$\partial \ln C / \partial \ln Y$. Another way to measure scale economies is by the relation between total variable cost and output along the expansion path (Yanikkaya, 2004). Hence, the elasticity of scale (ε) is measured by the reciprocal of the elasticity of cost with respect to output i.e. $\varepsilon = (\partial \ln C / \partial \ln Y)^{-1} = 1/\alpha_q$ where α_q is elasticity of cost with respect to output. In the estimated translog cost function/input demand systems in Table 2, the coefficient of milk output (α_o) is 3.717104 (i.e. $\partial \ln C / \partial \ln Y$=3.717104). Therefore, the scale economy (SCE) is -2.717104 (i.e. 1- 3.717104=-2.717104). The SCE is negative, which implies scale diseconomies in dairy production. These scale economies measure the relative changes in output when expenses change but input prices are held constant. This is a reciprocal of the cost elasticity with respect to output. Therefore, the scale economy for milk production in the marginal zones is 0.269 (i.e.1/3.717104). The existing literature does not have similar reports of studies in livestock which can be used to compare this finding. But in other sectors of the economy, particularly in the developed countries, studies indicate scale economies of 2.4 in forestry logging in Canada (Kant & Nautiyal, 1997) and 0.79 in a study on import demand for the US (Yanikkaya, 2004). The scale economy factor of 0.269 means that every 1% increase in milk output would lead to an increase in variable costs by 0.269%, since milk production is experiencing scale diseconomies (i.e. as milk output increases, costs are increasing but at a decreasing rate).

5. Conclusions and policy implications

The purpose of this study was to determine the existing structure of dairy production in the marginal zones of Kenya, using the translog approximation to the cost function. Neoclassical duality results were extensively used for this purpose. Given the liberalized market structure of the dairy sector in Kenya, this is quite appropriate. The analyses used cross-sectional survey data collected for the period July 2005 to June 2006. The translog cost function was estimated jointly with the dairy input demand equations by using Zellner's (1962) systems analysis of a seemingly unrelated regression method which provides asymptotically more efficient estimates than the production function estimates given by the principle of OLS. This method was implemented by using LimDep (Greene, 2002). Various hypotheses were tested to establish whether the dairy production structure attested to the assumptions of restrictions across the translog cost function and the system of input demands according to theoretical underpinnings.

The results showed that the symmetry restrictions cannot be rejected. It also emerged that estimating cross equation equality restrictions in the input demand system simultaneously with the translog cost function was an economically true representation of the production structure of dairy in the marginal zones. It was therefore concluded that the cost of production and input demands is an integrated simultaneous system of activities in dairy production. Estimation of price elasticities of factor demands and the elasticities of substitution between inputs showed that all feed price elasticities are elastic. The uptake of protein feeds versus roughages and own produced feeds was of central importance in this study. It showed that farmers find it easier to substitute protein feeds, which are of high quality, with roughage feeds and own produced feed, which are usually of poor quality. It was also observed that farmers purchased protein feeds as significant complements to roughage and own produced feeds. These findings led to the conclusion that with the rising prices of protein feeds the dairy farmers would be more likely to purchase less protein feed and to use more roughage feeds and own produced feeds. In addition, farmers seem to purchase small quantities of protein feeds just to supplement roughage and own produced feeds.

The results of scale economies showed that dairy production experiences scale diseconomies. It was further established that the scale economy factor is 0.269, which implies that every 1% increase in milk output would lead to an increase in variable costs by 0.269%, since dairy production is experiencing scale diseconomies in the marginal zones. It was therefore concluded that one of the things that hinders the expansion of dairy production in the marginal zones is the seemingly low uptake of protein feeds and the increasing costs of production. On the basis of the above conclusions, several policy implications can be drawn.

The protein feeds are the most expensive of all the feeds. They are also used by relatively few farmers, particularly the concentrates, compared to the other feeds, and they are used in the lowest quantities in production. Concentrates contain the highest levels and the best balance of protein and energy feed for dairy cows. Yet, on average, a cow is given 1.16 kilograms of concentrates per day (i.e. 423.53/365). The high prices of protein feeds seem to militate against their substantial use in dairy production. The result is that protein feeds are substituted by roughage feeds, or used in relatively small quantities to supplement own produced feeds. This finding seems to imply that there is need to rationalize the animal feed markets as well as the quality of animal feed and to remove the constraints which result in high prices. The goal would be to make animal feeds affordable to farmers. There is therefore need to study and determine the efficiency of animal feed markets in Kenya. The findings could shed some light on how these markets and the prices operate. This would determine the kind of policy that could be used to intervene in the industry in order to enhance its operations and ultimately expand the dairy sector.

Another area of interest is the production of protein feeds and balancing protein needs with roughage consumption. In the marginal zones, relatively little research has been done on dairy feeds and especially protein feed production and how to balance the various nutrient requirements for the dairy cows. There is therefore need for extension and research on this topic. Some production scientists believe that this alone could double production (personal communication, Bill Wailes, Head of Department, Department of Animal Sciences. Colorado State University, 2007). On the farm level, it might be necessary to create two simultaneous extension programs to teach farmers how to grow high protein feeds suitable to the marginal zones, and to encourage dairy producers to use these feeds.

The dairy production system in the marginal zones is experiencing scale diseconomies. Thus, dairy farmers are facing increasing costs of production. Constraints in some of the institutional and socioeconomic factors result in high cost inefficiencies (Kavoi, 2007) which translate into increased costs of production. To mitigate the current situation of increasing costs of production facing farmers, interventions are needed in areas where there are imperfect markets and information asymmetries and where the necessary production inputs are in the form of public goods (Kavoi, 2007). Therefore, improvements in farm gate terms of trade and supply response means that there must be an increase in public expenditure on rural road infrastructure, water supply, extension education, credit services, farm record keeping services and other agricultural support services that are not provided in the marketplace. Policy interventions should focus on creating the institutional and socioeconomic frameworks necessary for reducing transaction and production costs and increasing access to production resources and markets for smallholder farmers in the marginal areas.

References

Berndt, ER & Wood, DO, 1975. Technology, prices, and the derived demand for energy. Review of Economics and Statistics 57(3), 259–67.

Binswanger, HP, 1974. A cost function approach to the measurement of factor demand and elasticities of substitution. American Journal of Agricultural Economics 56, 377–86.

Blackorby, C & Russell, H, 1989. Will the real elasticity of substitution please stand up? (A comparison of the Allen/Uzawa and Morishima elasticities). American Economic Review 79(4), 882–8.

Christensen, LR & Greene, WH, 1976. Economies of scale in US electric power generation. Journal of Political Economy 84(4), 655–75.

Christensen, LR, Jorgensen, DW & Lau, LJ, 1971. Conjugate duality and the transcendental logarithmic production function. Econometrica 39, 255–6.

Christensen, LR, Jorgensen, DW & Lau, LJ, 1973. Transcendental logarithmic production frontiers. Review of Economics and Statistics 55, 28–45.

Christev, A & Featherstone, A, 2005. A note on Allen-Uzawa partial elasticities of substitution: The case of the translog cost function. School of Management and Languages, Centre for Economic Reform & Transformation, School of Management & Languages, Heriot-Watt University. Edinburgh, United Kingdom. Discussion paper series in economics, DP2004-E07.

Conelly, WT, 1998. Colonial era livestock development policy: Introduction of improved dairy cattle in high potential farming areas of Kenya. World Development 26, 1733–48.

Fuller, F, Koç, AA, Şengül, H & Bayaner, A, 1999. Farm level feed demand in Turkey. Working Paper 99-WP, 226. Center for Agricultural and Rural Development, Iowa State University, Ames.

GoK (Government of Kenya), 2000. Second report on poverty in Kenya: Volume II, poverty and social indicators. Government Printer, Nairobi.

GoK (Government of Kenya), 2002. Machakos District Development Plan 2002–2008. Government Printer, Nairobi, Kenya.

Greene, WH, 2002, Limdep Version 8.0: Econometric Modeling Guide. Econometric software, Inc, Plainview, New York.

Kant, S & Nautiyal, JC, 1997. Production structure, factor substitution, technical change, and total factor productivity in the Canadian logging industry. Canadian Journal of Forest Research 27, 701–10.

Kavoi, MM, 2007. Economic performance of smallholder exotic dairy cattle in the marginal zones of Kenya. Unpublished PhD dissertation. Colorado State University, Fort Collins, CO.

Kimenye, D & Russell, WS, 1975. Comparison of Ayrshire x Sahiwal cows with high grade Ayrshires in Kenya. East African Agricultural and Forestry Journal 40, 416–21.

Mbithi, LM & Huylenbroeck., GV, 1999. Agricultural policy and maize production in Kenya. PhD dissertation, Applied Biological Sciences, Section Agriculture, Ghent University, Belgium.

Meil, JK & Nautiyal, JC, 1988. An intraregional economic analysis of production structure and factor demand in major Canadian softwood lumber producing regions. Canadian Journal of Forest Research 18, 1036–48.

Meyn, K & Wilkins, JV, 1973. National cattle breeding programmes in Kenya. Proceedings of the Third World Conference on Animal Production, Melbourne, Australia, Vol. 5(e), 9–10.

Morishima, M, 1967. A few suggestions on the theory of elasticity (in Japanese), Keizai Hyoron (Economic Review) 16,144–50.

Nicholson, CF, Philip, KT & Mungai, RW, 2004. Household-level impacts of dairy cow ownership in coastal Kenya. Journal of Agricultural Economics 55 (2), 175–95.

Omore, A, Muriuki, H, Kinyanjui, M, Owango, M & Staal, S, 1999. The Kenya dairy sub-sector: A rapid appraisal. Smallholder dairy, research & development project report. MoARD/KARI/ILRI, Nairobi. Kenya

Ray, SC, 1982. A translog cost function analysis of US agriculture, 1939–77. American Journal of Agricultural Economics 64(3), 490–98.

Staal, SJ, 2002. The competitiveness of smallholder dairy production: Evidence from sub-Saharan Africa, Asia and Latin America. In Rangnekar, D & Thorpe, W (Eds), Smallholder dairy production and marketing opportunities and constraints. Proceedings of a South-South workshop held at National Dairy Development Board, Anand, India, 13–16 March 2001. NDDB, Anand, India, and ILRI (International Livestock Research Institute), Nairobi. Kenya.

Varian, HR, 1992. Microeconomic analysis. WW Norton, New York.

Winrock International, 1992. Assessment of animal agriculture in sub-Saharan Africa. Winrock International Institute for Agricultural Development, Morilton, Arkansas, US.

Yanikkaya, H, 2004. Import demand for the United States: A translog cost function analysis. Akdeniz İ.İ. Dergisi, BF 7, 145–55.

Zellner, A, 1962. An efficient method for estimating seemingly unrelated regressions and tests for aggregation bias. Journal of American Statistical Association 57, 348–68.