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Smallholder production structure and rural roads in Africa: the case of Nakuru District, Kenya

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Abstract

Data from a 1998 survey of farming households in Kenya is used to estimate the effects of poor rural road infrastructure (and high market access costs) on the structure of smallholder farm production. Simultaneous estimation of cost and input share equations reveals rational responses by farmers to high access costs. In the expected continued absence of major investments in rural infrastructure in countries such as Kenya, the policy challenge is to identify and catalyse institutional innovations that reduce a range of transaction costs, increase financial liquidity, increase social capital, and reduce risk.
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1. Introduction

Rural roads across Africa are inadequate in coverage and quality; they are also usually poorly maintained, and therefore poorly served by low-cost, high-volume transportation providers (Pederson, 2000; Riverson and Carapetis, 1991). The impacts of the resultant high transportation costs are not difficult to imagine: high farm gate input costs; low farm gate output prices; low traded volumes; volatile markets; low productivity. Rigorous microeconomic analyses of these impacts are few (Goetz, 1992, 1993; Jayne, 1994; Njehia, 1994; Omamo, 1998b). To our knowledge, no attempt has been made to estimate the effects of poor rural road infrastructure (and high market access costs) on the structure of smallholder farm production in Africa.[1] This paper aims to fill that gap using data from a 1998 survey of farming households in Kenya. We estimate a translog cost function incorporating three production enterprises and four production factors. A key feature of the estimated model is a farmer-specific 'access cost' variable through which a range of farm-level effects of the extant road infrastructure can be traced. Simultaneous estimation of cost and input share equations reveals rational responses by farmers to high access costs. Implications for policy centre on a range of cost-reducing investments in rural markets.

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[1] Omamo (1998b) uses a numerical simulation to explore this question. The current paper builds on several insights developed in that study.

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2. Data setting, review and description

The study area lies within one of Kenya's higher potential agricultural areas, as measured by rainfall and soil type (Jaetzold and Schmidt, 1983). A range of food crops (e.g. maize and potatoes) and cash crops (e.g. pyrethrum and various horticultural commodities in relatively small scale) are grown. The road infrastructure in the area is generally poor. Paved roads are few and concentrated around rural townships. Unpaved roads and pathways are the norm. During rainy periods—which, coincide with the most active period in the agricultural calendar—most of these roads and paths are scarcely passable. Transportation of goods in the area is by head loading, donkeys and donkey drawn carts, bicycles, tractors, trucks and by *matatus*.[2] Head loading and *matatus* are the most frequently used modes (Obare, 2000).

The data come from a cross-sectional survey conducted on a sample of smallholder farmers in Nakuru District, Kenya, during the 1997–1998 cropping year. The sampled households were randomly selected from eight clusters within the five divisions in the district, namely: Molo, Njoro, Elburgon, Mau-Narok and Keringet.[3] The cluster sites are within the upper highland (UH2) agro-ecological zone otherwise called the wheat pyrethrum. Thus, the sites have similar agro-climatic conditions. However, they are characterised by dissimilar road infrastructure endowments and physical distances from trading and administrative centres.

Production data focused on maize and potatoes—the two most important staple crops in the area. Of the 227 farmers sampled, 213 were engaged in the cultivation of maize and potatoes. Maize production was undertaken in either pure or mixed stands. The survey revealed that the two maize production enterprises were mutually exclusive; farmers grew maize either in pure or in mixed stands. There was variation in the sample farmers' resource use and market access profiles (Table 1). The average shares of cropped land devoted to the maize enterprises were 51 and 65% for pure and mixed stands, respectively. Potato cultivation, with an average cropped land share of 25%, was undertaken entirely in pure stand.

Information that was extracted for this study focused on land, fertiliser, machinery and labour as the major resource constraints in crop production. This was augmented by information on road infrastructure endowments as this was also considered a major binding constraint to market accessibility.

Family and hired labour use across crop enterprises was widespread, although the average labour engagement varies from crop to crop. Total labour requirements varied between 184 and 280 man-hours (mh) per acre depending on the crop with a mean sample aggregate of about 220 man-hours per acre.

Fertiliser use in crop production was common. Over 90% (78%) of the farmers used fertiliser in maize (potatoes). Fertiliser application intensity was between 39 and 69 kg per acre, which is within the recommend rate for maize but below the 208 kg per acre for potato production (KARI, 1998; Ministry of Agriculture, 1986; Jaetzold and Schmidt, 1983).

About 4% of the farmers owned tractors and tractor implements. Nevertheless, most of the farmers relied on hired tractors from neighbouring large-scale farm operators or from the 'Tractor Hire Service'—a service provided by the Ministry of Agriculture's Farm Machinery Division—for land preparation, while other farming operations are done manually. The average machinery engagement in farm production was about 1.3 tractor hours per acre. Agro-chemical use was limited to a few farmers engaged in potato production.

The required operational variables were: total production costs (C), input cost shares for the respective crops (S_i), input prices and the road infrastructure variable. The descriptive statistics for the explanatory variables are presented in Table 2.

The total expenditure on labour (C_L), both family and hired, was determined as the product of the number of days, the number of man-hours employed per day, and the hourly wage rate (w_L). There is an active labour market in the region. The underlying assumption in the valuation of family labour was the opportunity cost of not working on the family farm. This cost was considered equivalent to the wage that would have been earned by working on farms other than one's own. The daily wage rate was taken to be

[2] *Matatu* is a term used to describe a form of transport widely used in Kenya where small omnibuses and vans are used to ferry both people and goods to and from various urban centres. Unlike buses, these type of vehicles ply almost all areas within the country.

[3] Divisions are administrative units that together comprise a district.

Table 1
Mean factor use and access cost profiles

Resource/access cost	Crop enterprise				Mean aggregate
	Maize (pure stand)	Maize (inter-crop)	Potatoes	Pasture	
Cropland share (%)	50.35 (32.29)	64.75 (41.81)	24.40 (18.23)	1.53 (2.26)	71.67 (15.86)
Labour (mh per acre)	276.18 (182.23)	184.39 (91.46)	280.83 (171.48)		219.75 (127.84)
Fertiliser (kg per acre)	51.3 (47.4)	39.1 (21.5)	59.6 (39.8)		41.04 (31.67)
Machinery (th per acre)	1.29 (0.78)	1.29 (0.78)	0.91 (0.61)		1.26 (1.05)
Access cost (Ksh)	349.13 (503.41)	578.39 (819.97	466.79 (704.30)		208 (706.93)

Figures in parenthesis are standard deviations; th, tractor-hour; mh, man-hour; Ksh, Kenya Shiling. *Source*: unpublished survey data partially reported in Obare (2000).

Table 2
Descriptive statistics for explanatory variables

Variable	Maize (pure stand)		Maize (mixed stand)		Potatoes	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
G	354.64	508.07	565.56	818.80	470.43	735.04
S_A	0.22	0.08	0.28	0.09	0.14	0.07
S_F	0.15	0.07	0.13	0.07	0.11	0.06
S_M	0.14	0.07	0.11	0.04	0.08	0.03
S_L	0.42	0.13	0.34	0.12	0.27	0.11
w_A	1688.00	389.71	2186.05	491.38	1890.91	512.27
w_F	26.23	2.19	26.68	5.30	26.07	1.76
w_M	1000.84	509.86	876.84	329.57	989.26	361.24
w_L	14.14	2.19	15.88	2.92	14.74	2.48
Y	2128.96	2159.36	3111.86	2579.56	3854.15	6557.23
C	13544.92	13909.53	18309.89	12416.06	10133.08	6335.41

S.D., Standard deviation; L, labour; F, fertiliser; M, machinery; A, land; w, factor price; S, cost share; G, access cost; Y, physical output; C, total production cost.

the actual cash paid by farmers to hired labour per man day of work done.

Almost all farmers in the sample used fertiliser. Fertiliser was acquired from stockists spread over various urban centres and regional markets. Expenditure on fertiliser (C_F) was determined as the product of the quantity of fertiliser used during the production period and the unit market price (w_F). The unit fertiliser price was the actual price paid by farmers to the stockists at point of sale. Machinery expenditure (C_M) was obtained as the product of the tractor rental price (w_M) and the acreage under a crop enterprise on which tractor operations were carried out.

Land rental market in the study area is very active with many farmers reporting recent experience of having rented or leased land. The rental price per acre was taken to be the price (opportunity cost) of land (w_A). The total land cost (AC) is obtained as the product of rental value per acre and the crop area.

Access cost (G) is as defined by Obare (2000), who calculates this as a composite of the physical distance, the travel time and the transport fare. It was calculated as the sum of cost of the time less the cost that would have been incurred by a farmer to cover a kilometre—and time taken to cover that distance under the existing road and transport infrastructure by using a *matatu*, and the actual cost of transport paid.[4] This variable combines the space and time utility of the road and transport infrastructure and, thus, is a good

[4] For example, assume t_b is the time it takes an individual farmer to get to the bus stop from a homestead located at a distance d_b; t_m, the time reach the market from the bus-stop; d_m, distance to the market from the bus stop; and c_m, the *matatu* transportation cost. The cost per unit of time of using a *matatu* will be (c_m/t_m), while the unit distance cost will be (c_m/d_m). Consequently, the homestead-bus stop distance equivalent would be $[[(t_b/t_m)d_m] \times (c_m/d_m)$, or $[(t_b/t_m)c_m]$. Thus, the total cost for the journey (to and from the market) is equal to $2[((t_b/t_m) \times c_m)+c_m]$.

measure of the existing state of road and transport infrastructure.

The mean access cost varied between approximately 350 Ksh to about 580 Ksh/km (Table 1). The mean aggregate access cost for the sample farmers was 208 Ksh/km, which was equivalent to roughly US$ 3.5.

3. The model

Because of its overall flexibility and limited a priori restrictions on substitution possibilities and scale economies, a translog cost function was selected for the estimation. In general form, the translog cost function for the four inputs, land (A), fertiliser (F), machinery (M) and labour (L), augmented by an access cost variable (G) can be expressed as

$$\begin{aligned}\ln C(w, Y, G) &= \alpha_0 + \sum_i \alpha_i \ln w_i + \frac{1}{2}\sum_i\sum_j \alpha_{ij} \ln w_i \ln w_j \\ &\quad + \sum_i \beta_{iY} \ln w_i \ln Y + \varphi_Y \ln Y \\ &\quad + \frac{1}{2}\varphi_{YY} \ln Y^2 \sum_i \gamma_{iG} \ln w_i \ln G \\ &\quad + \psi_G \ln G + \phi_{YG} \ln Y \ln G \\ i, j &= \mathrm{A, F, M, L} \end{aligned} \tag{1}$$

where C is the total cost of production, Y the physical output, w_i are factor prices, and α, β, φ, γ, ψ and ϕ are coefficients such that $\alpha_{ij} = \alpha_{ji}$ (a direct consequence of cost minimisation behaviour of producers).

Differentiating Eq. (1) with respect to input prices yields Shephard's lemma

$$\frac{\partial \ln C}{\partial \ln w_i} = \frac{w_i x_i}{C_i} = S_i, \quad i = \mathrm{A, F, M, L} \tag{2}$$

where S_i signifies the cost share of the ith input factor. Consequently, the translog cost function yields a cost share equation as follows:

$$\begin{aligned} S_i &= \alpha_i + \sum_i a_{ij} \ln w_j + \beta_{iY} \ln Y + \gamma_{iG} \ln G, \\ i, j &= \mathrm{A, F, M, L} \end{aligned} \tag{3}$$

The translog cost function would be homogeneous if the elasticity of cost with respect to output is constant. Moreover, the homotheticity and the homogeneity properties of the specified translog cost function can be explored. The required restriction for the translog function being homothetic is $\sum \beta_{iY} = 0$, whereas the requirements for homogeneity of the function are $\sum \beta_{iY} = 0$ and $\varphi_{YY} = 0$. These restrictions can be statistically tested. Furthermore, resource substitution and road infrastructure effects on crop production structure can be analysed.

Allen elasticities of substitution (AES) and Morishima elasticities of substitution (MES) can be used to examine smallholder agricultural production structures (e.g. Dalton et al., 1997).[5] AES do not indicate the curvature or ease of substitution (Blackorby and Russell, 1989). They are single input/single price elasticities obtained from a derived demand function. They do not relate the optimal input ratios to those of input price and thus they cannot provide information on the relative input responsiveness to changes in input prices. In contrast, the MES preserve the salient features of the Hicksian concept in the multifactor context and measure the ease of substitution. Therefore, the MES is a sufficient statistic for assessing the effects of changes in the price or quantity ratios on relative factor shares.

Following Feltenstein and Ha (1995), once the translog cost function in Eq. (1) has been specified and the cost and factor share equations have been estimated, the effect of road infrastructure on agricultural production structure can be analysed. The cost elasticity with respect to road infrastructure (η_{CG}), is computed as follows:

$$\begin{aligned}\eta_{CG} &= \frac{\partial \ln(C, Y, G)}{\partial \ln G} \\ &= \psi_G + \sum_{i=1} \gamma_{iG} \ln w_i + \phi_{YG} \ln Y \end{aligned} \tag{4}$$

[5] Given Eq. (1), Allen partial elasticities of substitution (σ) are calculated as: $\sigma_{ij} = 1/s_i s_j(\alpha_{ij} + 1)$, and $\sigma_{ii} = 1/s_i^2(\alpha_{ii} + s_i^2 - s_i)$, i, j = A, F, M, L. The respective price elasticities of demand for the input factors (ε), are $\varepsilon_{ij} = S_j\sigma_{ij}$ and $\varepsilon_{ii} = S_i\sigma_{ii}$, where ε_{ij} and ε_{ii} are cross and own price elasticity of demand, respectively. The Morishima cross price elasticities of substitution between factors i and j and vice versa, respectively, are determined as $M_{ij} = \varepsilon_{ij} - \varepsilon_{ii}$ and $M_{ji} = \varepsilon_{ij} - \varepsilon_{jj}$.

where η_{CG} measures the productivity effect of road infrastructure via adjustments in factor demands. The factor adjustment effect is measured by the elasticity of factor shares with respect to infrastructure, $\partial S_i/\partial \ln G$, which is equivalent to the parameter γ_{iG} of the cost share equations. The elasticity of demand for inputs with respect to road infrastructure is given as

$$\eta_{iG} = \frac{\partial(\ln x_i)}{\partial(\ln G)} = \frac{\gamma_{iG}}{S_i} + \eta_{CG} \quad (5)$$

for all i; $i \neq j$.

The value of η_{iG} obtained from (5) can be positive or negative depending on whether poorer road infrastructure leads, respectively, to increased or decreased demand for the ith input in crop production.

Making confident inferences about the effects of road and transport infrastructure on smallholder production structure will depend on the estimation procedure adopted. It is possible to estimate the parameters of the translog cost function using ordinary least squares (OLS). However, OLS estimation will yield inefficient results because of the imposed restrictions ($\alpha_{ij} = \alpha_{ji}$) and the correlation of the error terms across the system of equations (Zellner, 1962). Furthermore, joint information contained in the cost share equations will be lost if a single equation estimation method is used.

The procedure in this paper is to estimate the cost function and the cost share equations jointly as a multivariate regression system. The inclusion of the cost share equations in the estimation yields more degrees of freedom and efficient parameter estimates without additional unrestricted coefficients (Kant and Nautiyal, 1997).

Additive disturbances are assumed for the cost function as well as for each of the cost share equations. The error in each equation is homoscedastic and non-autocorrelated but, again, there is non-zero correlation between contemporaneous error terms across equations.

Given the cost share constraint and the parameters of $n - 1$ equations for the cost shares, the parameters of the remaining nth equation can be determined.[6] The iterative Zellner procedure, a computationally efficient method for obtaining estimates under contemporaneous correlation (Judge et al., 1988; Christensen and Greene, 1976), was used to estimate the parameters of the system equations.

4. Results and discussion

First, the homothetic and homogenous models are compared with the unrestricted model. The likelihood ratio, the calculated and the critical χ^2 for the three models are presented in Table 3. Homotheticity and homogeneity cannot be rejected at normal significance levels. Hence, the homogenous cost function is taken to represent the crop production structure of the sampled farmers. Non-negativity, symmetry, and concavity conditions are satisfied. The concavity condition is especially meaningful because it indicates that observed input choices are consistent with cost minimisation.

The estimated parameters of the homogenous cost function are presented in Table 4. The results show that two out of six coefficients of both the potato and pure stand maize cost share functions respectively, and five out of six coefficients from the potato cost share functions are significant. This is a relatively 'reliable' result considering that the $\sum \alpha_{ij} = 0$ restriction was imposed. Furthermore, the coefficients of the road infrastructure effect on output, ϕ_{YG}, are significant for the potato and intercropped maize cost functions. This has a bearing on the reliability of the factor adjustment and input elasticity of demand. The road infrastructure effect on production cost (ψ_G) is not significant in any of the three cost functions. This is possibly because road infrastructure has minimal direct effect on production costs.

The elasticities of substitution were calculated at the mean levels of input shares as they vary with input share levels. The Allen and Morishima elasticities of substitution are presented in Table 5. The AES between all combinations of inputs (land and fertiliser, land and machinery, land and labour, fertiliser and machinery, fertiliser and labour, and machinery and labour) are positive. This implies that land, fertiliser, machinery and labour substitute each other in crop production.

The highest degree of substitutability is in response to price changes between labour and land, and fertiliser and labour. This result suggests that lower relative

[6] Due to the homogeneity restriction only $n - 1$ equations are linearly independent.

Table 3
Model, restrictions, log-likelihood ratio, calculated and critical χ^2 for unrestricted and restricted cost functions

Model	Number of restrictions	log-likelihood ratio	Calculated χ^2	Critical χ^2 (5% significance)
Maize (pure stand)				
Unrestricted		485.15		
Homothetic	3	447.24	3.20	7.89
Homogenous	4	446.9	3.25	9.49
Maize (mixed stand)				
Unrestricted		315.75		
Homothetic	3	299.21	7.01	7.89
Homogeneous	4	296.78	5.65	9.49
Potatoes				
Unrestricted		651.46		
Homothetic	3	622.35	6.29	7.89
Homogenous	4	619.25	5.58	9.49

Table 4
The translog cost function coefficient estimates for input price and output variables

Parameter	Crop		
	Maize (pure stand)	Maize (mixed stand)	Potatoes
α_0	−4.7243 (0.385)	−2.7538 (−0.151)	0.8029 (0.086)
α_A	1.8226 (0.736)	1.2778 (−0.364)	1.397 (0.767)
α_F	0.0672 (0.446)	0.0831 (0.342)	0.1129 (0.423)
α_M	0.0726 ((1.902)*	−0.0099 (−0.119)	0.0208 (0.307)
α_L	0.9664 (−0.388)	2.2046 (0.623)	0.5306 (−0.295)
α_{AA}	–	–	–
α_{FF}	0.00036 (0.414)	0.00058 (0.421)	0.0006 (0.418)
α_{MM}	−0.00037 (1.637)	−0.0001 (−0.213)	0.0001 (0.264)
α_{LL}	−0.00094 (−0.798)	−0.1505 (−2.59)**	−0.0149 (−0.226)
α_{AF}	−0.00092 (−0.623)	−0.0034 (−1.62)	0.00079 (0.64)
α_{AM}	−0.0016 (−1.933)*	−0.0044 (−2.039)**	−0.00099 (−1.819)*
α_{AL}	0.00072 (0.310)	0.1374 (2.505)**	0.015 (0.234)
α_{FM}	–	0.00001 (1.784)*	–
α_{FL}	0.00072 (0.309)	0.0012 (1.689)*	−0.0028 (−1.442)
α_{ML}	0.00203 (1.714)*	0.0089 (2.688)***	0.0022 (1.719)*
β_{AY}	−0.1568 (−0.478)	0.1082 (0.321)	−0.0556 (−0.291)
β_{FY}	−0.0001 (−0.188)	0.0018 (1.442)	0.00008 (0.345)
β_{MY}	−0.00014 (−0.716)	−0.00005 (−0.147)	0.00003 (−0.165)
β_{LY}	0.157 (0.479)	−0.1099 (−0.326)	0.0556 (0.291)
φ_Y	0.9499 (0.559)	1.1409 (0.632)	0.0454 (0.043)
φ_{YY}	–	–	–
γ_{AG}	−0.0586 (−0.451)	0.0012 (0.003)	−0.0453 (−0.414)
γ_{FG}	−0.0214 (0.399)	−0.0631 (−0.107)	−0.0122 (−0.628)
γ_{MG}	−0.0153 (−1.055)	−0.0224 (0.725)	−0.0244 (−1.532)
γ_{LG}	0.0586 (0.450)	−0.0013 (−0.004)	0.0457 (0.416)
ψ_G	0.4656 (0.628)	1.2041 (0.712)	−0.2299 (−0.423)
ϕ_{GY}	−0.0142 (−0.29)	−1.1422 (−2.525)**	0.0558 (2.387)**

Figures in parenthesis are t-values.

* Significant at $P < 0.10$.

** Significant at $P < 0.05$.

*** Significant at $P < 0.01$.

Table 5
Estimates of Allen and Morishima elasticities of factor of substitution for translog cost function

Factor input	Land	Fertiliser	Machinery	Labour
Maize (pure stand)				
Land	−0.738 (0)	0.956 (0.366)	1.006 (0.355)	1.099 (0.706)
Fertiliser	0.956 (0.398)	−0.817 (0)	0.975 (0.305)	1.064 (0.689)
Machinery	1.006 (0.397)	0.975 (0.31)	−0.831 (0)	1.015 (0.649)
Labour	1.099 (0.538)	1.064 (0.443)	1.015 (0.415)	−0.493 (0)
Maize (mixed stand)				
Land	−0.655 (0)	0.998 (0.381)	0.996 (0.357)	1.050 (0.672)
Fertiliser	0.998 (0.475)	−0.841(0)	0.186 (0.155)	0.997 (0.554)
Machinery	0.996 (0.549)	0.186 (0.144)	−0.869 (0)	0.995 (0.537)
Labour	1.050 (0.757)	0.997 (0.550)	0.995 (0.526)	−0.930 (0)
Potatoes				
Land	−0.726 (0)	0.996 (0.780)	1.003 (0.738)	1.054 (1.147)
Fertiliser	0.996 (0.428)	−0.804 (0)	0.990 (0.306)	1.000 (0.680)
Machinery	1.003 (0.398)	0.990 (0.314)	−0.856 (−0.123)	0.996 (0.646)
Labour	1.054 (0.553)	1.000 (0.457)	0.996 (0.047)	−0.503 (0)

Figures in parenthesis represent the Morishima elasticities of factor substitution. The Allen elasticities of substitution are symmetric because of the restriction $\alpha_{ij} = \alpha_{ji}$.

land/labour costs (or higher relative labour/fertiliser prices) are associated with higher land/labour-use intensity. It thus provides an alternative way of discerning possible factor use pattern based on changes in relatives factor prices.

The MES of machinery by labour (0.649, 0.537 and 0.646 in pure and mixed maize stand and potatoes, respectively) are higher than the MES of labour by machinery (0.415, 0.526 and 0.047, respectively), which confirms the labour intensive nature of smallholder agriculture. The MES of land by fertiliser (0.78) in potato production is higher than that of fertiliser by land (0.428). However, the MES of land by fertiliser in pure and mixed maize stands (0.366 and 0.381, respectively) are lower than the substitution of fertiliser by land (0.39 and 0.475, respectively). A possible explanation is that existing fertiliser-using maize production enterprises are more land-intensive than are those for potatoes. In general, the results seem to confirm that even with the current technology, farmers do have substantial substitution possibilities at their disposal.

Table 6
The derived price elasticities of factor demand for the translog cost function

Factor input	Land	Fertiliser	Machinery	Labour
Maize (pure stand)				
Land	−0.193	0.173	0.162	0.513
Fertiliser	0.250	−0.148	0.157	0.541
Machinery	0.263	0.176	−0.134	0.515
Labour	0.287	0.192	0.164	−0.251
Maize (mixed stand)				
Land	−0.226	0.155	0.131	0.446
Fertiliser	0.344	−0.131	0.024	0.423
Machinery	0.344	0.029	−0.115	0.422
Labour	0.362	0.155	0.131	−0.395
Potatoes				
Land	−0.594	0.186	0.144	0.553
Fertiliser	0.273	−0.155	0.151	0.525
Machinery	0.275	0.191	−0.123	0.523
Labour	0.289	0.193	0.143	−0.264

Table 7
Production cost and factor demand elasticities with respect to access cost

Variable	Crop		
	Maize (pure stand)	Maize (mixed stand)	Potatoes
Production cost	0.362	0.116	0.196
Land	0.138	0.159	−0.117
Fertiliser	−0.374	−0.095	−0.078
Machinery	−0.850	−0.067	−1.503
Labour	0.455	0.156	0.247

Table 8
Cobb-Douglas specification parameter estimates

Variable/statistic	Crop		
	Maize (pure stand)	Maize (mixed stand)	Potatoes
Land	0.4535 (1.959)**	−0.0115 (0.059)	0.6419 (4.771)***
Fertiliser	0.0008 (3.084)***	−0.0003 (−0.866)	0.0004 (1.929)*
Machinery	−0.0002 (−1.006)	−0.0001 (−0.297)	−0.0003 (−1.524)
Labour	−0.1428 (−0.547)	1.6709 (5.740)***	0.0498 (0.177)
Output	0.1428 (2.939)***	0.7502 (14.48)***	0.0044 (3.056)***
Access cost	0.0719 (1.922)*	0.1001 (2.517)**	0.0083 (−0.194)
Constant	4.6317 (3.940)***	−1.2499 (−0.91)	11.283 (7.935)***
$\bar{R}^2$	0.235	0.806	0.405

Figures in parenthesis are t-values.
* Significant at $P < 0.10$.
** Significant at $P < 0.05$.
*** Significant at $P < 0.01$.

The derived price elasticities of factor demand in Table 6 show that the own price elasticities are negative as expected just as the cross-price elasticities are positive. All elasticities lie in the inelastic range, with labour being more price sensitive than other factor inputs.

The effect of road infrastructure on variable production costs is given by the elasticity of production cost with respect to access cost. This elasticity is a composite of direct and indirect effects of access costs on production costs. Direct costs arising from differential access are Obtained from the parameter ϕ_G in Eq. (1). The indirect costs are a result of the interaction among access costs, factor prices and the scale of production. The production cost and factor demand elasticities with respect to access costs by crop are presented in Table 7. The production cost elasticity depicts the expected variation in the production cost structure that would result from changes in access costs. As suggested by Jayne (1994) and Omamo (1998a and 1998b), the expected changes are crop-specific. These elasticities are highest in pure stand maize and lowest in mixed stand maize production (0.362 and 0.116 respectively). This means that high access costs favour production of maize in mixed stand. Njehia (1994) reports a similar finding. The overall elasticities are positive, implying that a high access cost index is costly to agricultural production.

Factor demand elasticities of land, fertiliser, machinery and labour with respect to access costs were calculated following Eqs. (4) and (5), using the estimated parameters. For the three crop enterprises, poor access (i.e. high access cost) was associated with less use of fertiliser and machinery (i.e. negative values) and more use of labour (positive elasticity) as can be seen in Table 7. The results for land are mixed. Poor access is associated with more land use in maize production but less in potato production. This result is plausible given that maize is the dominant staple, rendering it the more likely focus of self-supply (i.e. food import substitution) in response to high access costs (Omamo, 1998b). The finding that poor access (high access cost) is associated with high labour use has, probably, a similar foundation. Labour is the resource over which farming households have the most control. Under conditions of high access costs, labour, most likely, substitutes for lower allocations of other, dearer inputs that must be acquired on the market.[7]

Finally, using the same data the cost function associated with a Cobb-Douglas production function is estimated. This was done to establish whether the cost elasticity of output with respect to the access cost index is robust or not, i.e. with respect to the data and

[7] At first, this finding seems at odds with that of Feltenstein and Ha (1995) in Mexico's non-agricultural sectors, where improved roads and lower transport costs led to an increase in the demand for labour in some industries. Note, however, that under conditions of high farm-to-market access costs, pressures to substitute domestic resources (and self-produced food) for those acquired in markets appear to be dominant. With lower access costs, these motives may be muted.

the specified cost function. The aggregate production costs for the individual crop enterprises is estimated as a function of total output, input prices and access cost. The Cobb-Douglas specification permits a conventional interpretation of *t*-statistics and also indicates how a policy maker may use a simple methodology to make an initial judgement regarding the benefits of a reduction of access costs through improvement in road and transport infrastructure in rural areas where agriculture is a dominant economic activity. The factor prices enter the specified Cobb-Douglas cost function as explanatory variable because it must be homogeneous of degree one in factor prices. The parameter estimates shown in Table 8 have a two interesting aspects. First, the cost elasticities of the access cost index have the same signs as those of the translog cost function results shown in Table 4. Second, the cost elasticities are statistically significant in the maize function and insignificant in the potato cost function.

5. Summary and implications

The results of this study indicate that an inadequate road infrastructure imposes significant burdens on cost-minimising smallholder farmers in the study region and, by extension, wherever similar conditions obtain. Farmers faced with high farm-to-market access costs commit less land, fertiliser and machinery resources to production, but more labour. Higher access costs are also associated with more land devoted to maize, the region's, Kenya's, and Africa's major staple food crop.

The results add credence to arguments that subsistence-oriented production patterns on small farms are rational responses to high farm-to-market transaction costs (Omamo, 1998a,b). They also provide solid microeconomic evidence of the negative impacts of high transport costs on farm productivity and income in Africa mentioned by several authors (e.g. Pederson, 2000). An obvious policy implication is that governments in countries such as Kenya, whose agricultural sectors are dominated by smallholders, should invest in rural road infrastructure improvements. But such governments are deep in the throes of chronic fiscal crises. Few can afford the high costs of major rural infrastructure investments. The expenditure required to increase Kenya's road density (which currently stands at just above 11 km/100 km^2) to the level of India (90 km/100 km^2) is at least 7 billion US$—assuming gravel roads only—and could be as high as 88 billion US$—assuming paved roads (MTC, 1998). By way of comparison, Kenya's entire gross domestic product currently stands at slightly over US$ 6 billion.

In the expected continued absence of major investments in rural roads, the policy challenge is to identify and catalyse 'bridging institutions' (or as Watts (1999, p. 77 puts it, 'shortcuts') of various kinds. The key recognition is that transport cost is a composite of physical distance, travel time and transport fare. The first component—physical distance—is given. The latter two are not. They lie within the control of farmers and traders. They also lie within the sphere of influence of a range of policies. These policies include institutional innovations that aim to reduce a range of transaction costs (e.g. enforcement, coordination and handling costs), increase financial liquidity, increase social capital and reduce risk.

These innovations are inherently context-specific. However, a range of options exists. For example, support for, and active participation in formation and functioning of farmers' associations (Dorsey and Muchanga, 2000); support for, and active participation in formation and functioning of trader associations (Fachamps and Gabre-Madhin, 2001); support for, and active participation in formation and functioning of industry associations, comprising not only producers (farmers) but also traders, manufacturers (processors), and scientists (Sabel, 1994); support for organisations that link farm input supply with information dissemination (Seward and Okello, 2000).

Further, and in view of the high internal rate of return (IRR) from improved market access in the less developed economies' rural areas (Delgado, 1995; Ijaimi, 1994), inexpensive measures can be introduced to facilitate an improvement or even an expansion of the existing road networks. For example, with assistance from government institutions and non-government organisations, rural communities can be mobilised to upgrade and maintain rural access roads. Communally upgraded and maintained roads will support production as supply shifters. The impact will be an improvement in farmers' marketing margins. Improved marketing margins will attract private input traders, leading to a more competitive and input supply system (Hassan, 1996; Von Oppen et al., 1985), and thus widening of the choice of markets and inputs for rural enterprises (Islam, 1997).

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