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Measuring factor substitution and technological change in the Tunisian agricultural sector, 1971 - 2000

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Abstract

The production structure of Tunisian agriculture over the last three decades is investigated using a translog variable cost function. Standard results of neoclassical duality theory are used to obtain measures of elasticities of substitution between inputs, price elasticities of factor demands and the rate of growth and bias of technological progress. Empirical results obtained from the joint estimation of parameters of the cost and share equations indicate an increasing trend in the degree of substitutability between labour and intermediate inputs. The own-price elasticities of labour and intermediate inputs are inelastic. While the labour price elasticity of demand has increased over time, the intermediate input price elasticity of demand has declined. Finally, technological progress occurred at an impressive and sustained annual growth rate of 3.8 percent.

Key words: Factor substitution, technological change, Tunisian agriculture

Introduction

During the last three decades, the agricultural sector in Tunisia has undergone substantial structural changes and a new development paradigm calling for a change from state-led to private-led growth made its way in the country. Input subsidization schemes that provide little incentives for resource conservation, price support programs that distort market allocation of resources and heavy border protection making food more expensive for consumers were being increasingly recognized as inefficient ways to achieve food security and rural development objectives. An important milestone within this time period is the Agricultural Sector Adjustment Program (ASAP) initiated by the government in 1986. The essence of this program is to: (i) remove the major sources of price distortions that adversely affect efficiency and productivity; (ii) transfer marketing functions that are under state control to the private sector; and (iii) improve the public sector management, which entails increasing privatisation.

While major revisions in past policy pricing have taken place namely, a gradual disengagement from price fixing and removal of input subsidies, it is a little surprising that empirical evidence on aggregate production structure and productivity growth in the Tunisian agricultural sector is lacking. To the authors knowledge, attempts to estimate an aggregate production model for Tunisian agriculture that simultaneously

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identify substitution elasticities, input demand elasticities and the rate of growth of technical change are missing despite the rich literature in this area.

Indeed, the literature is awash of studies that used aggregate production relations to examine the underlying technological structure of production. The surge in the popularity of these functions has been due in part to the advent of duality theory and to the development of flexible functional forms. The transcendental logarithmic (translog) function, introduced by Christensen *et al.*, has been particularly used to analyse, among others, factor input demands, substitution between production factors, returns to scale and the growth rate and bias of the occurring technological progress. Studies using the translog cost function with aggregate agricultural time series data include those by, Binswanger (1974), Kako (1978), Ball and Chambers (1982), Ray (1982), Capalbo (1988) and Lachaal (1994). Others used non-parametric approaches to productivity analysis (Fulginiti and Perrin, 1997; Hailu and Veeman, 2000 and Nin *et al.* 2003)¹.

The purpose of this paper is to investigate production structure and technological change in Tunisian agriculture for the period 1971-2000. The analysis is facilitated by using a translog variable cost function and by appealing to the theory of duality. The translog variable cost function provides a convenient framework for analysing productive behaviour when physical input data are simply not available².

This article is organized as follows. In the next, second section, the model of variable cost function is specified. In the third section the database for the estimation is presented. The estimation results follow in the fourth section and the final section concludes.

Model specification

An important assumption that underlies most of the cost function applications is that all factor inputs are in full static equilibrium in the sense that they all adjust instantaneously to changes in exogenous variables. Brown and Christensen (1981) note that in many instances, this assumption of full static equilibrium is suspect and so are the empirical results. Indeed, the agricultural sector can be assumed to be in equilibrium with respect to a subset of inputs (variable inputs) conditional to the observed levels of the remaining inputs (quasi-fixed inputs). This framework is referred to as a partial static equilibrium framework. Other applications of the variable cost function have been provided by Caves *et al.* (1981) and Capalbo (1988). An earlier application of the partial static equilibrium framework was provided by Lau and Yotopoulos (1971) using a profit function.

In this study, we choose to investigate productivity growth and aggregate production structure in Tunisian agriculture using a *variable* cost framework *à la Brown and Christensen*. The choice for such a framework is based on the following grounds. First, in the short run, we regard land as a fixed production factor, since there is a little latitude of change in the amount of land held by the entire farm sector. The same argument applies here to capital stock factor, which in the short run is considered as fixed. Second, total cost function, as opposed to variable cost function, could not be

estimated due to lack of price data on land and capital. Time series data for agricultural land and capital stock prices are simply unavailable. The elasticities computed are thus partial, rather than full, static equilibrium elasticities.

The translog variable cost function for two variable and two fixed factors can be written as follows:

$$\begin{aligned} \ln CV = & \alpha_0 + \alpha_Q \ln Q + \sum_i \alpha_i \ln W_i + \sum_k \beta_k \ln Z_k + 1/2 \gamma_{QQ} (\ln Q)^2 + 1/2 \sum_i \sum_j \gamma_{ij} \ln W_i \ln W_j \\ & + 1/2 \sum_k \sum_l \delta_{kl} \ln Z_k \ln Z_l + \sum_i \rho_{iQ} \ln W_i \ln Q + \sum_i \sum_k \rho_{ik} \ln W_i \ln Z_k + \sum_k \pi_{kQ} \ln Q \ln Z_k \\ & + \phi_T T + 1/2 \phi_{TT} T^2 + \sum_i \phi_{iT} \ln W_i T + \phi_{QT} \ln Q T + \sum_k \phi_{kT} \ln Z_k T \end{aligned} \quad (1)$$

Where CV denotes the variable cost³; Q represents the level of aggregate output; W_i are the prices of the variable factors (E = labour, I = intermediate inputs⁴); Z_k is the subset of fixed factors (K = capital, L = land); T represents the time trend proxy for disembodied technological change; and \ln is the natural logarithm.

The minimisation of variable cost implies, by Shephard's Lemma that S_i , the share of the i^{th} factor in variable cost, is given by:

$$\frac{\partial \ln CV}{\partial \ln W_i} = S_i = \alpha_i + \sum_j \gamma_{ij} \ln W_j + \rho_{iQ} \ln Q + \sum_k \rho_{ik} \ln Z_k + \phi_{iT} T \quad (2)$$

Linear homogeneity of the cost function in variable input prices, symmetry and constant returns to scale restrictions were imposed *a priori*. Linear homogeneity implies the following restrictions:

$$\sum_i \alpha_i = 1; \quad \sum_i \gamma_{ij} = \sum_i \phi_{iT} = \sum_i \rho_{iQ} = \sum_i \rho_{ik} = 0 \quad (3)$$

Symmetry on the cross-price effects implies the following restrictions:

$$\gamma_{ij} = \gamma_{ji} \text{ for all } i, j \quad (4)$$

Constant returns to scale in fixed factors implies the following restrictions⁵:

$$\begin{aligned} \alpha_Q + \sum_k \beta_k &= 1, \quad \rho_{iQ} + \sum_k \rho_{ik} = 0 \quad \forall i, \quad \gamma_{QQ} + \sum_k \pi_{kQ} = 0 \\ \pi_{iQ} + \delta_{ik} + \delta_{il} &= 0, \quad \pi_{kQ} + \delta_{kl} + \delta_{kk} = 0, \quad \phi_{QT} + \sum_k \phi_{kT} = 0 \end{aligned} \quad (5)$$

Under the restrictions of linear homogeneity and symmetry only one of the two variable input shares is independent. All of the parameters in the model are identified by estimating the translog variable cost function jointly with one share equation.

The time trend parameters ϕ_T and ϕ_{TT} in (1) indicate the direction and the rate of change of the shift in the variable cost function independent of prices and quantities. The parameters ϕ_{iT} , on the other hand, indicate the effect of the time trend proxy for

technological progress on the shares holding all other variables constant and are interpreted as measuring non-neutral technical change. Further, if production technology is homothetic, its dual variable cost function is multiplicatively separable and the optimal input combination is independent of the scale of output. For the translog variable cost function in (1) this requires:

$$\rho_{iQ} = \pi_{kQ} = \phi_{TQ} = 0, \text{ for all } i \text{ and } k \quad (6)$$

Data and estimation procedure

To implement the above-specified model, annual data from 1971 to 2000 of the Tunisian agricultural sector are used. In particular, data on output, variable input prices and quantities; fixed input levels and production variable costs are required. These measures are derived and constructed based on several data sources.

The index of agriculture output is taken from the Food and Agricultural Organization's online database. The current and real values (expressed in 1990 prices) of labour and intermediate input were collected from the *Institut National de la statistique* (INS) publications. Price indices of labour and intermediate inputs were computed as the ratio of current and real values. The farm capital stock variable (machinery, installations and buildings) is taken from the *Institut d'Economie Quantitative* (IEQ) publications. These data are used to construct a quantity index of agriculture capital input. Finally, the agricultural land variable, which represents the sum of arable land, land under permanent crops and permanent meadows and pastures, was computed from various issues of the *Annuaire des Statistiques* of the Ministry of Agriculture. All quantities and prices are normalized to 1 in 1990.

The empirical variable cost function developed above is considered an approximation to the true underlying variable cost function. Hence, the function specified in (1) is jointly estimated with the cost share equation (2). However, since the cost shares sum to one, the intermediate inputs share equation is dropped to avoid a singular covariance matrix. The system of equations is estimated using the full maximum likelihood method (FIML) in the e-views econometric package and empirical results are reported in Table 1 below.

Empirical results

The variable cost function in (1) has 28 parameters; however, with the imposition of linear homogeneity in factor prices (3), symmetry (4), and constant returns to scale in fixed factors (5), we are left with 15 independent parameters to be estimated. Table 1 presents the FIML estimates of the full set of parameters of the variable cost function specified in (1). The model seems to fit the data reasonably well (the system R^2 statistic is 0.95)⁶.

The fitted variable cost function satisfies, at the point of approximation, the regularity conditions that it be non-decreasing and concave in variable input prices.

Furthermore, the estimated function is increasing in output ($\alpha_Q > 0$) although the estimated parameter is not statistically significant at the 5 percent level. The estimated dual measure of technical change, evaluated at the point of approximation, is 3.6 percent per year indicating that the fitted function exhibits technological progress. Further, results indicate that technological change in Tunisian agriculture has been labour saving and intermediate inputs using.

Table 1. Estimated coefficients of the variable cost function for Tunisian agriculture, 71-2000

Parameter	Coefficient estimates	Asymptotic t ratios	Parameter	Coefficient estimates	Asymptotic t ratios
α_0	8.455	(110.617)*	ϕ_{TT}	-0.001	(-2.357)*
α_Q	0.819	(1.176)	ρ_{EQ}	0.025	(0.507)
α_E	0.362	(10.267)*	ρ_{IQ}	-0.025	(-0.507)
α_I	0.638	(18.107)*	ρ_{EL}	0.097	(1.990)*
β_L	0.433	(0.557)	ρ_{EK}	-0.122	(-1.782)
β_K	-0.253	(-0.340)	ρ_{IL}	-0.097	(-1.990)*
ϕ_T	-0.036	(-3.171)*	ρ_{IK}	0.122	(1.782)
γ_{QQ}	2.476	(0.959)	Π_{LQ}	-1.104	(-0.757)
γ_{EE}	-0.043	(-0.870)	Π_{KQ}	-1.372	(-0.751)
γ_{II}	-0.043	(-0.870)	ϕ_{ET}	-0.005	(-3.249)*
γ_{EI}	0.043	(0.870)	ϕ_{IT}	0.005	(3.249)*
δ_{LL}	0.851	(0.635)	ϕ_{QT}	-0.018	(-0.451)
δ_{KK}	1.119	(0.532)	ϕ_{LT}	-0.021	(-0.461)
δ_{LK}	0.253	(0.237)	ϕ_{KT}	0.039	(0.764)
Log of likelihood = 129.6053 R ² (CV) = 0.975 R ² (SE) = 0.956					

Asymptotic t ratios are in parenthesis. A single asterisk indicates significance at the 5 % level. The subscript Q, E, I, L, K and T refer to output, labour (employment), intermediate inputs, land, capital and time trend, respectively.

The parameter estimates of the cost function are used to compute the Allen partial elasticity of substitution (AES), as reported in Table 2. Using neoclassical duality theory, the AES, which measures the effect of a change in the price of the j^{th} input on the quantity demanded of the i^{th} input when output is held constant can be derived from the data and the estimated parameters (Uzawa, 1962) as:

$$\sigma_{ij} = \frac{\gamma_{ij}}{S_i S_j} + 1, i, j = E, I \quad i \neq j \quad (7)$$

and,

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \quad i = E, I \quad (8)$$

Where S_i and S_j are the shares of factors i and j in total variable cost, respectively. At constant output, positive AES between factors i and j suggests they are substitutes, while they are complements if AES is negative. Results of the estimated AES indicate a high degree of substitutability between intermediate inputs and labour and that the degree of substitutability between these factors has been increasing over time. Hence, increases in the price of intermediate inputs tend to lead to an increase in demand for labour.

Table 2. Estimated Allen partial elasticities of factor substitution in Tunisian agriculture

Decade	σ_{EI}
1971-1980	1.162
1981-1990	1.192
1991-2000	1.214
Mean	1.189

The AES can also be used to obtain the own-price and the cross-partial elasticities of factor demands by multiplying the AES by the cost shares (Binswanger, 1974a) as:

$$\varepsilon_{ij} = S_j \sigma_{ij} = S_j + \frac{\gamma_{ij}}{S_i} \quad (9)$$

and,

$$\varepsilon_{ii} = S_i \sigma_{ii} = S_i - 1 + \frac{\gamma_{ii}}{S_i} \quad (10)$$

The price elasticities of factor demands in Tunisian agriculture are reported in Table 3 below.

Table 3. Estimated Price elasticities of factor demands in Tunisian Agriculture

Decade	ε_{EE}	ε_{EI}	ε_{IE}	ε_{II}
1971-1980	-0.663	0.641	0.539	-0.539
1981-1990	-0.838	0.838	0.357	-0.353
1991-2000	-0.913	0.913	0.304	-0.314
Mean	-0.805	0.797	0.400	-0.402

The own price elasticity of factor demands are less than 1 in absolute value, indicating that labour and intermediate input demand functions are price inelastic. Demand for farm labour, however, is more sensitive to price changes than that for intermediate inputs. Over time, the labour price elasticities of demand has increased, while the intermediate input price elasticities of demand has declined. Further, the relatively high cross-price elasticity between intermediate inputs and labour confirms that increases in intermediate inputs price are associated with elastic responses in the demand for labour.

Using the translog variable cost framework, the rate of technological change can be empirically measured using the Caves, Christensen, and Swanson's (1981) approach. Antle and Capalbo (1988) referred to this as the dual measure of Total Factor Productivity (TFP) and the approach was also used by Deborger (1984) and Thiry and Lawaree (1987). Therefore, under constant returns to scale and efficient production process, the conventional measure of TFP is identical to the rate of technological change. This rate can be obtained by:

$$TFP = \frac{-\partial \ln CV / \partial t}{\partial \ln CV / \partial \ln Q} \quad (11)$$

Table 4 shows the average annual growth rates of the estimated TFP for the last three decades. For the entire sample period 1971-2000, empirical results reveal that Tunisian agriculture has experienced remarkable productivity gains at an average annual rate of 3.8 percent. The gain of productivity in the 1980's was the highest compared to the other two decades. The decline in productivity growth in the 1990's could be the result of the severe successive droughts that hit the country from 1997 to 2000.

Table 4. Estimated total factor productivity growth rates in Tunisian agriculture

Decade	TFP (%)
1971-1980	3.7
1981-1990	4.6
1991-2000	3.3
Mean	3.8

Finally, consider estimating factor biases for the translog model of Tunisian agriculture. Biased technological change occurs when shifts in the technology alter the equilibrium factor shares, holding factor prices constant. Antle and Capalbo (1988) proposed a dual cost measure of bias, including a bias effect and a scale effect:

$$B_i^c = B_i + \left(\frac{\partial \ln S_i}{\partial \ln Q} \right) \left(\frac{\partial \ln C}{\partial \ln Q} \right)^{-1} \left(\frac{\partial \ln C}{\partial T} \right) \quad (12)$$

Where $B_i = \partial \ln S_i(Q, P, Z, T) / \partial T$ ($i = E, I$) denotes the pure bias effect. Thus, equation (12) indicates that the overall Hicksian bias measure is composed of the pure bias effect

(interpreted as a shift in the expansion path) and the scale effect (interpreted as a movement along the nonlinear expansion path). It can be noted that when the technology is homothetic, the scale effect disappears since $\partial \ln S_i / \partial \ln Q = 0$. In this case, the overall Hicksian bias measure can only be interpreted as a measure of the shift in the expansion path. The pure Hicksian bias effect can be obtained as:

$$B_i = \frac{\partial S_i}{\partial T} \cdot \frac{1}{S_i} \quad i = E, I \quad (13)$$

Where S_i is the share of factor i . Technical change is i^{th} input-saving if $B_i < 0$, neutral if $B_i = 0$ and i^{th} input-using if $B_i > 0$. Table 5 presents the estimated factor biases for the translog model of Tunisian agriculture over the last three decades. Results indicate that, over time, the degree of labour-saving has been increasing, while the degree of intermediate input-using has been decreasing.

Table 5. Bias in Technical Change in Tunisian agriculture

Decade	Labour	Intermediate input
1971-1980	-0.010	0.009
1981-1990	-0.015	0.007
1991-2000	-0.018	0.006
Mean	-0.015	0.007

Conclusions

This study attempts to analyse the structure of agricultural production in Tunisian agriculture using a translog variable cost function (VCF) with capital and land inputs fixed in the short run. Neoclassical duality results are extensively used for this purpose. Of primary interest for this study is estimation of the elasticities of substitution between labour and intermediate inputs, the price elasticities of factor demands and the rate of growth and bias of technological progress. The main conclusions that can be drawn from this study can be summarized as follows. Labour is found to be a substitute for intermediate inputs and the degree of substitutability has increased over time. This result indicates that farmers can substitute between these factors as relative prices change, particularly to increase intermediate inputs use as the rural population declines.

The own price elasticity of factor demands are less than 1 in absolute value, indicating that labour and intermediate input demand functions are price inelastic. Demand for farm labour, however, is more sensitive to price changes than that for intermediate inputs. Overall, this implies that price based policies alone will have relatively a limited impact in promoting the use of fertilizers and improved varieties of seeds.

Another important finding is the rate of technological progress in Tunisian agriculture. A 3.8 percent annual growth rate of productivity sustained over three

decades is quite impressive. This has been the result of considerable investments in the agricultural sector particularly in the early 1980's, the use of intensive production systems, water resource mobilization and the adoption of new production technologies. Further, technological progress in Tunisian agriculture has been non-neutral (labour-saving, intermediate input-using). The degree of labour-saving has increased while the degree of intermediate input-using has decreased over time.

These findings have important policy implications in promoting further technological progress in Tunisian agriculture. This latter is an important ingredient in Tunisian agricultural competitiveness as the country is looking for new partnerships through bilateral or multilateral agreements (World Trade Organization, Euro-Med free trade area, etc.).

While this study constitutes the first attempt to production structure analysis of Tunisian agriculture, an unfortunate limitation imposed by data availability did not allow at this stage to estimate a model that is disaggregative enough. Further, research in this area should probably consider decomposition of the growth in total factor productivity into technological progress and efficiency effects. Indeed, ignoring these latter may overstate the true measure of technological change.

Notes

- ¹ While Fulginiti and Perrin used a nonparametric, output-based Malmquist index to examine changes in agricultural productivity in 18 developing countries, Hailu and Veeman used a parametric input distance function to generate environmentally sensitive productivity and efficiency measures for the Canadian pulp and paper industry.
- ² The use of a cost function rather than a production function for analyzing aggregate production structure has several advantages (Binswanger, 1974).
- ³ Variable cost is defined as the sum of labor and intermediate inputs expenditure.
- ⁴ Economies of scale (SCE) specific to the translog variable cost function can be expressed (Caves et al. 1981) as: $SCE = \frac{1 - \sum \partial \ln CV / \partial \ln Z_k}{\partial \ln CV / \partial \ln Q}$. The constant returns to scale restriction was used, among others, by Lau (1978), Brown and Christensen (1981) and Capalbo (1988).
- ⁵ Intermediate inputs include fertilizers, seeds, feeds, fuel and electricity used in farm production.
- ⁶ The system R^2 compares the current model with a base model that includes intercepts only (Bewley and Young, 1987). The measure has the following expression:

$$R^2 = 1 - \frac{1}{1 + 2 * [LL_u - LL_b] * \frac{1}{T * (N - 1)}}$$

Where LL_u is the log-likelihood of the unrestricted model and LL_b is the log-likelihood of the base model (intercepts only), T is the number of observations, and N is the number of equations in the system.

References

- Antle, J. M. and Capalbo, S. M. (1988) An introduction to recent developments in production theory and productivity measurement, in *Agricultural productivity: measurement and explanation*, (Eds) S. M. Capalbo and J. M. Antle, Resources for the Future, Washington DC, pp. 1-14.
- Ball, V. L. and Chambers, R. G. (1982) An economic analysis of technology in the meat products industry, *American Journal of Agricultural Economics*, 64, 699-709.
- Berndt, E. R. and Christensen, L. R. (1973) The translog function and the substitution of equipment, structure and labour in U.S. manufacturing, 1929-68, *The Journal of Econometrics*, 1, 81-114.
- Bewley, R. and Young, T. (1987) Applying multinomial extension of the linear logit model to meat expenditure data, *American Journal of Agricultural Economics*, 69, 151-157.
- Binswanger, H. P. (1974a) A cost function approach to the measurement of Elasticities of factor demand and elasticities of substitution, *American Journal of Agricultural Economics*, 56, 377-86.
- Binswanger, H. P. (1974b) The measurement of technical change biases with many factors of production, *American Economic Review*, 64, 964-76.
- Brown, R. S. and Christensen, L. R. (1981) Estimating elasticities of substitution in a model of partial static equilibrium: An application to U.S. Agriculture 1947 to 1974, in *Measuring and modelling natural resources substitution*, (Eds) E. R. Berndt and B. C. Field, pp. 208-229.
- Capalbo, S. M. (1988) A comparison of econometric models of U.S. agricultural productivity and aggregate technology, in *Agricultural productivity: measurement and explanation*, (Eds) S. M. Capalbo and J. M. Antle, Resources for the Future, Washington DC, pp.159-188.
- Caves, D.W., Christensen, L. R. and Swanson J. A. (1981) Productivity growth, scale economies and capacity utilization in US railroads, 1955-74. *American Economic Review*, 71, 994-1002.
- Christensen, L. R., Jorgenson, D. W. and Lau, L. J. (1973) Transcendental logarithmic production frontiers, *Review of Economics and Statistics*, 55, 28-45.
- DeBorger, B. (1984) Cost and productivity in regional bus transportation: the Belgian case. *Journal of Industrial Economics*, September, 37-54.
- Diewert, W. E. (1971) An application of the Shephard duality theorem: A Generalized Leontief Production Function, *Journal of Political Economy*, Vol. 79, 3, 481-507.
- Fulginiti, L. E. and Perrin, R. (1997) LDC agriculture: nonparametric Malmquist productivity indices, *Journal of Development Economics*, 53, 373-390.
- Hailu, A. and Veeman, T. S. (2000) Environmentally sensitive productivity analysis of the Canadian pulp and paper industry, 1959-1994: an input distance function approach, *Journal of Environmental Economics and Management*, 40, 251-274.
- Huffman, W. E. (1993) Productivity indexes and returns to research, paper presented at the AAEA meeting, Orlando, Florida.
- Jorgenson, D. and Griliches, Z. (1967) The explanation of productivity change, *Review of Economic Studies*, 34, 249-83.

- Kako, T. (1978) Decomposition analysis of derived demand for factor inputs: The case of rice production in Japan, *American Journal of Agricultural Economics*, 60, 628-35.
- Lachaal, L. (1994) Subsidies, endogenous technical efficiency and the measurement of productivity growth, *Journal of agriculture and applied economics*, 26, 299-310.
- Lachaal, L. (1998) Production structure characteristics and adaptations of productivity growth measures: a survey, *Cahiers d'Economie et Sociologie Rurales*, 48, 62-78.
- Lau, L. J. and Yotopoulos, P. A. (1971) A test for relative efficiency and application to Indian agriculture, *American Economic Review*, 61, 94-109.
- Lau, L. J. (1978) Applications of profit functions, in *Production economics: a dual approach to theory and applications*, (Eds) M. Fuss and D. Mac Fadden, Amsterdam, North-Holland, pp.133-216.
- Nin, A., Arndt, C. and Preckel, P. V. (2003) Is agricultural productivity in developing countries really shrinking? New evidence using a modified nonparametric approach, *Journal of Development Economics*, 71, 395-415.
- Ray, S. C. (1982) A translog cost function of U.S. agriculture, *American Journal of Agricultural Economics*, 64, 490-98.
- Shephard, R. W. (1970) *Theory of cost and production function*, Princeton, N.J. Princeton University Press.
- Thiry, B. and Lawaree, J. (1987) Productivité, coût et caractéristiques technologiques des sociétés belges de transports urbains, *Annales de l'économie publique, sociologie et coopérative*, 4, 369-96.
- Uzawa, H. (1962) Production function with constant elasticity of substitution, *Review of Economic Studies*, 29, 291-99.