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Cross Section Translog Production and Elasticity of Substitution in U.S. Manufacturing Industry

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ABSTRACT: This paper examines elasticity of substitution among electricity, labor and capital in U.S. manufacturing industry, using cross section data of 2007. In this analysis, Manufacturing industries were categorized into three categories based on input use and technology. Translog homothetic and non-homothetic production functions for each category were estimated but the restrictions imposed for homothetic production were rejected. The estimated parameters of non homothetic production function were used to estimate the own, cross price and Morishma elasticities of inputs for three different manufacturing categories. These elasticities indicate that capital, electricity and labor are substitutes each other. Cross price elasticities indicate that that electricity is weak substitute to capital and labor but capital and labor are strong substitutes to electricity. These elasticities and the availability of nonrenewable energy source suggest that price of electricity or energy will rise faster than wage and interest rate increase with economic growth. This implies that policies promoting the development and commercialization of alternative energy sources would be a better solution than policies promoting new energy saving physical capital or increasing labor productivity to meet the increasing demand for electricity.

Keywords: Elasticity of substitution; Manufacturing industries; Translog production function
JEL Classifications: D24; L60

1. Introduction

Economists have debated about whether energy and capital are substitutes or complements (Apostolakis, 1990). There are large number of conflicting econometric estimates of the elasticity of substitution between energy and capital. For example, using time-series data Hudson and Jorgenson (1973) and Berndt and Wood (1975) found that energy and capital are complements. But, Humphrey and Moroney (1975), Griffin and Gregory (1976) and Halvorsen (1977) found energy and capital substitutable based on their cross-section estimates. Field and Grebenstein (1980), Hazilla and Kopp (1984), Nguyen and Andrews (1989) and Morrison (1993) found mixed results. Griffin and Gregory (1976) and Apostolakis (1990) suggest that because cross-section data capture the long run response to price changes the estimated result may show the substitutable relationship between two inputs. In contrast, since time-series data reflect short run responses to price changes the estimation may lead to a complementary relationship between the two inputs.

Miller (1986) points out that, at aggregate levels, (mixtures of many industries), when energy prices change the product mix substitution effects dominate the true factor substitution effects because energy - intensive products are often produced where energy costs are lowest. As a result, elasticity of substitution estimates based on aggregate cross-section data are most likely to be biased upward, while the elasticity of substitution estimates based on aggregate time-series data are most likely to be biased downward. When energy prices goes up, prices of products, particularly energy-capital intensive products, goes up. This will reduce the demand and production for these products and then the demand for factor inputs including capital and energy.

In this study, Cross section data of four digits four hundred sixty U.S. manufacturing industries in 2007 were used to estimate three-input translog production function. There are large variations across the industries in terms of input use and technology. These industries were categorized into three categories based on input use and technology. These groups are NAICS 311 & 312 (food, Beverages and tobacco manufacturing), NAICS 334 – 339 (Computer and Electronic Product Manufacturing, Electrical Equipment, Appliance, and Component Manufacturing, Transportation Equipment Manufacturing,) and NAICS 313-333 (all other manufacturing). A Translog production function for each category was separately estimated. The homothetic and non-homothetic production functions were estimated and selected most suitable one for each category. Then, own and cross price elasticities of factor inputs for each category.

2. Production Function

The translog function is a flexible function. This function has both linear and quadratic terms with the ability of using more than two factor inputs. The three-input translog production function can be written in terms of logarithms as follows,

$$Ln\ Y = \alpha_o + \beta_K \ln K + \beta_L \ln L + \beta_E \ln E + ½\, \beta_{KK} \ln K^2 + \beta_{KL} \ln K \ln L + \beta_{KE} \ln K \ln E$$
$$½\, \beta_{LL} \ln L^2 + \beta_{LE} \ln L \ln E + ½\beta_{EE} \ln E^2 \qquad (1)$$

Where Y is the gross manufacturing output, K is real stock of capital input, L is labor input, and E is electricity. α_o is the intercept or the constant term. β_K , β_L and β_E are first derivatives. β_{KK}, β_{LL}, and β_{EE} are own second derivatives. β_{KL} , β_{KE} , and β_{LE} are cross second derivatives.

Under perfect competition assumption, output elasticity with respect to input equals to cost share of that input.

$$\frac{\partial ln y}{\partial ln E} = \frac{dy}{dE}\frac{E}{Y} = \frac{Y_E E}{Y} = \frac{eE}{Y} = \theta_E$$

Thus, we can get a system of equations from differentiating the translog production function with respect to each factor input,

$$\partial ln\ Y/ \partial ln\ K = \beta_K + \beta_{KK} \ln K + \beta_{KL} \ln L + \beta_{KE} \ln E$$
$$\partial ln\ Y/ \partial ln\ L = \beta_L + \beta_{LK} \ln K + \beta_{LL} \ln L + \beta_{LE} \ln E$$
$$\partial ln\ Y/ \partial ln\ E = \beta_E + \beta_{EK} \ln K + \beta_{EL} \ln L + \beta_{EE} \ln E \qquad (2)$$

Coefficients in (2) are symmetric across equations due to Young's theorem on partial derivatives applied to (1). Simultaneous estimation improves estimation properties over single equations, and imposing the symmetry constraints in (2) typically improves estimates further.

(Marginal product of the input) Y_E equals $\theta_E \frac{Y}{E}$

Own derivative of marginal product equals $Y_{EE} = \frac{(\beta_{EE} + \theta_E^2 - \theta_E)y}{E^2}$

Cross derivative of marginal product equals $Y_{EK} = \frac{(\beta_{EK} + \theta_E\, \theta_K)y}{E^2}$

We assumed that the economy minimizes the cost of producing a unit of output by choosing the level of inputs based on the input prices given. First order conditions of the cost minimization leads to the symmetric Hessian matrix of the constrained cost minimization

$$\begin{pmatrix} 0 & Y_K & Y_L & Y_E \\ . & Y_{KK} & Y_{KL} & Y_{KE} \\ . & . & Y_{LL} & Y_{LE} \\ . & . & . & Y_{EE} \end{pmatrix} \begin{bmatrix} \partial\lambda \\ \partial K \\ \partial L \\ \partial E \end{bmatrix} = \begin{bmatrix} 0 \\ \partial r \\ \partial w \\ \partial e \end{bmatrix} \qquad (3)$$

The inverted Hessian matrix is used to derive own price and cross price input elasticities such as $\varepsilon_{Ke} = (\partial K/\partial e)(e/K)$. Elasticities are calculated at estimated marginal products such as $Y_E = e$. In this model, we assume factor prices are exogenous because US is a price taker in global energy and capital markets. Wage is considered as exogenous because of wage contacts.

3. Estimation and Empirical Results

The cross section data of U.S. manufacturing data were collected from the U.S Census Bureau report for 2007. The available data for the four digit (NAICS) four hundred and fifty four manufacturing industries were value added, number of employees, pay roll, purchased electricity and expenditure on electricity, and expenditure of fuel. In order to estimate three input transolg production, the dependent variable for production function was calculated by subtracting expenditure of fuel from value added. Then, residual capital expenditure was estimated by subtracting payroll and expenditure on electricity from the dependent variable. Share of input expenditures were estimated.

The translog production function (1) is non homothetic and imposes no restrictions except symmetry. For a homothetic production function, the marginal rate of technical substitution is homogenous of degree zero in inputs which requires $\sum_j \beta_{ij}= 0$. The production function is homogenous of degree θ if $\sum_i \alpha_i= \theta$ and $\sum_j \beta_{ij}= 0$. The linear homogeneity obtains if $\theta = 1$. The translog production function is additively separable if $\beta_{ij} =0$ (i # j) and reduces to a cob-douglas technology.

We estimate three input translog production function without restriction except symmetry and also with restriction for homothetic production $\sum_j \beta_{ij}= 0$ and symmetry. We did not restrict linear homogeneity. The three-input symmetric translog production was estimated by using seemingly unrelated regression method. Because of additive condition, we drop one of the three equations to avoid singularity problem in estimation and we estimate only two equations. The restrictions imposed for homothetic production were rejected. The estimated parameters of regressions for non homothetic production function were given in Table 1 and own, cross price elasticities of inputs and Morishma elasticities for three different manufacturing categories were given in Table 2. All these elasticity estimates are evaluated at the sample mean.

Table 1. Regression parameter estimates by manufacturing categories

Parameter	311-312	313-333	334-339
α_k	0.1517*	0.1253*	0.1451*
	(0.0489)	(0.0219)	(0.0467)
α_l	0.7704*	0.8659*	0.8636*
	(0.0465)	(0.0239)	(0.0442)
α_e	0.1002*	0.0279*	0.0165*
	(0.0246)	(0.0113)	(0.0041)
β_{kk}	0.1313*	0.1536*	0.1563*
	(0.0064)	(0.0037)	(0.0073)
β_{ll}	0.1109*	0.1397*	0.1514*
	(0.0050)	(0.0037)	(0.0074)
β_{ee}	0.0223*	0.0327*	0.0129*
	(0.0024)	(0.0011)	(0.0006)
β_{kl}	-0.1038*	-0.1243*	-0.1472*
	(0.0056)	(0.0031)	(0.0073)
β_{ke}	-0.0226*	-0.0262*	-0.022*
	(0.0027)	(0.0015)	(0.0033)
β_{le}	-0.0052*	-0.0071*	0.0091*
	(0.0026)	(0.0014)	(0.0033)
N	51	291	112

* Significant at 1% level, Standard errors are given in parentheses.

Table 2. Elasticities by manufacturing categories

Elasticity	311-312	313-333	334-339
Price Demand			
η_{kk}	-1.12	-2.05	-1.91
η_{ll}	-3.75	-3.17	-3.26
η_{ee}	-5.11	-12.26	-8.08
η_{kl}	0.96	1.53	1.77
η_{ke}	0.16	0.52	0.14
η_{lk}	3.71	2.89	3.18
η_{le}	0.05	0.27	0.09
η_{ek}	4.76	9.59	6.02
η_{el}	0.35	2.67	2.07
Morishma			
σ^{m}_{kl}	4.72	4.70	5.03
σ^{m}_{ke}	5.27	12.78	8.22
σ^{m}_{lk}	6.25	4.95	5.08
σ^{m}_{le}	5.15	12.53	8.17
σ^{m}_{ek}	7.60	11.64	7.93
σ^{m}_{el}	4.10	5.84	5.32

All the estimated parameters in the regressions for three categories of manufacturing are significant at 1% level. These results shows that all the own price elasticities are negative and cross price elasticities are positive. The greater own price elasticities for electricity suggest that demand for electricity is more elastic than demand for capital and labor. Capital is less elastic than labor and electricity. The cross price elasticity estimates η_{ke} and η_{le} suggest that one percent increase in electricity price leads to less than one percent increase in capital and in labor demand. This means that electricity is weak substitute to capital and labor but the cross price elasticities η_{ek} and η_{el} suggest that one percent increase in capital and labor price leads to more than one percent increase in electricity. This means the capital and labor are strong substitutes to electricity. This suggests that price of electricity or energy will increase at the higher rate than the increase in real wage and interest rate with economic growth. This implies that, for the increase in the electricity price from current available energy sources, energy conservation policies promoting new energy saving physical capital or increasing labour productivity will not be a better solution in long run than the policies promoting the development and commercialization of alternative energy sources.

Morishma elasticity is not symmetric because the Morishma elasticity measures the responsiveness of input ratios to changes in different input prices. Morishma elasticities show that the change in electricity and capital ratio for one percent increase in capital price is greater than the change in electricity and labor ratio for one percent increase in labor price. This indicates that capital is stronger substitutes to electricity than labor. Since we use aggregate cross section data across the industries the elasticities are higher than the elasticities estimated previous studies from time series data. In this study, manufacturing categories (313-333 NAICS series) have more variation among industries and they are high energy intensive product and should be produced in the place where electricity price is low. In manufacturing categories (313-333 NAICS series), All the own price and cross price elasticities related to electricity are greater than those of other manufacturing categories.

4. Conclusion

The empirical findings show that capital, electricity and labor are substitutes each other in the U.S. manufacturing sector. Cross price elasticities indicate that that electricity is weak substitute to capital and labor but capital and labor are strong substitutes to electricity. These elasticites and the availability of nonrenewable energy source suggest that price of electricity or energy will rise faster than wage and interest rate increase with economic growth. This implies that policies promoting the development and commercialization of alternative energy sources would be a better solution than policies promoting new energy saving physical capital or increasing labor productivity to meet the increasing demand for electricity.

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