Technology Dependency and Energy Substitutability In a Small, Open, and Petroleum-Importing Developing Economy:

The Case of Puerto Rico*

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I. Introduction

In striving toward the goal of economic growth, most developing nations have imported substantial amounts of technology and capital from the industrialized countries. However, it has often been the case that these imports *cum* transfers prove to be inappropriate, for they are designed to be used in economies characterized by relative labor scarcity and capital/energy abundance. In contrast, the factor mix generally found in developing areas consists of labor surpluses, capital and energy shortages, high energy import demands, and a lack of technical skills.

Under such conditions, the following scenario might emerge: the adoption of capital-intensive and/or energy-intensive production methods which are highly labor-saving create technological disfunctionalities in terms of the resource endowments of developing countries; these, in turn, can lead to a falling relative output/energy input ratio and to limited substitution possibilities between energy and capital or between other energy inputs

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(interfuel substitution). Reduced substitution potential may be derived from:

A. The adoption of a production function which exhibits low or zero substitutability (i.e., fixed coefficient technology);
B. The lack of technical skills and/or financial resources to implement or expand new "unconventional" energy sources (e.g., solar or wind power systems);
C. The unwillingness of firms to invest in new production processes that are energy-efficient due to low rate of return expectations.

Such limitations on substitution have led developing countries to depend to an increasing extent on imported petroleum and to maintain production processes which are inefficient in terms of the least-cost factor combinations that determine profitability and capital investment. Moreover, these inefficiencies aid in exacerbating a host of socio-economic problems: low labor force absorption rates, technological dualism, and high (non-indigenous) energy import bills (balance of payments difficulties). It therefore follows that development efforts in these nations ought to be directed toward finding ways to increase the elasticity of substitution between energy and other factors of production.

Over the past decade a number of empirical studies pertinent to developed countries have attempted to estimate the energy elasticity of substitution with other inputs [Hudson and Jorgensong (1974); Berndt and Wood (1975 and 1979); Griffin and Gregory (1976); Pyndick (1979); and Anderson (1980)]. Differing methodologies and data bases have led to divergent conclusions. For example, Griffin/Gregory and Pyndick found that energy and capital are substitute inputs, whereas Berndt/Wood and Hudson/Jorgenson concluded that they are complementary.

It is the purpose of this paper to estimate energy substitution possibilities for the small, open, and oil-importing economy of Puerto Rico using data pertinent to the manufacturing sector and covering the period 1967 to 1980. In addition to dealing with the case of a developing country, the 14 year interval is significant, for it straddles the post-1973 oil price shocks; none of the above-cited studies does so. Inclusion of the highly unstable post-1973 interval is expected to shed light on recent responses to higher petroleum prices. A KLE (capital, labor, energy) translog cost function will be employed to measure energy substitution potential. Use of such a function permits a better estimation of capital-labor and capital-energy elasticity of substitution coefficients. Conventional functions such as CES and its variants (e.g., Cobb-Douglas) are highly restrictive in terms of their elasticity estimation reliability, and can therefore lead to incorrect interpretations, especially as applied to developing countries. The translog cost function provides a better estimate of the required parameters, since it permits one to obtain non-restrictive elasticity coefficients from among various inputs incorporated in a production function.

II. The Puerto Rican Economy and Energy Situation: An Overview

In the late 1940's Puerto Rico adopted an economic development strategy based upon tax exemption to attract foreign capital, externally-focused manufacturing (i.e., the importation of raw materials and semifinished goods to which value was added and then re-exported), massive capital and technology imports mainly from the United States (U.S.), and the ready availability of low-cost energy (petroleum imports from the U.S. and Venezuela). This development model was emminently successful until the early 1970's, as real per capita gross product tripled between 1950 and 1973. Dependence upon oil imports for energy supplies became overriding, for nearly 100% of total energy was established on the island's south coast in response to cheap and plentiful oil supplies from Venezuela and to U.S. oil quota rules. The manufacturing sector became the predominant generator of national income, its relative contribution coming in at around 40% by the late 1970's. Nevertheless, as the capital-intensity of this same sector increased, the proportion of total employment created by it remained essentially constant at the 20% level.

The 1973/74 energy crisis and subsequent instability in world oil markets greatly affected the adopted development strategy. The energy-cost rises were felt in all economic sectors, but no sector was more severely damaged than was manufacturing (especially hurt were petrochemicals, oil refining, and cement, so vital to the construction sector). By 1980 Puerto Rico's imports of petroleum and derivatives amounted to close to one-quarter of its gross product. Not coincidentally, real per capita gross product rose a mere 8% between 1973 and 1980. Moreover, the unemployment rate, which during the boom years of the 1950's and 1960's had hovered around 12%, jumped to the 16-20% range. Of course, the island's locational advantages were seriously eroded, and private capital investment declined significantly from the early 1970's[1].

Since the mid-1970's a number of efforts have been underway to develop energy alternatives (the promising nuclear energy program of the 1960's has been totally discarded). Research has been directed toward tapping both inexhaustible resources (sun, wind, sea) and renewable energy sources (biomass, bioconversion). Yet, these porjects cannot be expected to produce short-or even medium-term results. Consequently, energy costs remain a high burden for an open and natural resource scarce economy, thereby leading to the conclusion that other avenues — different factor substitution possibilities — should also be explored.

III. The Deterministic Model

We assume that there exists a production function summarizing the underlying technology of the form:

(1) $Q = f(K, L, E, M)$

where Q = gross output
K = capital stock input
L = labor input
E = energy input
M = raw materials (non-energy intermediate good)

Such a function is twice-differentiable, and is postulated to embody constant returns to scale (CRTS) and Hicks-neutral technical change. Corresponding to this production function is a dual cost function which, given cost-minimizing behavior and exogenously determined output and prices, can be represented by:

[1] This long-run, or structural, growth problem has often been noted. See, for example, Alameda (1980) or Committee to Study Puerto Rico's Finances (1975).

(2) $C = C(P_K, P_L, P_E, P_M, Q)$

where C = total factor cost
P_K = capital input price
P_L = labor input price
P_E = energy input price
P_M = non-energy intermediate goods price
Q = gross output

The cost function (2) will be represented by a translog cost function. A homothetic production function is dual to a cost function of the form:

$$(3)\quad \ln C = \ln\alpha_o + \sum_i \alpha_i \ln P_i + 1/2 \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j$$

$$i, j = K, L, E, M$$

where α and β refer to parameters. A non-homothetic production structure is dual to a cost function of the following form:

$$(4)\quad \ln C = \ln\alpha_o + \sum_i \alpha_i P_i + \alpha_Q \ln Q + 1/2 \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j$$

$$+ \sum_i \beta_{iQ} \ln Q \ln P_i + 1/2\, \beta_{QQ} (\ln Q)$$

$$i, j = K, L, E, M$$

A useful feature of (3) and (4) is that factor substitution elasticities can be directly determined.

We also assume that the cost function is weakly separable from raw materials (M). Therefore, (2) can be rewritten as:

$$(5)\quad C = C\left[\phi(P_K, P_L, P_E), P_M, Q\right]$$

Elements i and j in (3) and (4) take into consideration only K, L, and E. Data constraints force us to posit this kind of separability[2].

[2] Griffin and Gregory (1976) used this variant in their paper. The lack of reliable data for most material inputs was the principal restrictive condition. Moreover, it was not possible to obtain reliable non-energy raw material prices for Puerto Rico due to the absence of disaggregated time-series figures.

Differentiating (3) logarithmically with respect to input price we obtain:

$$(6) \quad \frac{\partial \ln \phi}{\partial \ln P_i} = \frac{\partial \phi}{\partial P_i} \frac{P_i}{\phi} = \alpha_i + \sum_i \beta_{ij} \ln p_j ; \; i, j = K, L, E$$

Applying Shephard's lemma, $\frac{\partial \phi}{\partial P_i} = X_i$, the cost minimizing quantity demand for the ith input becomes:

$$(7) \quad \frac{\partial \ln \phi}{\partial \ln P_i} = P_i X_i = S_i, \text{ in which,}$$

$$(8) \quad S_i = \alpha_i + \sum_i \beta_{ij} \ln P_j ; \; i, j = K, L, E$$

Therefore, the input demand functions, in terms of cost share, take the form of equation (8); cost share equations take a linear form of the factor prices.

Repeating the same steps for equation (4) generates the subsequent cost share equation:

$$(9) \quad S_i = \alpha_i + \sum_j \beta_{ij} \ln P_j + \beta_{iQ} \ln Q ; \; i, j = K, L, E$$

To satisfy the adding up criterion ($\sum_i S_i = 1$) and the properties of neoclassical production theory[3], the following parameter restrictions have to be met:

(10) a. $\sum_i \alpha_i = 1$,

b. $\sum_j \beta_{ij} = \sum_i \beta_{ij} = 0$ (Cournot aggregation),

c. $\sum_i \beta_{iQ} = 0$ (Engel aggregation) for (4) and (9)

d. $\beta_{ij} = \beta_{ji}$ (Slutsky symmetry), $i \neq j$.

[3] It is generally assumed that a neoclassical production function satisfies the following properties: (a) both factor inputs are indispensable in the production process; (b) both marginal productivities are non-negative; (c) the Hessian matrix of second-order partial derivatives of the production function is negative semidefinite, thereby ensuring the proper curvature of the isoquants.

Combining (10a), (10b), and (10d) yields a series of linearly homogenous share equations (8), where the parameters of any two equations completely specify the model. Empirical implementation requires that these input demand equations (8) be imbedded within a stochastic framework. Added to each of the equations in (8) is an additive and correlated disturbance term across equations. Since cost shares always sum to unity, the sum of the disturbance across the equations (8) is zero at each observation.

Factor substitution and price elasticities can be computed directly from the parameter estimates. Factor substitution elasticities (Allen-Uzawa elasticities of substitution) between input i and j are:

$$(11)\quad \sigma_{ij} = \frac{\phi\phi_{ij}}{\phi_i\phi_j}$$

where;

$$(12)\quad \phi_i = \frac{\partial\phi}{\partial P_i}, \text{and} \quad \phi_{ij} = \frac{\partial^2\phi}{\partial P_i \partial P_j},$$

and by definition $\sigma_{ij} = \sigma_{ji}$. In a translog model, the Allen-Uzawa elasticities of substitution are:

$$(13)\quad \sigma_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^2} \quad ; \quad i = K, L, E \quad \text{and,}$$

$$(14)\quad \sigma_{ij} = \frac{\beta_{ij} + S_i\ S_j}{S_i\ S_j} \quad ; \quad i \neq j\ ;\ i, j = K, L, E,$$

Similarly, the price elasticities of demand (E_{ij}) for inputs come directly from (14):

$$(15)\quad E_{ij} = S_j\, \sigma_{ij} \quad ; \quad i, j = K, L, E$$

From (15) cross and own factor-price demand elasticities can be estimated.

With respect to the estimation of the equation systems, since linear homogeneity has been assumed the regressors in (8) may be rewritten as logarithms of the price ratios. In addition, the estimation procedure technique employed here — the Iterative Zellner Efficient (IZEF) method — not only meets all translog parameter restrictions, but also enables one to obtain invariant estimators of the omitted equation. Therefore,

$$(16)\quad S_E = \alpha_E + \beta_{EE} \ln (P_E/P_K) + \beta_{EL} \ln (P_L/P_K) + u_E$$

$$S_L = \alpha_L + \beta_{EL} \ln (P_E/P_K) + \beta_{LL} \ln (P_L/P_K) + u_L$$

Consistent estimates of the parameters are provided by iterating regression coefficients until the estimates and the residual covariance matrix converge. A non-zero covariance, COV (U_E, U_L), is explicitly taken into account by transforming the equations to obtain a zero covariance and by minimizing the trace of the transformed residual variance-covariance matrix. An IZEF estimate is consistent, asymptotically efficient, and a maximum likelihood estimator[4].

IV. The Empirical Estimates

The IZEF estiamtes of the KLE translog cost function for the Puerto Rican manufacturing sector over the period 1967-80 are presented in Table 1; linear homogeneity is imposed on input prices. The conventional R^2 are 0.956 for the energy share equation and 0.645 for the labor share equation, with the respective residual sum of the squares being 0.00345 and 0.00380. The estimated variance-covariance matrix of these estimates is found in Appendix Table A-3.

To measure factor substitution possibilities we have calculated the Allen-Uzawa partial elasticities of substitution (σ_{ij}) and price elasticities (E_{ij}) as found in equations (13) through (15). Since the estimated elasticities do not display large year to year variations, some years are omitted from the presentation in Tables 2 and 3 of the factor substitution and price elasticities. Analysis of these estimates generates the following general conclusions for the 1967-80 interval:

4 For amplification see Berndt and Christensen (1973).

A. Capital and labor display a high degree of substitutability[5].
B. Energy and capital are complementary, a result compatible with the Berndt/Wood and Hudson/Jorgenson studies.
C. Energy and labor are readily substitutable (but less so than capital and labor), and this relation has been growing increasingly stronger.
D. The capital price elasticity coefficient demonstrates that the capital demand-price (the interest rate) relationship remained essentially constant, but that the capital demand-energy price connection showed decreasing sensitivity.
E. The energy price elasticity coefficient shows that energy demand became more sensitive to energy price variations after the 1973/74 oil price hikes; in fact, prior to this time the elasticity coefficient was positive.
F. Labor demand became more sensitive to changes in both labor prices and energy prices.

V. Interpretation and Developmental Implications

The high value for the capital-labor elasticity of substitution coefficient is not surprising in view of the type of manufacturing enterprise that has been increasingly lured to Puerto Rico since the mid-1960's. Electronics and pharmaceuticals represent relatively capital-intensive and high value-added industries, but are certainly labor-saving. Moreover, labor demand has become more elastic with respect to its own price, thereby implying that further rises in federal (U.S.) minimum wage standards will simply lead to additional "firm-drain" to lower wage areas of the Caribbean and other regions. Neither of these phenomena brings positive news for the island's long-term labor market outlook, where unemployment rates linger at around one-fifth of the labor force. Despite the continuance of net out-migration to the U.S. during the 1970's, the participation rates of the overall population (above 16 years of age) and especially of central age males continue to decline. Clearly, the present manufacturing-led development strategy will make little dent in these labor market problems. Furthermore, such a model appears to be creating a definite job market dualism, handsomely compensating the

[5] This finding agrees with previous estimates presented in Gutiérrez (1977) covering the period 1959-63.

relatively skilled persons who find work but excluding those lacking the necessary aptitudes.

That energy and capital emerge as complementary factors of production even after the oil crises of the 1970's is mildly surprising, although the effects of higher energy prices may not be thoroughly felt until well into the 1980's. There are various alternative explanations for this limited energy substitution result. By

Table 1

IZEF PARAMETER ESTIMATES OF THE KLE TRANSLOG COST FUNCTION: PUERTO RICO MANUFACTURING, 1967-1980 (t-values in parenthesis)[a]

Parameter	Estimates	Standard Error
α_K	.33026 (63.76)	.00518
α_E	.04693 (6.64)	.00707
α_L	.62281 (68.67)	.00907
β_{KK}	.06448 (1.20)	.05000
β_{EK}	-.09243 (7.96)	.01161
β_{KL}	.02795 (0.968)	.02888
β_{EE}	.12873 (10.92)	.01179
β_{EL}	-.03630 (-1.82)	.01996
β_{LL}	.00835 (0.1784)	.04681

[a] Four iterations were performed. The converge criterion difference is lower than .00001.

Table 2

IZEF ESTIMATED ALLEN-UZAWA PARTIAL ELASTICITIES OF SUBSTITUTION (A-UES),[a] TRANSLOG COST FUNCTION: PUERTO RICO MANUFACTURING, 1967-1980
(standard errors in parentheses)

A-UES	1967	1970	1972	1974	1976	1978	1980
σ_{LL}	-.512	-.62	-.587	-.672	-.66	-.753	-.80
σ_{KK}	-1.67	-1.41	-1.53	-1.54	-2.11	-2.35	-2.47
σ_{EE}	2.55	23.74	16.66	4.36	-.48	-.92	-.94
σ_{KL}	1.15*	1.14*	1.14*	1.15*	1.20*	1.24*	1.27*
	(.151)	(.142)	(.147)	(.156)	(.220)	(.252)	(.277)
σ_{EK}	-4.77*	-3.9*	-3.58*	-2.04*	-1.3*	-0.94*	-0.85*
	(.724)	(.615)	(.575)	(.382)	(.288)	(.243)	(.232)
σ_{EL}	-0.13	-.057	.090	.366	.097	.683*	.747*
	(.555)	(.580)	(.499)	(.348)	(.193)	(.151)	(.139)

[a] A positive sign denotes substitute inputs, while a negative sign denotes complements. An asterisk (*) indicates that the null hypothesis $\sigma_{ij} = 0$ has been rejected at the 95% confidence level. Refer to the technical note in the Appendix.

the late 1970's the adoption of energy-saving plant and equipment had either not been seriously undertaken or had not yet had time to work itself through the economy; it does seem to imply that the manufacturing sector has implicitly employed an essentially fixed coefficient production function with respect to energy and capital. Of course, the degree of technical substitution between these factors does widely vary between industrial groups, but the aggregate time-series analysis performed in this paper does not (unfortunately) permit such distinction. Nevertheless, on the whole it is evident that the rather inflexible transfer of technology and capital from the developed countries (mainly the U.S.) to Puerto Rico has resulted in the observed complementarity between capital and energy, subsequently exacerbating the economic difficulties created by rising real energy costs.

Table 3

IZEF ESTIMATED PRICE ELASTICITIES OF DEMAND, TRANSLOG COST FUNCTION: PUERTO RICO MANUFACTURING, 1967-1980 (standard errors in parentheses)[a]

Price Elasticity	1967	1970	1972	1974	1976	1978	1980
E_{KK}	-.487*	-.473*	-.481*	-.482*	-.49*	-.48*	-.47*
	(.171)	(.150)	(.160)	(.160)	(.215)	(.245)	(.026)
E_{LL}	-.334*	-.378*	-.365*	-.396*	-.391*	-.423*	-.438*
	(.072)	(.077)	(.075)	(.079)	(.079)	(.083)	(.085)
E_{EE}	1.40*	1.34*	1.07*	.423*	-.083*	-.216*	-.247*
	(.214)	(.209)	(.183)	(.121)	(.068)	(.05)	(.045)
E_{KL}	.75	.69	.71	.678	.713	.699	.693
E_{EL}	-.00067	-.0032	.0058	.0356	.017	.16	.196
E_{KE}	-.262	-.22	-.28	-.20	-.23	-.22	-.22

[a]An asterisk (*) indicates that the null hypothesis $\sigma_{ij} = 0$ has been rejected at the 95% confidence level. Refer to the technical note in the Appendix.

Enhanced substitution possibilities between energy and capital appear to be a strict requirement for both the island's manufacturing sector and overall economy. With little or no substitution, a reduction in energy demand necessarily implies a decline in capital utilization, which in turn generates a drop in labor and capital productivities and in overall economic activity; better substitution alternatives would enable the economy to minimize the impact of higher energy prices and improve competitiveness and profitability. To what extent the adoption of more energy-substitutable capital goods will occur is uncertain, given the decade-long slide in private capital investment which is, in part, a reflection of the erosion of the locational advantages that Puerto Rico once had as a plant site.

That energy and labor are readily substitutable may be derived from the relatively high substitutability found between capital and labor, which, in turn, flows from the importation of capital and capital-intensive production processes from abroad. Thus, the complementarity that appears between energy and capital is certainly not unexpected, for such imports in essentially unaltered and unadapted form do not create energy-saving. The simplistic public policy prescription to attack this quandary would be to state that industrial promotions should henceforth emphasize more labor-intensive industries. However, this is far more easily said than done, and Puerto Rico can no longer compete with other much lower labor cost areas for many of these industries (even taking into account productivity differentials). Therefore, what these results do suggest is that a great deal more resources should be devoted to basic research and development and/or to the import of energy-saving manufacturing processes.

The observed decline in private capital accumulation can be tied in with the decrease in the cross capital-energy price elasticity coefficient. This implies that even in the face of energy price drops (such as those that occurred after 1981), the rate of private capital investment will probably not increase as rapidly as it did during the 1960's. Such behavior emerges because investment demand is a function of a host of interrelated factors rather than the sole consequence of changing energy prices.

The changing value and sign of the energy demand price elasticity coefficient has striking implications for policy purposes. Whereas prior to the 1973/74 OPEC-spurred price jumps this coefficient displayed a positive sign, it subsequently depicted the more expected negative sign. Such sign-switching is most likely due to the fact that at the beginning of the period under study the income effect was strong enough to outweigh the price effect because energy demand growth was more a function of substantial real income increases than of price variations; the sudden real price leaps simply inverted these tendencies. Total purchased energy consumption grew proportionally with output between 1967 and 1973 (when oil prices were stable), but rose much more slowly after 1973. Thus, the elasticity estimates probably reflect these two different energy price structures. This certainly suggests that substantial energy-saving accompanied by positives balance of payments effects can be induced through the price mechanism; tax induced energy price rises would have similar results. On the other hand, due to the increasing energy price elasticity, revenue projections for the publicly-owned and deficit-ridden Electric Power Authority would exaggerate the expected income from rate rises.

In summary, in the case Puerto Rico the large quantities of capital and technology that have been imported over the years generated both positive and negative effects. The most positive result was that of a greatly enhanced standard of living, although the post-1973 years have witnessed decidedly lower (and even negative) growth rates. The negative effects have been reflected in labor market and balance of payments disequilibria, created, at least in part, by the adoption of capital and energy-intensive industrial production methods. It would have been thought that the post-1973 energy price jumps might have reduced capital/energy intensiveness and enhanced labor intensiveness, but this has apparently not occurred. Rather, the existence of a gamut of tax incentives (full U.S. tax exemption and partial — up to 90% — Puerto Rican exemption) vastly reduce the price of capital services. As a result, the complementarity between energy and capital implies that these tax incentives, as presently structured, actually may generate even more demand for both energy and capital. What needs to be looked at, then, is the nature of these (and other) fiscal incentives. They must be revised so as to promote and reward the job-creating and energy-saving capacities of capital investment.

Appendix:
Data, Sources, and Technical Note

Table A-1

ENERGY COSTS, QUANTITIES, AND PRICES: PUERTO RICO MANUFACTURING SECTOR, 1967-1980

Year	(1) Total fuel consumed, all Puerto Rico (MOB)[a]	(2) Total fuel consumed in manufacturing (MOB)[b]		(3) Cost of fuel consumed in manufacturing (million $)[c]	(4) Cost of electricity consumed in manufacturing (million $)[d]	(5) Total energy costs (million $)[e]	(6) Electric power consumed (MOB)[f]	(7) Total energy consumed (MOB)[g]	(8) = (5)/(7) Average price of energy ($ per barrel of oil)
1967	21.6	5.1	6.6	14.5	20.3	34.7	1.4	8.0	4.3
1968	24.3	6.2	8.1	17.4	23.3	40.8	1.6	9.7	4.2
1969	26.5	6.7	8.7	21.1	26.8	47.9	1.9	10.6	4.5
1970	29.8	7.8	10.2	25.4	30.8	56.3	2.1	12.3	4.6
1971	33.7	9.3	12.1	30.7	35.3	66.1	2.5	14.6	4.5
1972	39.0	11.2	14.5	37.0	40.6	77.6	3.9	18.4	4.2
1973	45.7	13.8	17.8	52.9	55.8	108.8	4.6	22.3	4.9
1974	54.9	13.6	17.7	72.7	76.6	152.4	4.8	22.5	6.8
1975	57.1	12.3	15.9	108.2	105.2	213.6	4.7	20.6	10.4
1976	56.4	14.5	18.8	154.7	144.5	299.4	4.9	23.7	12.6
1977	56.5	15.3	19.8	221.1	198.5	419.6	5.2	25.0	16.8
1978	58.8	16.2	21.0	338.1	212.6	550.7	5.2	26.2	21.0
1979	62.3	16.6	21.5	337.6	208.5	546.1	5.0	26.5	20.6
1980	57.3	16.8	21.8	536.3	259.8	796.1	4.5	26.3	30.2

MOB — Millions of barrels of oil.

Table A-2

TOTAL ESTIMATED INPUT COSTS, COST SHARES, AND INPUT PRICES: PUERTO RICO MANUFACTURING SECTOR, 1967-1980[a]

Year	(1) Capital input opportunity cost (million $)	(2) Energy cost, current prices (million $)	(3) Labor compensation, current prices (million $)	(4) Total estimated input cost (million $)	(5) Capital Share	(6) Energy Share	(7) Labor Share	(8) Capital price index (1972=100)	(9) Energy price index (1972=100)	(10) Labor price index (1972=100)
1967	184.5	34.7	412.6	631.8	.2920	.0549	.6531	70.5	102.4	64.5
1968	241.1	40.8	476.8	758.7	.3178	.0538	.6284	96.5	100.0	82.2
1969	274.8	47.9	557.0	879.7	.3124	.0545	.6332	99.4	107.1	78.8
1970	334.4	56.3	607.9	998.6	.3349	.0564	.6088	106.8	109.5	87.1
1971	354.4	66.1	658.8	1,079.3	.3284	.0612	.6104	101.4	107.1	93.4
1972	380.6	77.6	751.3	1,208.9	.3143	.0642	.6215	100.0	100.0	100.0
1973	427.6	108.8	841.9	1,378.3	.3102	.0789	.6108	106.5	116.7	108.0
1974	491.6	152.4	925.8	1,569.8	.3132	.0971	.5898	118.6	161.9	121.0
1975	467.5	213.6	964.9	1,646.0	.2840	.1298	.5862	111.3	247.6	138.0
1976	401.8	299.4	1,028.1	1,729.3	.2324	.1731	.5945	94.6	300.0	139.0
1977	402.8	419.6	1,149.4	1,971.8	.2043	.2128	.5829	94.8	400.0	152.0
1978	480.1	550.9	1,323.4	2,354.4	.2040	.2234	.5622	112.1	500.0	168.0
1979	532.7	546.1	1,496.7	2,575.5	.2068	.2120	.5811	124.2	490.7	186.0
1980	577.9	796.1	1,657.5	3,031.5	.1906	.2626	.5468	135.4	720.7	210.0

Notes to Table A-1

[a] Data for 1976-80 from Energy Office of Puerto Rico, *Estadísticas Energéticas Anuales*, 1981 (San Juan); data for 1967-1975 from J. Bonnet and W. Ocasio, "La situación energética de la isla de Puerto Rico," Center for Energy and Environment Research, October 1980.

[b] Estimated under the assumption that manufacturing consumed either 27% or 35% of total fuel consumed, with the Puerto Rico Electric Power Authority consuming 40%. Historically, the Authority has accounted for from 34% to 40% of total fuel consumed, but the divergent figures for manufacturing sector consumption come from different and varying sources; the 27% and 35% represent the extremes of the possible range, and the actual proportion lies somewhere within these extremes.

[c] Time-series data for fuel cost in manufacturing are not available. Three data points are available from the U.S. Department of Commerce Censuses of Manufacturing for the years 1967, 1972, and 1977; the annual compound rate of growth between data points was used to interpolate those years between these points. The 1979-80 data were calculated by multiplying the average fuel oil prices in each year (16.1, 15.7, and 24.6) by the upper range of column 2.

[d] Estimated as in note "c"; 1978-80 data from the P.R. Electric Power Authority's annual reports.

[e] Estimated as in note "c". Due to rounding, the sum of (3) and (4) might not equal (5).

[f] Calculated using 1 kwh = 0.0010736 barrels.

[g] is the upper range of column (2) plus column (6).

Notes to Table A-2

[a] The data required for the estimation of the KLE translog cost function are the cost shares of the three inputs and their prices. Energy costs are taken from Table A-1. Labor costs include wages and salaries plus supplements, and are taken from Puerto Rico's national accounts; see Puerto Rico Planning Board, *Income and Product*, various years.

Capital costs were far more difficult to estimate. The "capital input opportunity cost" figures which are presented in the first column of the table are unobservable, and represent proxies for the desired data. Total input costs in Puerto Rico's manufacturing sector cannot be equated with gross output value (observable) for several reasons. The relatively low cost of current capital and the high returns enjoyed by private investors widen the gap between total input costs and gross output. The low capital cost has been intentionally generated by the island's Economic Development Administration via the building and subsequent leasing of plants and via the absorption of employee training expenses. Thus, any attempt to equate the cost of capital with the private investment rate of return would produce misleading results.

The data required for the estimation of capital costs are investment in constant prices, a capital benchmark, and a rate of capital stock replacement. The 1947 benchmarks in 1954 dollars are $27.8 million for machinery and equipment and $14.5 million for structures; this involves the implicit assumption that these figures constituted the accumulated capital stock in 1947. Such an assumption can be defended by arguing that the pre-1950 rate of capital accumulation was very low, since the overall economic development process did not really get under way until then. Therefore, the estimated capital stock figures for 1967-80 closely approximate the "true" capital stock values under the depreciation rates selected for each category. Replacement rates (chosen arbitrarily) are 0.10 for machinery and 0.07 for structures, and are very similar to those used in Berndt/Christensen (1973) and Christensen/Jorgenson (1969).

Cost shares have been calculated using the following expressions:

$$\text{Capital share} = \frac{\text{capital input opportunity costs}}{\text{total estimated input costs}}$$

$$\text{Labor share} = \frac{\text{compensation of employees}}{\text{total estimated input costs}}$$

$$\text{Energy share} = \frac{\text{energy costs}}{\text{total estimated input costs}}$$

Prices for capital, energy, and labor are, respectively, the rate of return on loans, average energy prices (See Table A-1), and average compensation per employee; simple indexes have been calculated for these prices.

Table A-3

IZEF ESTIMATED VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	α_E	β_{EE}	β_{EL}	α_L	β_{LL}
α_E	.00004977	.00006537	.00008245	-.00005237	-.0001335
β_{EE}	-.00006537	.0001385	-.0002004	.0000860	.0003658
β_{EL}	.00008245	-.000200	.0003968	-.0001532	-.0008749
α_L	-.00005237	.0000860	-.0001532	.00008176	.0003088
β_{LL}	-.00013335	.0003658	-.000875	.0003088	.002184

Technical Note

Significance tests were performed for factor and price elasticity estimates. As it is conventionally presented:

$$H_o : \sigma_{ij} = 0$$

$$H_A : \sigma_{ij} \neq 0$$

for elasticity of substitution estimates. For own price elasticity estimates:

$$H_o : E_{ii} = 0$$

$$H_A : E_{ii} \neq 0$$

The t ratios for factor and own price elasticities were calculated as follows:

$$t = \frac{\sigma_{ij}}{S.E.(\sigma_{ij})} \text{ and, } \hat{t} = \frac{E_{ii}}{S.E.(E_{ii})}, \text{ where}$$

S.E. is the standard error of the estimates. Standard errors were computed using the following equation:

$$\text{S.E. } (\sigma_{ij}) = \sqrt{\text{Var } (\sigma_{ij})} = \frac{\text{Var } (\beta_{ij})}{(S_i S_j)^2} \text{ and,}$$

$$\text{S.E. } (E_{ii}) = \sqrt{\text{Var } (E_{ii})} = \frac{\text{Var } (\beta_{ii})}{(S_i)^2}$$

For further details refer to Humphrey (1977).

Degrees of freedom were computed as: d.f. = m–k where m (sample size in the system) is 2xn (n = single sample size), and k (number of parameters in the system) is 2xj (j = number of parameters per equation). Therefore, d.f. is 22 = 2 (14–3). At a 95% confidence level the t value is 1.717.

Cross elasticities have already been reported using the σ_{ij} test results and need not be repeated here.

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