Sectoral Linkages and Industrial Efficiency: A Dilemma or a Requisition in Identifying Development Priorities?

Giannis Karagiannis
(*Dept. of International and European Economic and Political Studies, University of Macedonia, Greece*)

Vangelis Tzouvelekas
(*Dept. of Economics, University of Crete, Greece*)

June 2003

Please direct correspondence to:

Vangelis Tzouvelekas

Dept. of Economics, University of Crete
University Campus, 741 00 Rethymno,
Crete, GREECE.
Phone: +30-28310-77417; Fax: +30-28310-77406;
e-mail: vangelis@econ.soc.uoc.gr

Sectoral Linkages and Industrial Efficiency: A Dilemma or a Requisition in Identifying Development Priorities?

Abstract

This paper attempts to provide an empirical evaluation of the potential relationship between sectoral linkages and technical efficiency using the 1996 US input-output tables. Sectoral input-oriented technical efficiency is obtained by the econometric estimation of a stochastic input-distance function based on Battese and Coelli (1995) model formulation. On the other hand, sectoral backward and forward linkage coefficients were computed using the non-complete hypothetical extraction method suggested by Dietzenbacher and Van der Linden (1997). The empirical results suggest that there is a negative relationship between sectoral efficiency and linkage coefficients, while on the other hand efficient sectors tend to purchase their intermediate inputs from efficient sectors and *vice versa*.

1. Introduction

In forming economic development policies the assessment of sectoral economic performance and production interdependence are both very important issues. While, sectoral interdependence is one of the most important source of economic expansion in a competitive economy, efficiency is the most important control parameter for assessing the utilization of inputs in the production process. A large and strongly interdependent sector may be seen as a good candidate for the economic development of a particular country or region. The expansion of this sector will have a significant impact, increasing output, income or employment domestically.

However, and equally important, a sector that operates more efficiently (i.e. producing as much output as the inputs at its disposal permit under the current state of technology) compared to the same sector in other countries or regions could be a better candidate for long term growth and development. That's because efficiency is one of the main factors determining the overall competitiveness of a sector. The higher the degree of efficiency, the lower will be the unit cost of production and as a result, industries will be able to supply their products at lower prices. Consequently, more efficient industries would have better chances of surviving and prospering in the future than less efficient ones. Furthermore, improvements in sectoral efficiency can increase productivity and thus output growth within the national or regional economy, thus providing a more cost-effective way for stimulating internal economic growth.

In the short-run, an economic sector may be large enough to attract policy attention but if it is not operating efficiently compared to the same sector in other nations or regions, sooner or later it will become less competitive and begin to diminish from external competitive pressures. It is evident therefore, that it is important to know how much a given sector can stimulate economic growth within the economy without resource waste, thereby improving its competitive status. In a long-term competitive environment the overall efficiency and thus productivity of a national or regional economy determines the general well-being of its people (Krugman, 1991).

Traditionally, input-output analysis and the subsequent measurement of linkage coefficients has been used excessively for the identification of key economic sectors in both national and regional economies. Since the pioneering work of Rasmussen (1956), Chenery and Watanabe (1958) and Hirschman (1958), a number of studies employing input-output techniques have relied on linkage analysis to describe the interdependent relationships between economic sectors and to assist in the formulation of economic development strategies. The economic rationale behind the empirical significance of linkage analysis is rather simple: the expansion of sectors with strong linkages and thus production interdependencies within the economy is likely to promote overall economic development.

Through the years the methodological framework has been improved and expanded in several ways, and many different analytical methods have been proposed for the measurement of interindustry linkage coefficients (i.e. Jones, 1976; Cella, 1984; Heimler, 1991; Sonis *et al*., 1995; Dietzenbacher and Van der Linden, 1997). Although it seems that the problem of the appropriate linkage indicator has been resolved, there still remains an important practical question: would the expansion of the "*key*" sectors identified by means of linkage coefficients would indeed promote economic development?

The aim of this paper is to explore this unknown relationship between sectoral interdependence and technical efficiency. The empirical analysis is based on the 1996 US input-output tables published by the Bureau of Economic Analysis. Both backward and forward linkage coefficients were computed using the approach suggested recently by Dietzenbacher and Van der Linden (1997), which is an adapted form of Strassert's (1968) hypothetical extraction method. Measurement of sectoral technical efficiency is based on Shephard's (1953) input-distance function which can easily accommodate multi-output technologies under the assumption of weak disposability. Finally, the stochastic frontier is modeled according to Battese and Coelli's (1995) inefficiency effects model.

The rest of this paper is organized as follows: the methodological framework for the estimation of backward and forward linkage coefficients using Dietzenbacher and Van der Linden's (1997) non-complete hypothetical extraction method is presented in the next section. The use of Shephard's input-distance function in stochastic frontier modelling and the associated measurement of technical efficiency is discussed in the third section. The empirical model and data sources are presented in the fourth section. A discussion of empirical findings and a comparison of sectoral technical efficiency and linkage coefficients are given in the fifth section. Concluding remarks follow in the last section.

2. Non-Complete Hypothetical Extraction Method

Consider the usual demand and supply-driven[1] Leontief input-output systems:

$$X = \left(Z\widehat{X}^{-1}\right)X + Y = AX + Y \tag{1a}$$

and

$$X' = X'\left(\widehat{X}^{-1}Z\right) + V' = X'B + V' \tag{1b}$$

where X is the vector of sectoral gross output, Z is the transactions matrix, Y is the vector of sectoral final demand, V is the vector of sectoral final payments and $\widehat{X}^{-1}$ is a diagonal matrix of sectoral gross output. Solving the above systems for the vector of sectoral output X we get:

$$X = [I - A]^{-1} Y \tag{2a}$$

and

$$X' = V'[I - B]^{-1} \tag{2b}$$

The basic idea of Strassert's (1968) original approach hinges on the hypothetical extraction of one sector from the economy and then the examination of the impact of this hypothetical extraction on other sectors of the economy. Under the usual assumption of the input-output system, the reduced output vector $\widetilde{X}_{(k)}$ is less than the original output vector X. Then the sum of the differential between the output vector X excluding the k^{th} element and $\widetilde{X}_{(k)}$ provide a measure of the total (both backward and forward) linkage effect of the extracted sector k on total output.

As noted by several authors, the hypothetical extraction method as suggested by Strassert (1968) has two important shortcomings: first, it fails to distinguish between backward and forward linkages, and second, the complete extraction of an entire sector from the system seems to be rather excessive (i.e. Meller and Marfán, 1981; Cella, 1984; Clements, 1990).

Recognizing the above deficiencies, Dietzenbacher and Van der Linden (1997) improved the methodological framework suggesting a non-complete extraction method.[2] Their approach is based on the assumption that backward linkages should reflect a sector's interdependence on inputs that are produced within the economy. Therefore, only these intermediate inputs should be hypothetically eliminated in order to measure the backward linkages.

Let us assume that the economy is divided into two separate blocks of industries, agriculture and manufacturing, and that we want to calculate the backward linkage for agriculture. Agriculture buys no intermediate inputs from the other production sectors within the economy; they have their origin outside of the system (i.e. imports). Therefore the corresponding elements of the technical coefficient matrix are set equal to zero. Thus, the demand-driven system in (*1a*) can be expressed as:

$$\begin{bmatrix} \widetilde{X}_a \\ \widetilde{X}_m \end{bmatrix} = \begin{bmatrix} 0 & A_{am} \\ 0 & A_{mm} \end{bmatrix} \begin{bmatrix} \widetilde{X}_a \\ \widetilde{X}_m \end{bmatrix} + \begin{bmatrix} Y_a \\ Y_m \end{bmatrix} \qquad (3)$$

where $\widetilde{X}_a$ is the vector of output for agricultural sectors, $\widetilde{X}_m$ is the vector of output of manufacturing sectors, $\widetilde{A}_{am}$ is the matrix of technical coefficients for the demand of the products of agricultural sectors by manufacturing, $\widetilde{A}_{mm}$ is the matrix of technical coefficients for self-consumption of manufacturing sectors, Y_a and Y_m are the final demand vectors of the agricultural and manufacturing sectors, respectively. Solving the above system for $\widetilde{X}_i$ (i=a, m) we obtain:

$$\begin{bmatrix} \widetilde{X}_a \\ \widetilde{X}_m \end{bmatrix} = \begin{bmatrix} I & A_{am}(I - A_{mm})^{-1} \\ 0 & (I - A_{mm})^{-1} \end{bmatrix} \begin{bmatrix} Y_a \\ Y_m \end{bmatrix} \tag{4}$$

The absolute backward linkage is defined as the difference between actual total output of the economy and that after the extraction of the agricultural sectors. The latter is less than the former due to the fact that agricultural sectors no longer depend on manufacturing with regard to their input requirements. This output decrease reflects the dependence of the agricultural sector on manufacturing, as well as on itself.[3]

$$ABL_a^D = e'\begin{bmatrix} X_a - \widetilde{X}_a \\ X_m - \widetilde{X}_m \end{bmatrix} \tag{5a}$$

$$\begin{aligned} ABL_a^D = {} & [(D - I) + e'G_{mm}A_{ma}D]Y_a + [(D - I)A_{am}G_{mm} + \\ & e'G_{mm}A_{ma}DA_{am}G_{mm}]Y_m \end{aligned} \tag{5b}$$

where $G_{mm} = (I - A_{mm})^{-1}$, $D = (I - A_{aa} - A_{am}G_{mm}A_{ma})^{-1}$ and e is a vector of ones. The magnitude of the above absolute backward linkage is determined by two factors: first the relative size of the sector, and second, its dependence per unit of output (its output multiplier). Since the primal concern is the sectoral interdependence, Dietzenbacher and Van der Linden (1997) suggest normalizing the above value by dividing the absolute figures by the value of sectoral output. This results in the backward dependence of agricultural sectors on manufacturing as:

$$BL_a^D = \frac{ABL_a^D}{X_a} \tag{6}$$

In a similar manner to backward linkages, forward linkage indicators can be obtained using the supply-driven Leontief input-output system (Dietzenbacher and Van der Linden, 1997).[4] These backward (forward) linkages actually examine the extent of the impact derived from the hypothetical extraction of a sector on total output when final demand (or primary inputs) increases in all sectors in the economy.

This includes the effect of all other sectors on total output through the feedback in connection with the inputs (or sales) of the hypothetical extracted sector (Andreosso-O'Callaghan and Yue, 2000).

3. The Stochastic Input-Distance Function and the Measurement of Technical Efficiency

Let us assume that the industrial sectors use a non-negative vector of inputs $x \in R_{+}^{k}$ to produce a non-negative vector of outputs $y \in R_{+}^{m}$. This defines a production possibility set $T = \{(y, x) \in R_{+}^{m+n} : x\, can\, produce\, y\}$. Then for all *x* we can define an input requirement set such that $L(y) = \{x \in R_{+}^{n} : (y, x) \in T\}$ describing the input vectors that are feasible for producing output vector *y*. In terms of inputs correspondence the input-distance function $D^{I} : N \rightarrow R_{+}$ is defined by (Russell, 1998):

$$D^{I}(y, x) = max\{\lambda > 0 : x/\lambda \in L(y)\} \qquad (7)$$

where $N = \{(y, x) \in R_{+}^{m+n} : 0^{(n)} \notin L(y) \wedge x/\lambda \in L(y)\ for\, some\, \lambda > 0\}$. The input-distance function defined above provides a radial measure of the distance from an input bundle to the corresponding isoquant, the lower bound of the input requirement set. Thus it provides a direct link between the functional characterization of the production technology and radial efficiency measurement. If, for example, $x \in L(y)$ but it does not belong to the corresponding isoquant, so that the input vector *x* can produce *y* given the technology *T*, the same output vector could be produced with less of all inputs if the production unit operated closer to the isoquant. In other words, the producer in question operates technically inefficiently in producing *y* in the sense of Farrell's (1957) definition. Hence, a radial measure of input-oriented technical efficiency can be given by the reciprocal of the input-distance function as (Färe and Lovell, 1978):

$$TE^{I} = \frac{1}{D^{I}(y, x)} \in (0,1] \qquad (8)$$

Which reveals the maximum radial contraction of the input vector such that the production of the output vector is still feasible. Quantitative measures of input-oriented technical efficiency can be obtained by econometrically estimating an input-distance function. This is feasible with only input and output quantity data, and the use of a single-equation estimation procedure is consistent with the fact that the input-distance function is agnostic with respect to the economic motivation of the decision-makers (Grosskopf *et al*., 1995). More importantly, flexible functional forms can be used that do not impose any *a priori* restrictions on the structure of production.

The translog function is such a flexible functional form that it may be used to approximate the underlying input-distance function. It is given as (see Coelli and Perelman, 1999; Grosskopf *et al*., 1995; Bosco, 1996):

$$\begin{aligned} ln\, D^I(y,x) = \alpha_0 &+ \sum_{m=1}^{M} \alpha_m \, ln\, y_m + \sum_{k=1}^{K} \beta_k \, ln\, x_k + \frac{1}{2}\sum_{m=1}^{M}\sum_{l=1}^{M} \alpha_{ml} \, ln\, y_m \, ln\, y_l \\ &+ \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{K} \beta_{kj} \, ln\, x_k \, ln\, x_j + \sum_{m=1}^{M}\sum_{k=1}^{K} \delta_{mk} \, ln\, y_m \, ln\, x_k \qquad (9) \end{aligned}$$

The required regularity conditions include homogeneity of degree one in inputs and symmetry. These imply the following restrictions on the parameters of (*9*):

$$\sum_{k=1}^{K} \beta_k = 1, \ \sum_{k=1}^{K} \beta_{kj} = \sum_{m=1}^{M} \delta_{mk} = 0, \ \alpha_{ml} = \alpha_{lm} \ \text{ and } \ \beta_{kj} = \beta_{jk} \qquad (10)$$

The homogeneity restrictions may also be imposed by dividing the left-hand side and all input quantities in the right-hand side of (*9*) by the quantity of that input used as *numeraire*.

Given the imposition of linear homogeneity, to obtain an estimable form of the input-distance function, rewrite (*9*) as $-ln\, x_k = f(\cdot) - ln\, D^I(y,x)$, where k is the *numeraire* input and $f(\cdot)$ is the right-hand side of (*9*). Since there are no observations for $ln\, D^I(y,x)$ and given that $ln\, D^I(y,x) \leq 0$ we can make the following replacement: $ln\, D^I(y,x) = -u_i$, where u_i is a one-side, non-negative, error term representing the stochastic shortfall of the i^{th} producer's output from its production frontier, due to the existence of input-oriented technical inefficiency

(Coelli and Perelman, 1999). Then, the stochastic input-distance function model may be written as:

$$-ln\, x_{ki} = f(\cdot) - u_i + v_i \qquad (11)$$

where v_i depicts a symmetric and normally distributed error term (i.e., statistical noise), which represents those factors that cannot be controlled by producers, left-out explanatory variables and measurement errors in the dependent variable. It is also assumed that v_i and u_i are independently distributed from each other.

Since our purpose in this paper is to explore the possible relationship between industrial linkages and technical efficiency we can replace the technical inefficiency effects, u_i, in (*11*) by a linear function of backward and forward linkages coefficients following the Battese and Coelli (1995) model formulation. Specifically,

$$u_i = \rho_o + \sum_{h=1}^{H} \rho_h z_{hi} + \omega_i \qquad (12)$$

where z_{hi} are sectoral-specific backward and forward linkage coefficients; ρ_0 and ρ_h are parameters to be estimated; and ω_i is a random variable with zero mean and variance σ_ω^2, defined by the truncation of the normal distribution such that $\omega_i \geq -\left(\rho_0 + \sum \rho_h z_{hi}\right)$. The above specification (*12*) implies that the means, $\mu_i = \rho_0 + \sum \rho_h z_{hi}$, of the u_i are different for different sectors but the variances, σ_ω^2, are assumed to be the same.

4. Data and Empirical Model

The comparative evaluation of sectoral linkage coefficients and technical efficiency was applied to the 1996 US input-output tables published by the Bureau of Economic Analysis (BEA) of the USDC. These tables are based on an update of the 1992 benchmark input-output accounts and they reflect the recent comprehensive revision of the national income and product accounts. The input-output accounts were transformed to an industry-by-industry framework (94 industries) assuming an industry-based technology prior to the estimation of linkage coefficients and sectoral technical efficiency (Miller and Blair, 1985, pp. 159-171; Jansen and ten Raa, 1990).

The stochastic input-distance function includes two outputs and four inputs. The output measures are: (*1*) the total domestic sectoral output measured as the sum of production sold to other sectors within the economy as intermediate goods, to final consumption, and to fixed capital formation; (*2*) the total sectoral exports. The decomposition by type of purchases into domestic and foreign markets is based on the methodological framework developed by Diewert and Morrison (1988), Lawrence (1990) and Nadiri and Son (1999).

The input measures are: (*1*) the total labor cost including wages and salaries and all kinds of benefits paid by state industries; (*2*) the total sectoral intermediate consumption purchased domestically; (3) the total value of sectoral capital stock; (*4*) the total sectoral imports.[5] In the inefficiency effects model, we have included the corresponding backward and forward linkage coefficients obtained from Dietzenbacher and Van der Linden's (1997) non-complete hypothetical extraction method.

5. Empirical Results

The maximum likelihood parameter estimates of the translog input-distance frontier function along with their corresponding standard errors are presented in Table 1. The translog input-distance frontier function is found at the approximation point to be non-increasing in outputs and non-decreasing in inputs. Also, at the point of approximation, the Hessian matrix of the first- and second-order partial derivatives is found to be negative definite with respect to inputs and positive definite with respect to outputs. These indicate the concavity and convexity of the underlying input-distance function for inputs and outputs, respectively. Finally, the logarithm of the likelihood function indicates a satisfactory fit for the particular functional specification.

Several hypotheses concerning model representation were examined.[6] First, the average input-distance function does not adequately represent the structure of technology. The null hypotheses that $\gamma = 0$ and $\gamma = \rho_0 = \rho_h = 0$ are rejected at the 5% level of significance, indicating that the technical inefficiency effects are in fact stochastic (this is also depicted by the statistical significance of the γ-parameter).[7] Thus, a significant part of output variability among industries is explained by the existing differences in the degree of input-oriented technical inefficiency.

In addition, our specification of the frontier model cannot be reduced to the models of either Aigner *et al.* (1977) or Stevenson (1980), as the null hypotheses of $\rho_0 = \rho_h = 0$ and $\rho_h = 0 \quad \forall h$, respectively, are rejected at the 5% level of significance. As a result, the explanatory variables included in the inefficiency effect models have non-zero coefficients and contribute significantly to the explanation of technical efficiency differences among US input-output sectors.

The frequency distribution of input-oriented technical efficiency ratings among US industries is presented in Table 2. The estimated mean technical efficiency was found to be 70.33%. Since input-oriented technical efficiency has a direct cost interpretation, this figure means that on average, a 29.67% decrease in total cost of production could be achieved, without altering the total volume of output, production technology and input usage. In other words it is possible for the US economy to become more technically efficient and to maintain the same level of sectoral output by reducing by almost 30% labour cost, intermediate consumption, capital equipment and imports.

The variation of technical efficiency ratings is considerable (the standard deviation is 17.7%). Specifically, sectoral technical efficiency ranges between a minimum of 40.92% and a maximum of 98.71%. It is important to note that only 36% of the industries achieved technical efficiency levels above 80%, while on the other hand there are 17 industries with technical efficiency levels below 50%. For these sectors considerable gains can be attained in their overall competitiveness by improving their resource use.

Among the sectors with the highest technical efficiency levels are: Owner-Occupied Dwellings (98.71%), Wholesale Trade (97.05%), Federal Government Enterprises (97.05%), Retail Trade (96.88%) and Insurance (95.78%). Conversely the sectors with the lowest technical efficiency levels include: Paints and Allied Products (40.92%), Primary Non-Ferrous Metals Manufacturing (41.73%), Metallic Ores Mining (41.85%), Agricultural Fertilizers and Chemicals (42.32%) and Engines and Turbines (43.10%).

Backward and forward linkage coefficients computed using the Dietzenbacher and Van der Linden (1997) non-complete hypothetical extraction method are also reported in Table 2 in the form of frequency distribution. The average of the sectors' backward and forward linkage values are more or less the same, 0.784 and 0.778, respectively. The empirical results reveal a weak relationship between backward and forward linkages. However, this relationship does not hold in general since backward linkages are measured with respect to purchasing sectors, whereas forward linkages are measured with respect to selling sectors.

For the majority of the input-output sectors the relevant backward linkage coefficient is below unity. There are only 17 sectors with a backward linkage coefficient value above one. The highest values are observed for the Metal Containers and Livestock sectors, 1.537 and 1.376, respectively. These values mean that if intermediate purchases of these sectors were hypothetically removed, the total output of the US economy would fall by 1.537 and 1.376 times this particular sector's actual output.

The first five sectors with the highest backward linkage coefficient value are Metal Containers (1.537), Livestock and Livestock Products (1.376), Paperboard Containers and Boxes (1.298), Petroleum Refining and Related Products (1.276) and Miscellaneous Textile Goods and Floor Coverings (1.220). Conversely among the sectors with the lowest backward linkage coefficient value are Owner-Occupied Dwellings (0.218), Real Estate and Royalties (0.399), Federal Government Enterprises (0.408), Other Business and Professional Services (0.426) and Footwear, Leather and Leather Products (0.443).

The highest forward linkage coefficient value is 1.865 achieved by Metallic Ores Mining. Therefore, if the intermediate sales of this particular sector were hypothetically removed from the system, the total output of the US economy would fall by 1.865 times the actual output of Metallic Ores Mining. The variation of forward linkages between sectors is larger than that of backward linkages. The standard deviations are 0.273 and 0.504 for backward and forward linkages, respectively. There are 33 sectors with a corresponding forward linkage coefficient value below 0.500, and 34 sectors with a forward linkage coefficient value above one.

Roughly speaking, sectors for which a large part of their output is destined for final demand purposes have weak forward linkages, whereas sectors whose output is primarily used for further production have strong forward linkages. The highest forward linkages are attained by Metallic Ores Mining (1.865), Non-Metallic Minerals Mining (1.785), Pipelines, Freight Forwarders and Related Services (1.670), Federal Government Enterprises (1.657) and Agriculture, Forestry and Fishery (1.626). On the other hand, the sectors with the lowest forward linkage coefficients are Furniture and Fixtures (0.103), Retail Trade (0.108), Educational and Social Services (0.122), New Construction (0.136) and Other Transportation Equipment (0.138).

Concerning the relationship among backward and forward linkages and technical efficiency, the corresponding parameter estimates in the inefficiency effects model were found to be negative and strongly significant, -0.913 and -0.132, respectively (see Table 1). Furthermore, the Spearman correlation coefficients among sectoral linkage coefficients and technical efficiency levels verify this negative relationship (see bottom line of Table 2). This means that high sectoral technical efficiency levels are generally associated with low backward and forward linkage values. In other words, sectors with a high potential to stimulate output growth within the US economy, are not using an optimal allocation of their existing resources.

Strengthening further the above finding Table 3 presents the first fifteen I-O sectors with the highest and lowest technical efficiency along with their corresponding backward and forward linkage coefficient values. As is clearly perceived from this table, apart from some notable exceptions, the general tendency is towards this negative relationship. Metal Containers, the sector with the highest backward linkage value, and Metallic Ores Mining, the sector with the highest forward linkage value achieve technical efficiency levels of only 46.67% and 41.58%, respectively.

On the other hand, Owner-Occupied Dwellings, the sector with the highest technical efficiency score, has backward and a forward linkage values of only 0.218 and 0.205 respectively. Contrarily, Paints and Allied Products, the sector with the lowest technical efficiency score, has backward and forward linkage values of 1.170 and 1.293, respectively.

Among the 30 sectors presented in Table 3, only seven -Eating and Drinking Places, New Construction, Crude Petroleum and Gas, Federal Government Enterprises, Other Business and Professional Services, Legal, Maintenance and Repair Construction and Materials Handling Machinery and Equipment- exhibit a relative correspondence between their technical efficiency and backward or forward linkage coefficients. The general tendency, however, is towards this negative relationship.

This finding, though not general, is rather important and should be taken into consideration in identifying sectoral development priorities for the US economy. For instance, according to backward and forward linkage coefficients, the Metal Containers sector seems to be a good candidate to promote overall economic development in the US economy as it exhibits strong interdependence with the rest of the economic sectors. However, the expansion of this particular sector would cause significant resource waste for the entire economy, while on the other hand the long-run viability of the anticipated economic benefits would not be as expected. The Metal Containers sector is operating far from its realized production frontier, achieving a technical efficiency level of only 46.67%.

In the next step we attempt to investigate whether or not efficient (inefficient) sectors purchase their inputs primarily from efficient (inefficient) sectors. Table 4 presents the amounts of intersectoral purchases per dollar of intermediate consumption expressed in percentages by every sector in the US economy. Columns present buying sectors and rows present producing sectors in a frequency distribution form according to their technical efficiency levels. As is clearly visible from this table, sectors with high technical efficiency levels purchase their inputs primarily from other highly technically efficient sectors. Specifically, sectors with a technical efficiency level above 90% purchase 74.1% of their intermediate consumption from sectors with a technical efficiency score above 80%. The situation is also the same for the sectors with technical efficiency within the 90-80 interval.

On the other hand, sectors with low technical efficiency levels tend to purchase the necessary inputs for their production from sectors with low technical efficiency levels. Sectors with technical efficiency ratings within the 50-40 interval purchase 40.7% of their resources from sectors with technical efficiency levels within the 60-40 interval. Although this share of intermediate purchases is not so high as it is for the technically efficient sectors, it is still significant, revealing a relative correspondence of the technical efficiency levels between the buying and selling sectors. On the average, 47.7% (27.9%) of total intersectoral purchases stem from sectors with technical efficiency levels above 80% (below 60%).

Exploring further the above finding, Table 5 presents the intersectoral purchases of the ten most and least technically efficient sectors by every other sector in the US economy. As is evident from this table, efficient sectors tend to purchase their intermediate inputs mainly from highly efficient sectors (upper panel of Table 5). For instance the case of the Owner-Occupied Dwellings sector is more profound as 92.5%

of its total intersectoral purchases originate from sectors with technical efficiency levels above 90%.

In the Wholesale Trade, Federal Government Enterprises, Retail Trade, Health Services, Educational and Social Services, New Construction and Other Business and Professional Services sectors, a large portion of their intermediate purchases stem from other efficient sectors (above 80%), 64.9%, 57.1%, 70.8%, 79.1%, 83.9%, 45.9% and 57.4%, respectively. It is also noteworthy that these intermediate purchases originate mainly from other sectors in the economy, with only two exceptions. For the Insurance and Finance sectors, 50.9% and 36.8% of their intermediate inputs arise from their own production process.

The ten least technically efficient sectors (lower panel of Table 5) reveal the same pattern though not so strongly. Specifically, in the Paints and Allied Products, Primary Non-Ferrous Metal Manufacturing, Metallic Ores Mining, Agricultural Fertilizers and Chemicals, Engines and Turbines, Materials Handling Machinery and Equipment, Coal Mining and Miscellaneous Textile Goods sectors a large share of their intermediate purchases originates from relatively inefficient sectors (below 60%), 32.6%, 38.1%, 40.6%, 43.8%, 54.9%, 48.7%, 44.4% and 65.7%, respectively. There are, however, two exceptions -the Plastic and Synthetic Materials and Paperboard and Containers Boxes sectors- whose intermediate inputs stem from relatively more efficient sectors.

6. Conclusions

In identifying sectoral development priorities the assessment of both sectoral economic performance and production interdependence are very important issues. A sector with strong interindustry transactions may be seen as a good candidate to promote overall economic development. However, if the same sector operates inefficiently, in the sense that it does not produce as much output as its input usage allows, the anticipated benefits would not be as great as initially expected.

Along these lines we attempted in this paper to present an empirical evaluation of the potential relationship between technical efficiency and sectoral linkages using recent methodological advances both in stochastic frontier modeling and in the measurement of interindustry linkages. The empirical results reveal a rather strong negative relationship. Technically efficient sectors tend to exhibit low backward and forward linkage coefficients and *vice versa*. This is confirmed from case to case examination as well as from the corresponding parameter estimates in the inefficiency effects model and Spearman correlation coefficients.

Strengthening further the above finding, we attempted to investigate whether or not technically efficient (inefficient) sectors purchase their intermediate inputs from other technical efficient (inefficient) sectors. The results suggest that indeed the majority of US sectors with a high technical efficiency level (above 80%) tend to buy intermediate inputs from other technically efficient sectors. This correspondence, although not so strong, is also observed for technically inefficient sectors (below 60%). Certainly the attained efficiency score of any given sector depends primarily on its own performance which, however, reflects the specific demand and supply situation it faces. However, our results suggest a possible pattern of intermediate sectoral transactions that should be taken into consideration in forming development plans.

Our empirical results although case specific can provide useful guidelines for policy makers in appropriately identifying the development prospects of a given sector in any regional or national economic system. For example, a technically efficient sector with a high linkage coefficient could serve as a good candidate for promoting internal economic development. This would give a competitive advantage to the specific economic system, contributing at the same time to its internal economic growth in terms of output, income or employment generation.

References

Aigner, D.J., Lovell, C.A.K. and P. Schmidt (1977). Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics* 6, 21-37.

Andreosso-O'Callaghan, B and G. Yue (2000). Intersectoral Linkages and Key Sectors in China 1987-1997: An Application of Input-Output Linkage Analysis. *XIII International Conference on Input-Output Techniques*, 21-25 August, Macerata, Italy.

Augustinovics, M. (1970). Methods of International and Intertemporal Measures of Structures, in A.P. Carter and A. Brody (Eds.), *Contributions to Input-Output Analysis*, Amsterdam: North Holland.

Battese, G.E. and T.J. Coelli (1995). A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, *Empirical Economics* 20, 325-32.

Bosco, B. (1996). Excess-input Expenditure Estimated by Means of an Input Distance Function: The Case of Public Railways. *Applied Economics* 28, 491-97.

Cella, G. (1984). The Input-Output Measurement of Interindustry Linkages. *Oxford Bulletin of Economics and Statistics* 46, 73-84.

Chenery, H.B. and T. Watanabe (1958). International Comparisons of the Structure of Production. *Econometrica* 26, 487-521.

Clements, B.J. (1990). On the Decomposition and Normalization of Interindustry Linkages. *Economics Letters* 33, 337-340.

Coelli, T.J. and S. Perelman (1999). A Comparison of Parametric and Non-parametric Distance Functions: With Application to European Railways. *European Journal of Operational Research* 117, 326-339.

Dietzenbacher, E. and J. Van der Linden (1997). Sectoral and Spatial Linkages in the EC Production Structure. *Journal of Regional Science* 37, 235-257.

Diewert, W.E. and C.J. Morrison (1988). Export Supply and Import Demand Functions: A Production Theory Approach, in R.C. Feenstra (Ed.), *Empirical Methods of International Trade*, Cambridge: MIT Press, 207-222.

Färe, R. and C.A.K. Lovell (1978). Measuring the Technical Efficiency of Production, *Journal of Economic Theory* 19, 150-62.

Farrell, M.J. (1957). The Measurement of Productive Efficiency. *Journal of Royal Statistical Society* Series A General, 120, 253-281.

Ghosh, A. (1958). Input-Output Approach in an Allocation System. *Economica* 25, 58-64.

Grosskopf, S., Hayes, K. and J. Hirschberg (1995). Fiscal Stress and the Production of Public Safety: A Distance Function Approach. *Journal of Public Economics* 57, 277-96.

Heimler, A. (1991). Linkages and Vertical Integration in the Chinese Economy. *Review of Economics and Statistics* 73, 261-267.

Hirschman, A.O. (1958). *The Strategy of Economic Development*. New York: Yale University Press.

Jansen, P.K. and T. ten Raa (1990). The Choice of Model in the Construction of Input-Output Coefficients Matrices. *International Economic Review* 31, 213-227.

Jones, L.P. (1976). The Measurement of Hirschmanian Linkages. *Quarterly Journal of Economics* 90, 323-333.

Kohli, U. (1991). *Technology, Duality and Foreign Trade*, Hertfordshire: Harvester Wheatsheaf.

Krugman, P. (1991). *The Age of Diminished Expectations*. Cambridge: MIT Press.

Lawrence, D. (1990). An Adjustment-Costs Model for Export Supply and Import Demand. *Journal of Econometrics* 46, 381-398.

Meller, P. and M. Marfán (1981). Small and Large Industry: Employment Generation, Linkages and Key Sectors. *Economic Development and Cultural Change* 19, 263-274.

Miller, R.E. and P.D. Blair (1985). *Input-Output Analysis: Foundations and Extensions*. Englewood Cliffs: Prentice-Hall.

Nadiri, M.I. and W. Son (1999). Sources of Growth in East-Asian Economies, in T.T. Fu, C.J. Huang and C.A.K. Lovell (Eds.), *Economic Efficiency and Productivity Growth in the Asia-Pacific Region*, Cheltenham: Edward Elgar.

Rasmussen, P.N. (1956). *Studies in Intersectoral Relations*. Amsterdam: North Holland.

Russell, R.R. (1998). Distance Functions in Consumer and Producer Theory, in R. Färe, S. Grosskopf and R.R. Russell (Eds.), *Index Numbers: Essays in Honour of Sten Malmquist*, Boston: Kluwer, 7-90.

Shephard, R.W. (1953). *Cost and Production Functions*. Princeton: Princeton University Press.

Sonis, M., Guilhoto, J.J.M., Hewings, G.J.D. and E.B. Martins (1995). Linkages, Key Sectors and Structural Change: Some New Perspectives. *The Developing Economies* 33, 233-270.

Stevenson, R.E. (1980). Likelihood Functions for Generalized Stochastic Frontier Estimation. *Journal of Econometrics* 13, 58-66.

Strassert, G. (1968). Zür Bestimmung Strategischer mit Hilfe von Input-Output Modellen. *Jahrbrücher für Nationakökonomie und Statistik* 182, 211-215.

Table 1. Parameter Estimates of the Translog Input-Distance Function

Parameter	Estimate	Std Error	Parameter	Estimate	Std Error
Stochastic Production Frontier					
β_0	4.422	(0.400)	β_{IC}	-0.483	(0.228)
α_G	-0.373	(0.169)	β_{IM}	0.293	
α_X	-0.131	(0.062)	β_{II}	0.250	(0.114)
β_W	0.386	(0.151)	β_{CM}	-0.462	
β_I	0.321	(0.119)	β_{CC}	0.152	(0.232)
β_C	0.177	(0.357)	β_{MM}	0.043	
β_M	0.117		δ_{GW}	-0.054	(0.023)
α_{GX}	0.126	(0.065)	δ_{GI}	-0.087	(0.109)
α_{GG}	0.068	(0.035)	δ_{GC}	-0.100	(0.142)
α_{XX}	0.017	(0.029)	δ_{GM}	0.240	
β_{WI}	-0.060	(0.133)	δ_{EW}	-0.092	(0.035)
β_{WC}	-0.173	(0.208)	δ_{EI}	0.024	(0.141)
β_{WW}	0.107	(0.044)	δ_{EC}	-0.039	(0.018)
β_{WM}	0.126		δ_{EM}	0.107	
Inefficiency Effects Model					
ρ_0	4.497	(0.460)			
ρ_{FL}	-0.132	(0.059)	ρ_{BL}	-0.913	(0.370)
γ	0.994	(0.061)	σ^2	0.341	(0.047)
Log(L)	-80.168				

Where G: domestic output, X: exports, W: wages and salaries, I: intermediate consumption, C: capital, M: imports, FL: forward linkage, BL: backward linkage.

Table 2. Frequency Distribution of Sectoral Input-Oriented Technical Efficiency and Backward Linkage Coefficients

%	TE^I	Value	BL^D	FL^D
<10	0	<0.500	10	33
10-20	0	0.500-0.600	9	4
20-30	0	0.600-0.700	14	7
30-40	0	0.700-0.800	19	2
40-50	17	0.800-0.900	9	8
50-60	14	0.900-1.000	16	6
60-70	14	1.000-1.100	7	4
70-80	15	1.100-1.200	5	9
80-90	18	1.200-1.300	3	4
>90	16	>1.300	2	17
N	94		94	94
Mean	70.33		0.784	0.778
Maximum	98.71		1.537	1.865
Minimum	40.92		0.000	0.000
StDev	0.177		0.273	0.504
Rho[1]			-0.428	-0.385

[1] Spearman correlation coefficients between sectoral technical efficiency and linkage coefficients.

Table 3. Fifteen Most and Least Technically Efficient Sectors and their Corresponding Backward and Forward Linkage Values

SIC	Sector	TE_i^I	BL_i^D	FL_i^D
Most Efficient				
71A	Owner-Occupied Dwellings	98.71	0.218	0.205
69A	Wholesale Trade	97.05	0.497	0.933
78	Federal Government Enterprises	97.05	0.408	1.657
69B	Retail Trade	96.88	0.516	0.108
70B	Insurance	95.78	0.712	0.454
77A	Health Services	95.51	0.560	0.187
77B	Educational and Social Services	95.09	0.749	0.122
11	New Construction	94.78	1.012	0.136
70A	Finance	94.50	0.549	0.650
73C	Other Business and Professional Services	93.59	0.426	1.324
71B	Real Estate and Royalties	93.30	0.399	0.876
73B	Legal, Engineering and Accounting Services	93.25	0.475	1.103
74	Eating and Drinking Places	91.94	1.021	0.228
18	Apparel	91.54	0.706	0.198
12	Maintenance and Repair Construction	91.34	0.922	1.161
Least Efficient				
65C	Water Transportation	49.67	0.984	1.326
08	Crude Petroleum and Natural Gas	48.48	0.512	1.344
03	Agriculture, Forestry and Fishery	48.46	0.621	0.936
39	Metal Containers	46.67	1.537	1.384
09-10	Non-Metallic Minerals Mining	46.13	0.685	1.785
17	Miscellaneous Textile Goods	45.36	1.220	0.672
25	Paperboard Containers and Boxes	45.17	1.298	1.507
07	Coal Mining	44.25	0.653	1.586
46	Materials Handling Machinery and Equipment	43.78	0.877	0.358
28	Plastics and Synthetic Materials	43.16	1.181	1.537
43	Engines and Turbines	43.10	0.954	0.593
27B	Agricultural Fertilizers and Chemicals	42.32	0.992	1.380
05-06	Metallic Ores Mining	41.85	1.087	1.865
38	Primary Nonferrous Metals Manufacturing	41.73	0.918	1.305
30	Paints and Allied products	40.92	1.170	1.293

Table 4. Sectoral Intermediate Purchases according to Technical Efficiency Levels (in percentages)

Efficiency Rating	100-90	90-80	80-70	70-60	60-50	50-40	Av/ge
100-90	58.0	28.6	26.0	26.4	22.1	21.5	30.4
90-80	16.1	31.9	14.8	14.8	14.3	12.0	17.3
80-70	11.1	16.7	14.3	14.3	6.9	19.2	13.8
70-60	6.4	4.0	19.4	19.4	8.0	6.6	10.6
60-50	5.5	10.8	10.9	10.9	33.4	11.8	13.9
50-40	2.9	8.1	14.1	14.1	15.3	28.9	14.0
Total	100	100	100	100	100	100	100

Note: payments to other primary inputs (labour, capital) are not included.

Table 5. Intermediate Purchases of the Ten Most and Least Efficient Sectors According to the Technical Efficiency Level of the Supply Sectors (in percentages)

Efficiency Rating	Ten Most Technically Efficient Sectors									
	71A	69A	78	69B	70B	77A	77B	11	70A	73C
Own	0.0	8.8	0.4	1.2	50.9	6.2	1.2	0.1	36.8	19.6
100-90	92.5	40.5	30.3	52.0	32.7	52.6	60.6	35.6	34.7	33.4
90-80	0.2	24.4	26.8	18.8	11.2	26.5	23.3	10.3	19.1	24.0
80-70	6.2	15.8	28.6	24.1	3.7	10.2	11.3	5.8	7.5	11.2
70-60	0.0	4.0	2.4	2.3	1.1	2.2	2.0	23.7	1.4	4.7
60-50	0.5	3.0	1.7	0.7	0.3	1.1	0.8	18.4	0.4	5.1
50-40	0.6	3.5	9.8	0.9	0.1	1.2	0.8	6.1	0.1	2.0
Total	100	100	100	100	100	100	100	100	100	100
	Ten Least Technically Efficient Sectors									
	30	38	05+06	27B	43	28	46	07	25	17
Own	1.8	33.5	19.4	11.4	7.3	3.3	1.9	11.3	0.2	3.2
100-90	12.9	6.5	12.1	10.5	15.9	17.6	21.2	15.6	14.6	12.4
90-80	9.9	8.2	14.1	18.1	8.2	16.3	8.4	14.1	11.4	9.2
80-70	39.7	2.7	13.4	10.9	2.7	51.3	3.0	9.4	32.6	6.9
70-60	3.1	11.0	0.4	5.3	11.0	3.5	16.8	5.2	34.8	2.6
60-50	0.1	16.3	11.3	0.0	31.1	0.2	34.2	12.1	1.9	27.1
50-40	32.5	21.8	29.3	43.8	23.8	7.8	14.5	32.3	4.5	38.6
Total	100	100	100	100	100	100	100	100	100	100

Note: payments to other primary inputs (labour, capital) are not included.

Endnotes

---

[1] Ghosh (1958) and Augustinovics (1970) used the same approach to describe the supply-driven input-output model. Under the usual assumptions the output vector is determined exogenously by the primary input vector V.

[2] Promising methodological improvements of the Strassert extraction method were also suggested by Cella (1984) and Sonis *et al*. (1995). However, the proposed backward and forward linkages are not symmetrical and thus they are comparable to the corresponding traditional linkage indicators of Chenery and Watanabe (1958) and Rasmussen (1956).

[3] In cases when a sector j purchases no inputs from any other sector in the economy, the total absolute backward linkage is zero and the actual situation is exactly the same as the hypothesized one.

[4] The use of the supply-driven Input-Output system for the computation of forward linkages dispenses with the restrictive assumption of the Hirschmanian forward linkages according to which the demand of every other industry increases simultaneously (Augustinovics, 1970). However, since the inverted matrix represents the sectoral sales shares and not the technology of production, forward linkages computed using the supply-driven system are mutually inconsistent with backward linkages computed using the demand-driven system (Cella, 1984; Heimler, 1991).

[5] Imports were treated as an input in the production process since they are often used as raw materials or intermediate goods, while even in the case that refers to finished products they have value added domestically through transportation and retailing costs (Kohli, 1991).

[6] The corresponding likelihood ratio tests are not presented herein but are available upon request.

[7] Notice that the probability of the technical inefficiency effect being significant in the stochastic frontier model is high, since the estimated value of the γ -parameter is close to one (see Table 1).