Is Leontief's Paradox Applicable to U.S. Agricultural Trade?

Gerald Schluter and Gene K. Lee

The labor and capital intensities of U.S. agricultural trade during 1973, 1974, and 1976 are examined through an input-output model. The empirical results indicate that U.S. agricultural exports tend to be more capital intensive while agricultural imports are more labor intensive, a result counter to Leontief's paradox.

The principal normative setting for the general equilibrium theory of international trade has been and remains the Heckscher-Ohlin model. According to the Heckscher-Ohlin Theorem, a country will tend to export those commodities in which production is relatively (to the other commodity) intensive in its relatively (to the other country) abundant factor. Thus, it is generally believed that the United States, with its intensive use of capital equipment and high wage rates in production, will export capital-intensive goods and will import labor-intensive goods.

It was a shocking experience, therefore, when Leontief made one of the more widely publicized empirical tests of the theory and found that the United States was exporting labor-intensive goods to the rest of the world in exchange for capital-intensive imports! This phenomenon was labeled the "Leontief Paradox" and touched off a flurry of research activity among trade economists, and prompted a vast literature of alternative explanations for the phenomenon. Some of these investigations involved a complex reexamination of the Heckscher-Ohlin Theorem and others involved making new empirical tests on the basis of either new data, different data or both.

The primary purpose of this paper is to make an empirical inquiry of the capital and labor intensity of U.S. agricultural trade and thereby examine the Leontief paradox in the context of agricultural trade. We shall start with the discussion of the specific approach used by Leontief in arriving at his conclusion and list a few other investigators' empirical tests, followed by our examination of capital and labor intensities in U.S. agricultural trade.

Gerald Schluter and Gene K. Lee are with the Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture.

Leontief's Estimation Procedure

In his pioneering study (1953) and in a reexamination of his initial study (1956), Wassily Leontief based his empirical studies on the 200 sector 1947 input-output table for the United States economy. He computed, using both 1947 and 1951 trade data, the labor and capital embodied within the U.S. exports and the same characteristics of domestic production which would be needed if our competitive imports were replaced. Thus, Leontief's original contribution rests on the empirical examination of the relationship between factor endowments and international trade.

Let R be the matrix consisting of vectors L and K which denote the direct labor and capital requirement per unit of output,

$$(1) \qquad R = \begin{pmatrix} L \\ K \end{pmatrix} = \begin{pmatrix} l_1, l_2, l_3, \ldots, ln \\ k_1, k_2, k_3 \ldots, k_n \end{pmatrix}; \quad n = 1, 2, 3, \ldots, 200$$

Postmultiplying the direct and indirect requirement matrix, $(I - A)^{-1}$, to the R matrix, yields matrix F below,

$$(2) \qquad F = R(I - A)^{-1}.$$

If row vectors E and M represent exported goods and imported goods respectively, the total direct and indirect labor and capital requirements for the production of this set of goods are,

(3) FE′ for exports and

(4) FM′ for imports,

where E′ and M′ are transpose of E and M, respectively.

Comparing the results of (3) and (4), Leontief found that

$$\sum_{i=1}^{200} F_{li}E_i > \sum_{i=}^{200} F_{li}M_i$$

$$\sum_{i=1}^{200} F_{ki}E_i < \sum_{i=1}^{200} F_{ki}M_i$$

which indicate that the production of the set of exported goods required more total labor than that of imported goods; the converse was true for capital requirements. More specifically, Leontief computed the capital and labor requirements for the production of $1 million worth of United States exports and import-competing commodities. His key numerical result is shown in the first set of rows in Table 1. This table clearly shows that the United States exports commodities which use only $14,010 of capital per man-year of labor while importing commodities which require $18,180 of capital per man-year.

Responding to his paradoxical result, the profession has frequently reexamined this phenomenon attempting to incorporate this empirical evidence into the received theory. Starting with himself, Leontief (1956) reexamined his finding using 1951 U.S. trade data with the 1947 I/O structure. His reexamination reaffirmed his initial finding that the U.S. was exporting labor-intensive commodities in return for capital-intensive commodities. Baldwin did a similar study employing 1958 input-output structure and 1962 trade data. As shown in the second row in Table 1, Baldwin also reaffirmed the Leontief paradox. In fact, Baldwin's calculations were very close to Leontief's.

Interest in this paradox has continued. For example the American Economic Association had a special invited session in the 1976 Annual meeting at Atlantic City dealing exclusively with the paradox. Leontief-type tests have been conducted for a number of other countries. Most recently, Hillman and Bullard found that when using energy as one factor of production, the United States exhibited a comparative advantage in labor intensive output and a converse disadvantage in output in a composite energy-capital input.

The paradox also has been investigated at less that the full economy level. Davies tested the paradox for the manufacturing sectors of the United Kingdom. Baldwin and Vanek examined the paradox with the exclusion of selected natural resource based sectors. Vanek, in particular, accepts the proposition that the United States is relatively more capital abundant than labor but states that natural resources are scarce in the United States and trade serves as a means of conserving these resources. Thus, excluding natural

TABLE 1. Capital and labor requirements in U.S. exports and import-competing replacements

Year for input-output structure (I-O) and trade pattern	Factor requirements per million dollars of product	Exports	Competitive imports	Ratio exports to imports
(1) 1947 I-O and trade structure (Leontief)	Capital stock	$2,550,789	$3,091,339	
	Labor (person-years)	192	170	
	Capital/labor ratio	$14,010	$18,180	0.77
(2) 1958 I-O and 1962 trade structure (Baldwin)	Capital stock	$1,876,000	$2,132,000	
	Labor (person-years)	131	119	
	Capital/labor ratio	$14,200	$18,000	0.79

Sources: (1) Leontief, 1956; (2) Baldwin.

resources industries from the sector classification of the trade matrix apparently eliminates the observation of the paradox.

As an addition to these studies, in this paper we will use implicit factor intensities to examine U.S. agricultural trade for evidence of the Leontief paradox. Recently, agricultural trade has been increasingly important in U.S. total trade, but due to an apparent lack of interest in and lack of knowledge of the uses of appropriately expressed capital and labor requirements data in agricultural trade, the factor intensity of agricultural trade has not received notice commensurate with the increasing importance of agricultural trade.

Factor Intensity in U.S. Agricultural Trade

Agricultural products valued at $23 billion were exported from the U.S. in 1976. Concurrently, we imported $11.0 billion worth of agricultural commodities. Some $4.7 billion of this total was for imports of complementary products such as bananas, coffee, and tea that do not compete directly with domestic agriculture. On the other hand, about $6.3 billion in imports were supplementary commodities that could have been produced domestically and thus are, to some degree, competitive with U.S. agricultural production. These supplementary agricultural imports are primarily processed or partially processed foods. Conversely, our export market tends to include more raw agricultural products, such as grains and soybeans.

We have chosen to use USDA's designation of imports as complementary and supplementary as reported in "Foreign Agricultural Trade of the U.S." There are some classification problems in this designation. For example, a French wine or Danish ham could be considered supplementary to some people who are indifferent between these imported commodities and their domestic counterparts, while to others these imports would be complementary because they feel these commodities have no domestic counterpart. In addition to this difference in preferences, the designation could be affected by seasonal factors. A fresh fruit or vegetable import could be supplementary in summer and complementary in winter when no domestic production occurs.

While acknowledging these difficulties we choose not to try to improve upon the judgment of the experienced trade analysts in the Foreign Demand and Competition Division of ESCS-USDA by experimenting with alternative classifications. Our professional judgment is that the results presented here are not sensitive to alternative classifications of agricultural imports.

Our estimation procedure for capital and labor intensity of agricultural trade is similar to Leontief's. Recall that the estimation expression was $R\ (I\text{-}A)^{-1}E'$ for exports and $R(I\text{-}A)^{-1}M'$ for imports and that R was a matrix of labor and capital requirement coefficients per unit of output. Our labor requirement coefficients are civilian employment per unit of output (in 1967 dollars). Our capital requirement coefficients are capital expenditures in 1967 required per unit of output (USDC, 1975). Leontief obtained his estimates from a dynamic input-output model. In his model an industry may respond to external shocks both by acquiring and disposing of fixed equipment and by readjusting its scale of operations. Thus his capital coefficients differ conceptually from ours. However, his theoretical argument seems to run in terms of the static model which was the type used in this study. His capital coefficients would have the same numerator as ours, but include the sector capacity level, depreciation rate, and rate of change in the capacity level, in their denominator.

Our $(I\text{-}A)^{-1}$ matrix is derived from a 38 sector aggregated version of the U.S. Department of Commerce's 478 sector input-output table of the U.S. economy (1974). The relationship between the 478 sector version and our 38 sector version is given in Table 2. As previously discussed, our E′ and M′ vectors are the official USDA agricultural trade statistics classified into our 38 sector scheme.

The presentation of the computation procedure highlights the underlying assumption

TABLE 2. Sectoring Plan

Sector	Title	Related 1967 I/O No.
1	Dairy Farm Products	010100
2.	Poultry and Eggs	010200
3.	Meat Animals	010301
4.	Miscellaneous Livestock	020302
5.	Cotton	020100
6.	Food Grains	020201
7.	Feed Grains	020202
8.	Grass Seed	020203
9.	Tobacco	020300
10.	Fruits	020401
11.	Tree Nuts	020402
12.	Vegetables	020501
13.	Sugar Crops	020502
14.	Miscellaneous Crops	020503
15.	Oil Bearing Crops	020600
16.	Farm Forest and Nursery Products	0207010,020702
17.	Meat Products	140101 - 140103
18.	Dairy Plants	140200 - 140600
19.	Canning, Freezing and Dehydrating except Fish	140800 - 141100, 141300
20.	Feed, Flour and Milling	141401 - 141700
21.	Sugar	141900
22.	Fats and Oil Mills	142400 - 142700, 142900
23.	Confectionaries, Bakery Products and Macaroni	141801, 141802, 142001 -
24.	Beverages and Flavorings	142003, 143100
25.	Fertilizers	142101 - 142300
26.	Petroleum Refining and Related Products	270201, 270202 310100
27.	Miscellaneous Food Processing	140700, 141200, 142800 143000, 143200
28.	Tobacco Manufacturer	150101 - 150200
29.	Textiles, Apparel and Fabrics	160100 - 190306
30.	Leather and Leather Products	330000 - 340305
31.	Forestry, Fishing and Mining	030000, 050000-100000
32.	Other Manufacturer	130100-130700,200100-270100, 270300-300000,310200-320400, 350100-641200
33.	Transportation and Warehousing	650100-650700
34.	Wholesale Retail Trade	690100, 690200
35.	Other Non-commodities	04,11,12,66,67,70,710100,72-7
36.	Utilities	680100 - 680300
37.	Real Estate	710200
38.	Imports	800100, 800200

that U.S. production technology is used to estimate the labor and capital content of imports. While the validity of this assumption likely varies from sector to sector, this assumption not only simplifies the data requirements (else the production technology for each product from each country must be known) but also focuses the attention on domestic producers and consumers where the relevant production and consumption decisions are being made. Similarly, as in the Leontief paradox, computations consider only supplementary imports which are to a degree competitive with domestic commodities.

The 1967 I/O table is the latest available and, in spite of its vintage, is likely more appropriate for this type of analysis than is

the formulation of an updated version. The 1967 table explicitly presents the potential bias of the analysis and allows readers to use their own knowledge of the 1967 and 1976 economies to temper the results. An updated table would substitute the authors' subjective judgment for the readers and diffuse this judgment into 38×38 or 1444 cells where observed economic relationships are combined with judgmental adjustments.

The E′ and M′ vector are deflated to 1967 dollars before the matrix multiplications and the results are presented in labor and capital intensity per million dollars of trade. The effect of the year chosen is to provide the relative weights given each of the 38 sectors. Thus, differences in labor and capital intensity between years are primarily the result of shifts in product mix. Our results are presented in Table 3 for 1973, 1974, and 1976. Because they are similar, only 1976 results will be discussed.

Results

Results for calendar year 1976, presented in Table 3, do not confirm the existence of the Leontief paradox in U.S. agricultural trade; rather, they are the results expected from the Heckscher-Ohlin theory. The capital requirements per million dollars of exports were greater than for imports, $224,675 versus $163,526, and the labor requirements of imports were slightly greater, 111.8 versus 107.0 man years. The U.S. is shown to export agricultural products which require $2,100 of capital per man-year, while importing commodities which require $1,463 of capital per man year. This condition is the opposite of that Leontief found for all U.S. foreign trade in 1947. This difference warrants a closer look at our general conclusion and the apparent inconsistency of our results with Leontief and others.

Obviously our estimates could be isolated from the general group of studies of the paradox because our study addresses but one part of U.S. trade. Had the exports from and the imports to the entire economy been considered, the broader range of production and consumption opportunities considered might have given different results.[1]

While true, this view misses the value of the study of the Leontief paradox. The insights provided are often much more useful than the results of the calculations. Thus Davies, would exclude trade in raw agricultural commodities from studies of trade patterns because of these commodities' dependence on land endowments. Following this approach and concentrating on manufactured products, estimates of capital and labor intensities are, of course, less biased by relative nonlabor and capital factor endowments. For an analysis of U.S. agricultural trade, however, this purity would come at a cost of possibly missing the implications of the insight that, while the U.S. cropland base has remained relatively constant as the capital combined with this land stock increased and

[1]In a study of labor requirements in the U.S. food system, researchers found changes in the A matrix to be substantially less important than changes in individual sector employment requirement coefficients in explaining changes in labor needs per unit of output (Schluter-Beeson). Applying this result together with the facts that farm labor productivity growth has exceeded nonfarm labor productivity growth (USDA, 1977 table 55) and that farm products were relatively more important in U.S. agricultural exports than imports would reenforce our results of relatively more capital intensive exports than imports.

TABLE 3. Domestic Capital and Labor Requirements per Million Dollars of U.S. Agricultural Exports and of Competitive Import Replacements, 1973, 1974, and 1976 Trade, 1967 Prices

	Exports			Imports		
	1973	1974	1976	1973	1974	1976
Capital, $	223,458	220,094	224,675	162,407	163,052	163,526
Labor (manyears)	108.0	109.1	107.0	110.5	112.2	111.8
Capital/ Labor ($/manyear)	2,069	2,017	2,100	1470	1453	1463

the labor input decreased, the level of U.S. agricultural exports grew.

A closer examination of our results suggests they may not be inconsistent with the Leontief paradox. Table 4 presents a disaggregation by broad economic sector and by capital and labor content of U.S. agricultural trade. The dominant statistic presented in this table is the relatively high equipment capital needs in the farm sector.[2] Because raw agricultural commodities account for a larger proportion of U.S. agricultural exports than of imports, this statistic alone accounts for much of the difference in capital requirements between exports and imports. The "total" row of Table 4 presents total factor requirement estimates, that include the farm sector. When only nonfarm sectors are considered some of the relationships change. Agricultural imports now have more of both labor and capital requirements per million dollars of trade than do agricultural exports. And the capital to labor ratios of the two are closer, although still higher for exports, 1,506 vs 1,622.[3] Thus from this perspective these results conform more closely to Leontief's observation. There actually is more consistency than is apparent at first glance. In Leontief's 1947 bill of goods, farm imports accounted for about 26 percent of the total import dollar versus a 10 percent share of total exports by farm exports. In our analysis farm exports account for 59 percent of U.S. agricultural exports and 12 percent of U.S. agricultural imports. Thus the "suspiciously high capital coefficient" for farming which critics pointed out in Leontief's study [Chenery, Swerling] would tend to increase the capital intensity estimate for his imports relative to exports and have an opposite effect on our estimates.

Without defending the precision of Leontief's "agriculture and fisheries" capital coefficient, he was right that farming was a capital intensive sector in 1947 and is even more so today.[4] Perhaps due to the emphasis on the family farm and the associations in the public mind inspired by the family farm, the conventional wisdom has not incorporated the reality of the capital intensity of this sector.[5] In fact, the farm sector and particularly the export-oriented subsectors, grains and soybeans, are very capital-intensive, particularly in machinery capital. This point appears to be overlooked in the discussion of the Leontief paradox as well as in general discussions of U.S. trade.

The latter point may also do violence to another aspect of conventional wisdom. When citing examples of U.S. exports of capital and technology, the United States aircraft and computer industries are most frequently cited in the popular press. Perhaps it surprises some people that the agricultural sector could have examples of high capital, high technology export commodities such as grains and soybeans. Our finding reaffirms that the U.S. agriculture is highly mechanized in production and that this mechanization contributes to a comparative advantage in trade with other nations.

Summary and Conclusion

Agricultural trade has been increasingly important in U.S. total trade, but consideration of the factor intensity of agricultural

[2]In 1975, farmers' expenditures for machinery and equipment were 8.8 percent of total gross farm income including government payments (USDA, 1976). Some commodities are produced with more machinery intensive methods, however. In recent years machinery costs have been 18 percent of corn production costs. Comparable estimates for cotton, soybeans, and wheat are 21 percent, 24 percent, and 24 percent respectively. (Krenz).

[3]From table 4: 100,904 ÷ 67.0 = 1,506 and 95,077 ÷ 58.6 = 1,622.

[4]Equipment costs per dollar of farm output were 6.2¢ in 1947 and 8.8¢ in 1975 (USDA, 1976).

[5]This incorrect perception may be perpetuated by text books used in undergraduate economic courses. For example, Kindleberger (p. 96), "On the export side, the United States is exporting farm products that happen to be relatively intensive users of both *labor* and land" and "And the seeming tendency of India to export capital-intensive goods to the United States in exchange for labor-intensive goods may have been due largely to its imports of U.S. food grains...."

TABLE 4. Domestic Capital and Labor Requirements per Million Dollars of U.S. Agricultural Exports and of Competitive Import Replacements, by Type of Capital and Broad Economic Group, 1976 Trade. (In 1967 $'s)

	Imports				Exports			
Economic Group	Employment	Structure	Equipment	Total Capital	Employment	Structure	Equipment	Total Capital
	(man-years)	(dollars)	(dollars)	(dollars)	(man-year)	(dollars)	(dollars)	(dollars)
Farm	44.8	14,387	48,234	62,621	48.4	22,661	106,937	129,598
Food Processing	15.0	5,783	14,951	20,734	4.6	2,083	5,384	7,467
Trade	15.4	3,065	5,998	9,063	16.2	3,215	6,292	9,507
Transportation	8.2	3,058	19,208	22,266	7.1	2,662	16,715	19,377
Other Manufacturing	10.8	1,928	3,526	5,454	11.2	2,403	4,476	6,879
Other Services	17.6	33,678	9,710	43,388	19.5	41,492	10,355	51,847
Total	111.8	61,899	101,627	163,526	107.0	74,516	150,159	224,675
Non-Farm	67.0	47,512	53,393	100,905	58.6	51,855	43,222	95,077

trade has not received attention commensurate with its increasing importance. This paper has specifically addressed the capital and labor intensities of U.S. agricultural trade and thereby tested the applicability of the Leontief paradox in U.S. agricultural trade. On the basis of an empirical testing of the model with three years of trade data we found that the U.S. agricultural exports were more capital-intensive while agricultural imports were more labor-intensive. This condition is the opposite of Leontief's findings. Our finding is also more in line with the expected characteristics of the U.S. trade given its relative capital and labor endowments. The results of both studies are easier to accept once one realizes the capital intensiveness (particularly in machinery and equipment) of U.S. farm production. Those farm subsectors which can best utilize machinery and equipment capital have been export-oriented and have become increasingly important to the overall U.S. balance of trade.

Perhaps the scarcity of labor in the U.S. relative to other countries explains our resort to capital-intensive production technologies to compete with foreign goods. Recent trade experiences may be signaling this condition. If so, our finding indicates an important policy implication. That is, to compete with other countries in world trade, we must reallocate our resources toward producing goods such as agricultural products which are more capital intensive.

References

Baldwin, Robert. "Determinants of the Commodity Structure of U.S. Trade," *Amer. Econ. Rev.* 61(1971): 126-146.

Cherney, Hollis B. and Paul G. Clark. *Interindustry Economics*, John Wiley and Sons, Inc., New York, 1959.

Davies, Robert. "The Leontief Paradox and the United Kingdom Patterns of Trade in Manufacturers" *Economic and Social Review*, 6(1975): 473-482.

Hillard, Aryel and Clark W. Bullard III. "Energy, the Heckscher-Ohlin Theorem and U.S. International Trade," *The Amer. Econ. Rev.*, 68(1978): 96-106.

Kindleberger, Charles P. and Peter H. Lindert. *International Economics* 6th Edition, Richard D. Irwin, Inc., Homewood, Illinois, 1978.

Krenz, Ronald, Gail Garst, Charles Michael, Stanley Rogers and David Fawcett. "Cost of Production Major Crops Easing in 1976" *Agricultural Outlook* AO-9, USDA, ERS, April 1976.

Leontief, Wassily. "Domestic Production and Foreign Trade: The American Capital Position Reexamined," a paper read on April 24, 1953 before the American Philosophical Society. Reprinted by Caves, Richard and Harry S. Johnson, Eds., *Readings in International Economics*, Richard D. Irwin, Homewood, Illinois, 1968.

Leontief, Wassily. "Factor Proportions and the Structure of American Trade; Further Theoretical and Empirical Analysis." *Rev. Econ. Stat.*, Nov. 1956.

Schluter, Gerald and Patty Beeson. Components of Labor Productivity Growth in the Food System, 1958-72 (forthcoming).

Swerling, B. C. "Capital Shortage and Labor Surplus in the United States?" *Rev. of Econ. and Stat.* 36(1954):286-289.

U.S. Dept. of Agr. Econ. Res. Ser. Farm Production and Efficiency, 1977, Statistical Bulletin No. 581, November 1977.

U.S. Dept. of Agr., Econ. Res. Ser. Farm Income Statistics, Statistical Bulletin No. 557, July 1976.

U.S. Dept. of Agr. Econ. Res. Ser. Foreign Agricultural Trade of the United States, selected issues.

U.S. Dept. of Commerce, Bureau of Economic Analysis. "Interindustry Transactions in New Structures and Equipment, 1967" *Survey of Current Business*, Vol. 55. No. 9, pp. 9-21. September, 1975.

Vanek, J. *The Natural Resource Content of United States Foreign Trade, 1870-1955*, The MIT Press, Cambridge, Mass., 1963.

U.S. Department of Commerce, Bureau of Economic Analysis. "Input-Output Structure of the U.S. Economy: 1967" *Survey of Current Business*, Vol. 54, No. 2, pp. 24-56, February 1974.