An Empirical Analysis of the Leontief Paradox in US Agricultural Trade

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The labor, land, and capital intensities of US agricultural trade during 1982 are examined through an input-output model. The empirical findings indicate that factor endowments are important determinants of US agriculture's comparative advantage in international trade. In contrast to the Leontief Paradox, US agricultural exports tend to be more land and capital intensive while agricultural imports are more labor intensive.

THE LEONTIEF PARADOX, CONTINUED

In the pure theory of international trade, patterns of trade are mainly determined by differences in relative factor endowments. According to the well known Heckscher–Ohlin (H–O) theory, a nation will export the commodity whose production requires the intensive use of the nation's relatively abundant and cheap factor and will import the commodity whose production requires the intensive use of the nation's relatively scarce and more expensive factor.

In a pioneering study Leontief examined the capital and labor intensities of US trade. Since the United States was considered the most capital abundant nation in the world, Leontief[1] expected to find that it exported capital intensive commodities and imported labor intensive commodities, in compliance with the H–O theory. His finding was contrary to this expectation: The US exported labor intensive goods and imported capital intensive goods. This unexpected result is well known as the Leontief Paradox. Since that time, numerous empirical studies have been conducted to re-examine the paradox. Jones and Kenen (See ref. 2, pp. 480–485) summarize in great detail recent developments in the examination of the

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Leontief Paradox. Today, in somewhat modified form, Leontief's procedure continues to be a standard method for the analysis of the factor content of trade. So far, however, no firm empirical conclusions have repudiated Leontief's basic findings.

In general there seem to be three main objections to Leontief's methodology. First, Leontief used a two-factor model (labor and capital), thus abstracting from other factors such as natural resources (land, climate, mineral deposits, forests, etc.). However, a commodity might be intensive in natural resources so that classifying it as either capital- or labor-intensive with a two-factor model would clearly be inappropriate. J. Vanek[3] thought that this point helped explain the Leontief Paradox and argued for restoring the traditional triad of capital, labor, and land in the consideration of factor endowments. Robert Stern (See ref. 4, p. 11) is also critical of an approach that excludes natural resources. He argues that both capital and labor are required to modify natural resources to give them economic value, and that countries may combine these factors in somewhat different proportions when producing natural resource-based products. Moreover, since primary commodities move in raw and processed forms, there may be a need to explain the basis for such specialization.

A second objection is that Leontief's results may reflect US tariff policy rather than factor intensity. According to this objection, since most heavily protected industries in the US were labor intensive industries, the tariff policy biased the pattern of trade and reduced the labor intensity of US import substitutes, thus contributing to the existence of the Leontief Paradox.

Perhaps the most extensive argument made in the literature objecting to Leontief's result was the fact that Leontief included in his measure of capital only physical capital (such as machinery, equipment, buildings, etc.) and completely ignored human capital. Human capital refers to expenditures on education, job training, and similar expenditures that increase labor productivity. Leontief's critics implied that since US labor embodies more human capital than foreign labor, adding the human capital component to physical capital would clearly make US exports more capital intensive than US import substitutes.

What then is the current state of the evidence regarding the Leontief Paradox? As an empirical phenomenon in any of several forms, it seems to have generated continued interest. However, its stubborn persistence in the data from the earlier decades continues to cast difficulties similar to Leontief's original findings. In a recent publication Leontief indicated that while many attempts have been made, his original findings remain a paradox in the literature and still neither unambiguously refuted or confirmed due to the lack of methodological standards. The methodological problems are:

(1) Capital requirements per unit of output and the units in which capital is *measured* are not standard.
(2) Technical data for a single year are sometimes assumed to apply for other years as much as a decade later.
(3) Sometimes only direct rather than total requirements are computed because of computational constraints.
(4) Typically the factor requirements to produce replacement capital are ignored.
(5) Sometimes trade in only manufactured goods or other portions of the trade bill is considered (See ref. 5, p. 2.3).

The analysis presented in this paper which examines the Leontief Paradox takes a different form. In contrast to past studies, which mostly examined factor intensities in US manufacturing trade, our analysis is on the factor intensities in US agricultural trade. Since we have detailed resource use, production, and trade data for the agricultural sectors of the US economy, the factor content of agricultural trade can be measured appropriately as total factor production requirements of agricultural trade on an economy-wide basis. Furthermore, in addition to the traditional factors of capital and labor, the focus on agricultural trade makes it useful to examine the land intensities of traded goods as well. In addition, we attempt to eliminate some of what Leontief described as a "lack of standards." First by using the 1977 I/O technology matrix—the latest available—with 1982 trade data, we reduce the problem of using outdated technical data. Second, by using an I/O inverse matrix, we are able to estimate total factor requirements, both direct and indirect. Third, the capital expenditure series used in our analysis is comparable to the capital replacements data used by Leontief. Finally, we use a 47-sector I/O model[6] reconstituted from the original 537 sectors to emphasize the sectors that produce agricultural products.

AGRICULTURAL OUTPUT AND TRADE

Table I shows the 47-sector model which contains 16 agricultural sectors (sectors 1 through 16) and 14 food processing sectors (17 through 26, 30, 31, 35, and 41). The table contains the value of sector outputs; coefficients of labor, land, and capital required per million dollar output; and the value of exports and imports. The trade data used are official estimates of agricultural trade by USDA[7].

Agricultural products valued at $36.6 billion were exported from the US in 1982. Concurrently, the US imported $15.2 billion worth of agricultural commodities of which $5.3 billion were imports of complementary products such as bananas, coffee, and tea that do not compete directly with domestic agriculture. On the other hand, about $9.9 billion of 1982 imports were supplementary commodities that could have been produced domestically and thus are, to some degree, competitive with US 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. Since Leontief omitted complementary products in his factor intensities calculation, we will also omit them from the calculation.

Among the 16 farm sectors, Fruits (sector 10), Tree Nuts (sector 11), and Forest, Greenhouse, & Nursery (sector 16) are relatively labor intensive sectors, with Forest, Greenhouse, and Nursery being the most labor-intensive farm sector. Even though mechanization is important, the growing of fruits, nuts, and greenhouse products still requires more direct labor per unit of output than any other sector in the agricultural sectors.

The foodgrains sector had the highest land-output ratio at 12,350 acres per million dollars output. This was almost twice as land-intensive as the feedgrain sector which used 7185 harvested acres per million dollars output and can largely be explained by lower yields. Grass seeds (sector 8) and Oil Bearing Crops also used land intensively requiring 7121 and 5099 harvested acres, respectively, per million dollars output.

Table I. Factors Required per Million Dollars Output, 1977 and Agricultural Trade, 1982.

	Output ($mil.)	Employment (worker-years)	Land (acres)	Capital ($)	1982 Exports ($mil.)	1982 Imports ($mil.)
1. Dairy Farm Products	12,420.5	9.9	—	49,547.1	0.0	0.0
2. Poultry and Eggs	7,444.5	7.4	—	32,561.0	71.3	4.9
3. Meat Animals	31,022.3	5.9	—	56,220.8	125.0	416.1
4. Miscellaneous Livestock	1,404.6	12.2	—	42,004.8	154.3	139.9
5. Cotton	4,063.8	17.5	3,266.7	165,485.5	1,601.3	13.2
6. Food Grains	5,636.6	11.3	12,350.0	228,719.4	5,353.5	13.8
7. Feed Grains	25,051.2	4.6	7,185.3	212,285.2	5,286.2	58.4
8. Grass Seeds	230.2	4.1	7,121.2	138,575.2	32.0	19.5
9. Tobacco	2,313.9	14.8	417.4	249,967.6	0.0	0.0
10. Fruits	4,170.7	30.0	734.0	142,757.8	521.9	224.0
11. Tree Nuts	565.9	33.6	1,639.2	159,215.4	242.4	24.1
12. Vegetables	5,921.4	17.7	1,113.1	117,438.4	450.9	525.3
13. Sugar Crops	1,078.0	18.5	1,832.7	205,102.0	0.0	0.0
14. Miscellaneous Crops	440.5	9.1	706.7	88,535.8	56.3	64.9
15. Oil Bearing Crops	12,363.1	5.5	5,098.5	172,060.4	5,920.5	24.4
16. Forest, Greenhouse, & Nursery	3,238.7	42.3	171.7	119,060.1	139.2	279.8
17. Meat Products	43,446.2	7.4	—	13,614.5	1,860.2	2219.3
18. Dairy Plants	23,720.4	6.8	—	20,062.9	353.9	368.1
19. Canning, Freezing, Dehydrating	19,364.8	12.8	—	27,591.3	903.6	1277.9
20. Feed & Flour Milling	12,888.0	7.1	—	42,830.5	1,940.1	94.8
21. *Prepared Feeds (nec)*	10,839.1	4.3	—	14,337.0	214.3	47.0
22. Sugar	4,135.6	7.5	—	35,061.4	61.2	862.8
23. Fats & Oils Mills	12,957.8	2.9	—	18,081.8	2,800.5	290.6
24. Confect., Bakery, & Macaroni	19,570.s	17.6	—	31,037.0	207.1	445.2
25. Beverages & Flavorings	26,885.4	7.7	—	42,580.7	328.1	1381.2

32. Leather & Prod	7,655.8	32.8	—	15,818.1	0.0	0.0
33. Crude Petrol & Natl. Gas	49,083.1	7.5	—	264,378.2	0.0	0.0
34. Coal Mining	16,653.1	14.2	—	170,160.5	0.0	0.0
35. Forestry, Fish and Other Mining	16,765.1	15.2	—	164,114.7	209.9	147.1
36. Other Manufacturing	953,659.3	15.6	—	41,061.2	218.2	204.4
37. Transportation & Warehouse	126,210.1	21.1	—	140,210.6	3,566.3	0.0
38. Wholesale, Retail Trade	384,248.6	32.9	—	61,594.0	2,178.2	0.0
39. Eating & Drinking Places	86,026.5	40.9	—	53,070.9	0.0	0.0
40. Other Noncommodities	1,044,362.0	22.5	—	115,433.9	0.0	0.0
41. Ag, For, Fish Services	7,826.6	38.5	—	222,957.6	54.4	3.4
42. Electric Services	56,431.3	7.3	—	137,531.8	0.0	0.0
43. Gas Prod and Distribution	44,986.5	5.4	—	172,520.6	0.0	0.0
44. Real Estate	144,125.3	5.9	—	335,798.8	0.0	0.0
45. Special Industries	214,745.7	69.6	—	0.0	0.0	0.0
46. Noncomparable Imports	—	0.0	—	—	0.0	0.0
47. Scrap	—	0.0	—	—	2.8	0.0
					36,622.1	9,909.0

Table I also shows that the farm sectors have very high ratios of capital purchases to output. Tobacco, Food and Feed Grains, and Sugar Crops head the list, each requiring over $200 thousand for each million dollars of output. For Tobacco farm products, drying and curing barns require a great deal of structural and equipment costs per unit of output. Sugar beets and sugarcane have the highest capital replacement requirements per planted acre of all the crops according to USDA estimates.[8] For food and feed grains, very large acres are needed to produce a million dollars worth of output. Since land and capital tend to be complementary inputs, the large acreages in turn require large purchases of capital.

ESTIMATING PROCEDURES

The Leontief inverse matrix of input–output coefficients is multiplied by the export vector *(X)* and import replacement vector *(M)*, each comprising representative bundles of final delivery of agricultural products. This yields a total (direct and indirect) interindustry demand for output to deliver one million dollars worth of agricultural exports and import replacements respectively. The resulting vector of total interindustry demand is premultiplied by a row vector of factor/output coefficients yielding total factor requirements for one million dollars worth of final demand. The computational procedure is as follows:

for labor: $E[I - A]^{-1} X$ and $E[I - A]^{-1} M$ (1)
for capital: $K[I - A]^{-1} X$ and $K[I - A]^{-1} M$ (2)
for land: $L[I - A]^{-1} X$ and $L[I - A]^{-1} M$ (3)

where E, K, and L are row vectors of labor, capital, and land coefficients per million dollar of output, respectively; $[I - A]^{-1}$ is an inverse matrix of interindustry input coefficients; X is a column vector of exports totaling one million dollars as prorated from actual export values; M is a column vector of competitive import replacements totaling one million dollars.

THE LEONTIEF PARADOX AND US AGRICULTURAL TRADE, 1982

Table II shows a selection of the results of Leontief and others which is adopted from Jones and Kenen[2]. Row 3(c) shows the capital/labor ratio in imports as a fraction of the capital/labor ratio in exports. Leontief's calculation of 1.3 for that ratio in 1947 is substantially greater than one, indicating the paradox of relatively capital intensive imports. Subsequent studies by Leontief and Baldwin, also shown in that row, reconfirm the paradox with both 1951 and 1962 trade with ratios of 1.02 and 1.14, respectively. However, still more recent studies typified by Stern and Maskus show the disappearance of the paradox in more recent years (0.95 for 1972). The table also shows that the ratio of capital/labor in row 3(c) falls in all three studies when natural resources industries are excluded which indicates capital intensity of natural resources industries. Our estimates are shown in the last two columns of the table. In 1982, for example, to export $1 million dollars of agricultural products, $276 thousand worth of new capital investments were also needed of which $179 thousand was for new equipment. Nearly 4700 acres of land and about 27 worker-years were also needed. For each million dollars of agricultural imports $212 thousand of new investment, more than 1200

Table II. Selected Estimates of the Factor Content of US Trade.

	Author (Date)	Leontief (1954)	Leontief[a] (1956)	Baldwin (1971)			Stern and Maskus (1981)		Lee and Wills (1987)
	Year of Trade Data	1947	1951	1982			1972		1982
	Year of Input Data	1947	1947	1958			1972		
	Coverage	All Industries	All Industries	All Industries[b] excl. N.R.		excl. N.R.	All Industries	excl. N.R.	Agriculture
1. Labor									
(a) Imports	(Worker years/$million)	170	168	207	118	106	96	29	32.88
(b) Exports	(Worker years/$million)	182	174	224	131	107	99	24	27.10
(c) Imports/exports	(Ratio)	0.93	0.96	0.92	0.91	0.99	0.98	1.18	1.21
(d) Net exports	(Million worker years)						−0.43		0.66
(e) Production	(Million worker years)						228.52		11.52
(f) Consumption	(Million worker years)						228.95		10.85
2. Capital[c]									
(a) Imports	($thousand/$million)	3091	2303	2093	2132	1259	1368	487	211.81
(b) Exports	($thousand/$million)	2551	2257	2577	1876	1223	1478	455	276.23
(c) Imports/exports	(Ratio)	1.21	1.02	0.81	1.14	1.03	0.92	1.09	0.77
(d) Net exports	($billion)						−2.26		8.02
(e) Production	($billion)						3163.35		59.84
(f) Consumption	($billion)						3165.61		51.82
3. Capital/Labor									
(a) Imports	($thousand/worker year)	18.1	13.7	10.1	18	11.9	14.2	17.3	6.4
(b) Exports	($thousand/worker year)	14	13	11.5	14.2	11.5	15	18.7	10.2
(c) Imports/exports	(Ratio)	1.30	1.06	0.88	1.27	1.04	0.95	0.93	0.63
(d) Net exports	($thousand/worker year)								12.06
(e) Production	($thousand/worker year)								5.20
(f) Consumption	($thousand/worker year)								4.78

Table II. Selected Estimates of the Factor Content of US Trade. (Continued)

Author (Date)	Leontief (1954)	Leontief[a] (1956)	Baldwin (1971)		Stern and Maskus (1981)		Lee and Wills (1987)
Year of Trade Data	1947	1951	1982		1972		1982
Year of Input Data	1947	1947	1958		1972		
Coverage	All Industries	All Industries	All Industries[b] excl. N.R.		All Industries excl. N.R.		Agriculture
4. Land							
(a) Imports (acres/$million)							1246.4
(b) Exports (acres/$million)							4688.7
(c) Imports/exports (Ratio)							0.27
(d) Net exports (million acres)							159.4
(e) Production (million acres)							477.3
(f) Consumption (million acres)							318.0
5. Land/Labor							
(a) Imports (acres/worker year)							37.9
(b) Exports (acres/worker year)							173.0
(c) Imports/exports (Ratio)							0.22
(d) Net exports (acres/worker year)							239.7
(e) Production (acres/worker year)							41.1
(f) Consumption (acres/worker year)							29.3

[a] Leontief (1956) used input coefficients that included capital replacement.

[b] Excluded natural-resource sectors differ slightly across studies. See original sources for details.

[c] Capital requirements reported from Baldwin (1971) are on a net basis, while those from Stern and Maskus (1981) are gross.

Source: Adapted from table 4.1 (2:1984)

acres of land, and 32.9 worker-years of labor would have been required to produce these products domestically.

Land/labor and capital/labor ratios were much higher for exports (173.0 acres and $10,212) than import replacements (37.9 acres and $6442). This is due to the fact that US agricultural exports consist largely of farm products, while imports consist primarily of processed foods. These ratios contrast with those of previous studies. For example, the labor ratio of agricultural trade (imports/exports) was 1.21 compared to Leontief's 0.93 (for 1947) or 0.96 (for 1951), Baldwin's .91 (for 1962), and Stern and Maskus' 0.98 (for 1972). The capital ratio of agricultural (imports/exports) was 0.77 compared to Leontief's 1.21 (for 1947), Baldwin's 1.14 (for 1962), and Stern and Maskus' 0.92 (for 1972). The capital/labor ratio of agricultural trade (imports/exports) was 0.63 compared to Leontief's 1.30 (for 1947), Baldwin's 1.27 (for 1962), and Stern and Maskus' 0.95 (for 1972). The land-labor ratio per unit of output was much higher for agricultural exports (173.0 acres/worker-year) than import replacements (37.9 acres/worker-year, Table II). These three ratios are significant for the agricultural sectors because they are contrary to Leontief's findings. Thus, no Leontief Paradox could be found in agricultural trade. Rather, the analysis of agricultural trade showed that capital-intensive agricultural products were exported while import replacements used labor-intensive production practices.

Table III presents the factor requirements of one million dollars agricultural trade in six broadly defined sectors. To export one million dollars of agricultural products required 12.7 worker-years in the farming sector, 7.2 worker-years in the food processing and 2.5 worker-years in the wholesale and retail trade sector. The farming sector accounted for nearly half of agricultural exports and as a result its total demand for factor inputs was the largest. In the case of imports, however, processed foods make up the bulk of trade and consequently total trade-based demand for factor inputs used in this sector was the largest.

The dominant statistic in this table is the relatively high purchases of equipment by the farm sector. Because raw agricultural commodities account for a larger portion of US agricultural exports than of imports this fact alone accounts for nearly all the difference in capital intensity between exports and imports. The "total" row of Table II presents the factor intensity estimates for all agricultural trade, including the farm sector. The capital-labor ratio for capital and labor needed in the farm sector for exports was $14,581 compared to $7009 for imports. The land-labor ratios show that exports use land more intensively than imports for both farm commodities (325.9 for exports vs. 58.2 for imports) and processed food (75.4 for exports vs. 35.7 for imports).

SUMMARY AND CONCLUSIONS

This article analyzed the capital, labor, and land intensities of US agricultural trade and examined the applicability of the Leontief Paradox to US agricultural trade for 1982. Since most of the literature on factor intensity of US trade is limited to trade in manufacturing, this study provides an additional look at the factor intensity of trade.

Several interesting aspects of the factor requirements of trade are revealed.

Table III. Factor Requirements in US 1982 Agricultural Trade by Broad Sector.

	One Million Dollars Exports					
	Labor (Worker-Years)	Wages ($)	Land (Acres)	Structures ($)	Equipment ($)	Capital ($)
Farming	12.7	137,024	4,139	65,127	120,482	185,611
Food Processing	7.2	101,321	543	19,221	32,864	52,084
Other Manufacturing	1.2	17,641	5	3,326	4,973	8,298
Transportation	3.4	58,836	1	6,054	16,284	22,338
Trade	2.5	32,990	1	3,347	4,060	7,407
Other Services	0.1	828	0	116	373	488
Total	27.1	348,642	4,689	97,190	179,036	276,227
Nonfarm Total	14.3	211,617	550	32,063	58,553	90,616
Capital/Labor						
Farming	$14,581					
Total	$10,212					
Nonfarm Total	$6,324					

	One Million Dollars Imports					
	Labor (Worker-Years)	Wages ($)	Land (Acres)	Structures ($)	Equipment ($)	Capital ($)
Farming	6.5	66,359	378	18,920	26,635	45,556
Food Processing	24.2	342,284	863	57,359	96,412	153,771
Other Manufacturing	2.2	32,655	6	4,940	7,429	12,370
Transportation	0.0	0	0	0	0	0
Trade	0.0	0	0	0	0	0
Other Services	0.0	194	0	27	87	114
Total	32.9	441,492	1,246	81,246	130,563	211,810
Nonfarm Total	26.4	375,133	869	62,326	103,928	166,255

Capital/Labor	
Farming	$7,009
Total	$6,442
Nonfarm Total	$6,302

First of all, agricultural exports are heavily land-intensive compared to imports. This is because most agricultural exports are farm products while most agricultural imports are processed food products. Thus, land use for import substitutes of one million dollars was about a fourth that of exports.

Second, our labor estimates show that worker-years required per million dollars output are much smaller than previous labor estimates. This appears to be the result of three factors. First of all, because of price increases, one million dollars of output represents less real output today than in 1947. Second, with increases in productivity, labor/output coefficients have declined in all industries since the previous studies were done. Third, while labor productivity has increased throughout the economy, farm labor productivity has increased at a much faster rate.*

Third, the scarcity of labor in the US relative to other countries explains our results that land- and capital-intensive production technologies are used to compete with foreign goods. The analysis of US agricultural trade signals this conclusion: the United States is relatively well endowed with capital and land and this may form the basis for a comparative advantage in agricultural production. As a result, the patterns of US agricultural trade are as suggested by the H–O theory.

Addressing the specific question of whether the H–O model is an adequate description of the realities of US agricultural trade, is difficult since much of US agriculture and that of our major trading partners is heavily supported through subsidies. Thus, agricultural trade is far from free. However, these government interventions do not appear to have distorted the general pattern of agricultural trade that one would expect. In this light, US agricultural trade is still in line with the H–O theory.

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*Output per hour in the total business sector increased 123% between 1947 and 1977 while that in agriculture increased by 525% during the same period.[9]

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