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Examining the Leontief Paradox in U.S. Agricultural Trade

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Abstract

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Factor intensity of United States agricultural trade is examined in the context of Leontief's classic paradox using Leontief's method as well as methods developed recently by Leamer and others. Findings indicate that factor endowments are important determinants of U.S. agriculture's comparative advantage in trade as suggested by the Heckscher–Ohlin theory.

Introduction

Relative factor endowment models continue to play a prominent role in trade theory. In a recent article, Markusen (1986) finds that while the volume of trade may be explained by a nonhomothetic preferences model, the direction (pattern) of trade can be better explained by the traditional trade theory based on relative factor endowments.

One indication of the continued interest in the relative factor endowments model is the ongoing theoretical and empirical analysis of the Leontief Paradox. Leontief (1954) found that, contrary to his expectation, the United States exported labor-intensive goods and imported capital-intensive goods. Since then, numerous empirical studies have been conducted to re-examine the Paradox for U.S. trade. Today, in somewhat modified form, the Leontief-type of test continues to be a standard method for the analysis of the Heckscher–Ohlin (H–O) factor endowments model of U.S. trade.

The purpose of this paper is to examine the Leontief Paradox in a different form. In contrast to past studies, which mostly examined factor intensities in U.S. manufacturing trade, this paper will examine the factor intensities in U.S. agricultural trade for 1982. We are interested in empirically testing if U.S.

agricultural trade follows the trade pattern suggested by (H-O)'s traditional trade theory based on relative factor endowments. Furthermore, since our focus is on agricultural trade, the land intensities of traded agricultural products will also be examined in addition to the traditional factors of capital and labor.

1. Recent developments in the Leontief Paradox

For the past three decades, Leontief's basic methodology has been reapplied by many economists to examine factor intensities of U.S. trade. Baldwin (1971), Leamer (1980), Stern and Maskus (1981), Brecher and Choudhri (1982) and Casas and Choi (1985) are among them. The results of Baldwin and Stern and Maskus were typical, reaffirming the Paradox for the early years although Stern and Maskus found some evidence that it may have disappeared by the 1970's.

Leamer, however, argues that the Leontief Paradox rests on a simple conceptual misunderstanding. According to Leamer (p. 495), Leontief's proposition is true only if the net export of labor and capital services show the opposite sign. However, Leontief's data show that the net export of labor and capital services are both positive. In such a case, the proper comparison is between the capital per worker embodied in net exports and the capital per worker embodied in domestic consumption. Leamer also argues that Leontief did not actually measure capital abundance in the United States but merely presumed abundance of capital relative to labor. However, the fact that U.S. net exports show more capital intensity than U.S. consumption expenditures implies that the U.S. is capital-abundant relative to labor. Therefore, there exists no paradox if the conceptually correct calculations are made.

More recently, however, Brecher and Choudhri have pointed out that a slightly different paradox still exists in Leontief's data. They show that expenditure per worker was substantially greater in the U.S. than in the rest of the world. Yet, Leamer's estimation indicates that the U.S. exported labor services in 1947. Brecher and Choudhri (p. 820) therefore, argue that Leamer's observation is itself paradoxical: that is, Leamer's observation is contrary to the expectation that a country is a net exporter of labor services if and only if its aggregate expenditure per worker is less than that in the rest of the world.

Most recently, however, Casas and Choi have shown that, even though Leamer established conclusively that the U.S. had been revealed to be abundant in capital compared to labor, his argument did not address the question of whether the positive net exports of labor services by the U.S. could be taken as an indication of labor abundance relative to all resources on the average. Casas and Choi (1985, p. 611) argue that if U.S. trade had been balanced, labor services would have been imported and the country's labor scarcity would have been directly revealed. This result contrasts sharply with Brecher and Choudhri's suggestion that trade balance would have left the U.S. a net exporter of labor services. Thus the argument over the Leontief Paradox continues.

What then is the current state of empirical studies of the Leontief Paradox? As an empirical examination of factor endowments theory, it seems to have continued interest. And, stubborn persistence of the Leontief Paradox in the data from the earlier decades continues to cast difficulties similar to Leontief's original findings. In a recent publication, Leontief indicates that while many attempts to refute or confirm the Paradox have been made, his original findings remain a paradox in the literature (Leontief and Duchin, 1985). The Paradox remains neither refuted nor resolved due to the lack of standards in computing similar to his original findings. The standard 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 distant.
- (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 (Leontief and Duchin, p. 2.3).

In this paper, we will attempt to eliminate some of what Leontief described as "lack of standards." For example, by using the 1977 I/O technology matrix — the latest available — with 1982 trade data, we cut the problem of 'a decade distant' to a half. Using the I/O inverse matrix, we were able to estimate direct and indirect (thus total) factor requirements. Finally, the capital expenditure series used in our analysis is comparable with the capital replacements used in his model.

One of the main objections to Leontief's methodology is that Leontief used a two-factor model (labor and capital), thus abstracting from other factors such as natural resources (land, climate, mineral deposits, forests, etc). Vanek (1959) indicated that a commodity might be intensive in natural resources so that classifying it as either capital- or labor-intensive would clearly be inappropriate. Vanek argues that this point helps explain the Leontief Paradox and he indicates the importance of restoring the traditional triad of capital, labor, and 'land' in factor endowment considerations. Robert Stern (1975) emphasized the need for models of more than two factors because capital and labor are required to improve natural resources to give them economic value, and countries may certainly combine these factors in somewhat different proportions when producing natural resource-based products. Thus, consideration of natural resources is important in the examination of the effect of factor endowment on trade. Our empirical analysis therefore, includes 'land' as well as capital and labor.

2. Estimation 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. The resulting vectors for the total interindustry demand for 1 million dollars worth of exports and import replacements, respectively, is premultiplied by a 3 by 47 matrix of factor-output ratios, yielding total factor requirements for 1 million dollars of exports and imports. The computational procedure is as follows:

$$F[I-A]^{-1}X \quad \text{and} \quad F[I-A]^{-1}M \quad (1)$$

where F is a 3 by 47 matrix of factor coefficients; labor, harvested acres, and capital.

Leamer demonstrated that, given a variety of assumptions commonly made within the H-O framework of international trade, factor abundance can be inferred by comparing the factor inputs contained in net exports with the factor inputs contained in consumption. Using equation (1):

$$F_{nx} = F[I-A]^{-1}N_x \quad (2)$$

$$F_c = F[I-A]^{-1}C \quad (3)$$

where F_{nx} is a 3 by 47 matrix whose elements in the rows are the amount of each factor (labor, land, and capital) contained in net exports (N_x), and F_c is a 3 by 47 matrix whose elements in the rows are the amount of each factor contained in domestic consumption (C). Leamer's condition (b) (p. 496) indicates that a country is well endowed in capital relative to labor if:

$$K_x - K_m > 0, L_x - L_m > 0$$

and

$$(K_x - K_m / L_x - L_m) > K_c / L_c$$

where K_x , K_m , L_x , L_m , K_c , and L_c are capital and labor embodied in exports, imports and consumption. Similarly the factor pair, land and labor, embodied in exports, imports and consumption are derived. Thus, a country which is an exporter of both labor services and capital (land) services is revealed by trade to be relatively capital-(land-)abundant if the capital (land) intensity of net exports exceeds the capital (land) intensity of consumption. In other words, Leamer shows that if labor embodied in net exports (L_{nx}) and capital embodied in net exports (K_{nx}) are positive, a necessary and sufficient condition for capital relative to labor abundance for a country is that $K_{nx}/L_{nx} > K_c/L_c$. Furthermore, from equations (2) and (3), the abundance ranking among factors can also be established directly by ranking the ratios of the amount of each factor

contained in net exports (N_x) relative to domestic consumption (C) (Sveikauskas, 1983, p. 547).

Brecher and Choudhri have shown that the amount of services of factor L embodied in country i 's net exports may be written as:

$$L_t = L_i [1 - (a_i L_w / L_i)] \quad (4)$$

where $a_i = C_i / C_w$, is the ratio of consumption (expenditure) in country i to that of the world. Equation (4) implies that:

$$L_t > 0 \quad \text{iff} \quad C_w / L_w > C_i / L_i \quad (5)$$

Equation (5) holds regardless of whether trade is balanced. If trade is balanced then:

$$L_t > 0 \quad \text{iff} \quad L_i / L_w > Y_i / Y_w \quad (6)$$

where Y_i and $Y_w (= C_w)$ represent the levels of income in country i and the world. Furthermore, under the factor-price equalization theorem, Y_i / Y_w can be interpreted as country i 's aggregate factor endowment relative to the world's, equation (6) reveals country i to be abundant in labor relative to all other factors when $L_t > 0$.

Casas and Choi have shown that, based on Brecher and Choudhri's model of factor services in a country's net exports, the net amount of services of factor L that would be exported under balanced trade can be written as:

$$L_{t*} = L_i [1 - (Y_i / C_i) (L_c / L_i)] \quad (7)$$

where L_{t*} denotes the amount of services of factor L that would be exported under balanced trade. Country i would therefore be revealed abundant in factor L , if the ratio of domestic consumption to endowment of the factor (L_c / L_i) is smaller than the ratio of domestic absorption to income (C_i / Y_i), and vice versa. Compared with Brecher and Choudhri's model shown in equation (4), Casas and Choi's equation (7) has the significant advantage of relying exclusively on domestic data.

If labor is scarce in a country, by definition, domestic income per unit of that factor will be larger than the world level, and vice versa. However, Brecher and Choudhri's findings were that both income and absorption per worker in the U.S. were considerably higher than in its major trading partners even though labor services are exported. Our estimation however, will show that labor services in agricultural import replacement sectors were indeed 'scarce'. Income per worker for import replacements of agricultural trade was higher than that of export sectors.

(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)	41.4
(f)	Consumption	(acres/worker year)	29.3

^aLeontief (1958) used input coefficients that included capital replacement.

^bExcluded natural-resource sectors differ slightly across studies. See original sources for details.

^cCapital requirements reported from Baldwin (1971) are on a net basis, while those from Stern and Maskus (1981) are gross.

Source: Adapted from Jones and Kenen (1984, table 4.1).

acre \approx 0.404686 ha \approx 4047 m².

US billion = 10⁹.

3. Examination of Leontief Paradox with U.S. agricultural trade, 1982

The first column of Table 1 shows Leontief's initial results which led to the original paradox. This table is adopted from Jones and Kenen (1984). Results of other selected studies are also shown in the table. Our results appear in the last column.

The 1.30 ratio of capital-labor intensity in imports and exports shown in row 3c for 1947 is crucial and defines the Leontief Paradox of relatively capital-intensive imports. Subsequent studies by Leontief and Baldwin, also shown in that row, reconfirm the paradox with the ratios of 1.06 and 1.27, respectively, for 1951 and 1962 trade. However, still more recent studies typified by Stern and Maskus suggest the apparent disappearance of the paradox in more recent years (0.95 for 1972). The table also shows that the ratio falls in all three studies when natural resources industries are excluded.

One should however read this table with some care. As footnotes in the Table 1 indicate, data across the table are not exactly comparable because different definitions and different data are used among different authors. For example, Baldwin defined natural resource products arbitrarily. He indicates that his definition of natural resources is roughly similar to the one used by Leontief except that petroleum refining is added and non-livestock agricultural products are included in the definition of natural resource products (Baldwin, 1971, p. 123). In the case of Stern and Maskus, the authors first calculated the factor requirements per million dollars of exports and competitive imports replacements for all industries. Then they repeated the calculations, omitting *sequentially both* the trade activities and the resource requirements in the service industries, then agriculture, forestry and fisheries, mining and construction (Stern and Maskus, 1981, p. 217). Thus, as Leontief indicated (Leontief and Duchin, 1985, p. 2.3), the lack of standards cast difficulties in computing similar to his original findings. However, the Leontief Paradox calculation of relative factor intensity of exports and imports is transparent to the measurement problems since the units of measurement cancel out.

Our estimates in the last column are based on the 47-sector input-output model by Lee and Wills (1988), which contains 16 agricultural sectors and 14 processed food and fiber sectors. The agricultural products that are traded include livestock products, food and feed grains, and all other farm commodities including wool and cotton. In 1982, to export 1 million dollars of agricultural products, \$278 thousand worth of new capital expenditures were needed of which \$179 thousand were for new equipment. Nearly 4700 acres of land and about 27 worker-years were also needed. For agricultural import substitutions (that is, if 1 million dollars of imported food and fiber products had been produced domestically), new capital investments would be \$212 thou-

sand, more than 1200 acres of land would be utilized, and 32.9 worker-years of labor would be needed.

The land-labor ratio was much higher for exports (173.0) compared to that of import replacements (37.9) (Table 1, last column). The capital-labor ratio was also much higher for exports (\$10.2 thousand per worker) than for imports (\$6.4 thousand per worker). Import/export ratios for labor, capital and land were 1.21, 0.77, and 0.27, respectively. These three ratios are significant statistics for agricultural trade because they are contrary to Leontief's findings. Thus, no Leontief Paradox could be found in agricultural trade. Rather, agricultural trade showed that capital- and land-intensive agricultural products were exported while import replacements called for labor-intensive production practices.

It should be emphasized that the above estimates of the labor content of agricultural trade include only hired workers as in previous studies. Unlike most other industries however, a high proportion of agricultural labor is provided by proprietors and unpaid family workers. The above estimates do not include the labor services of these workers. To determine if this exclusion affects the results, the estimates were recalculated using labor coefficients that included proprietors and unpaid family workers in all industries. While the estimated level of labor services in agricultural trade increased as expected, the ratio of labor content in imports to that in exports remains about the same at 1.15 and the capital-labor ratio for exports was higher (6900) than that of imports (4600). Thus even when proprietors and unpaid family workers are included, the basic conclusion holds: the U.S. exports capital- and land-intensive agricultural products while importing labor-intensive agricultural products.

Using equations (2) and (3), factor intensities of U.S. agricultural production, consumption, and net trade in 1982 are calculated and are shown in Table 2. This table is similar to Leamer's table 3 except that Leamer calculated factor embodied for total production, consumption and net exports while Table 2 shows factor embodied per million dollars production, consumption, and net

TABLE 2

Factor content per million dollars 1982 agricultural production, consumption and net trade

		Production	Consumption	N_x	$N_x/\text{Consumption}$	Rank
Employment	(worker-years)	34.6	35.5	24.9	0.70	5
Compensation	(dollars)	469,618.9	483,195.2	314,199.6	0.65	6
Land	(acres)	1,435.6	1,039.8	5,965.5	5.74	1
Structures	(dollars)	70,834.1	68,015.2	103,104.7	1.52	4
Equipment	(dollars)	109,126.2	101,448.8	197,016.0	1.94	2
Capital	(dollars)	179,960.3	169,463.8	300,122.5	1.77	3
Capital/Labor	(dollars/worker)	5,201.2	4,773.6	12,053.1		
Land/Labor	(acres/worker)	41.5	29.3	239.6		

exports. The labor required per 1 million dollars production was smaller (34.6 worker-years) than labor required per million dollars consumption (35.5 worker-years). Thus, more labor-intensive agricultural products are consumed in the United States than are produced. The labor required for net exports was also smaller (24.9 worker-years) than that for consumption. Consequently, the ratio of labor required for net export and consumption was less than one (0.70) indicating that U.S. agricultural exports are less labor-intensive than consumption. The land intensity of net exports per worker-year by agricultural trade was 239.6 (5965.5/24.9) acres compared to 41.5 (1435.6/34.6) acres per worker-year for production, and 29.3 (1039.8/35.5) per worker-year for consumption.

Total capital intensities per worker-year were \$5.2, \$4.77 and \$12.05 thousand, respectively, for production, consumption, and net exports. Thus, Table 2 reveals that U.S. agricultural trade was relatively intensive in capital and land compared to labor. The last column of the table, which ranks factor intensities based on the ratios of factor uses in net exports over that of domestic consumption, also confirms relative factor intensities of land and capital. It should be emphasized that these factor requirements per million dollars of imports are based only on import-competing products. Leamer has suggested that non-competing imports are more labor-intensive than competitive imports. In that case, the omission of non-competitive imports would understate the amount of labor required per million dollars of imports. Non-competitive imports accounted for 50% of total agricultural imports in 1982.

Our calculations show that: (1) net exports are positive in capital-labor and land-labor ratios, and (2) the ratios of capital-labor and land-labor in net exports are greater than those in consumption. Thus, the share of domestic capital exported exceeded the share of labor exported and satisfy Leamer's condition (b) mentioned above.

An important corollary of the H-O-Vanek model of international trade patterns is that when a country experiences balanced trade, it will be a net exporter of the services of its abundant factors and a net importer of the services of its scarce factors. However, when embodied factors are exported or imported simultaneously as was the case for the 1947 U.S. data used by Leontief, it is not possible to infer relative factor endowments (abundance versus scarcity) from the observed factor intensity ranking of traded goods. Leamer's method, however, was able to establish conclusively that Leontief's data implied that the U.S. had been revealed to be abundant in capital compared to labor. Application of Leamer's method to U.S. agricultural trade shows that U.S. had been revealed to be abundant in both capital and land relative to labor.

Equation (7) specifically reveals that a country with a trade imbalance would have been a net importer of the labor services under balanced trade if the ratio of labor embodied in domestic consumption to the endowment of labor is greater than the ratio of domestic absorption to production. Assuming that the total

labor content of production is equal to the labor endowment under the condition of full employment and using 1982 sector level data, the ratio of labor embodied in domestic absorption (L_c) to domestic endowment (L_i) is 0.94 (10.9 million worker-years/11.5 million worker-years). This can be compared with the ratio of domestic absorption (C_i) to domestic production (Y_i) of 0.92 (\$305.8 billion/\$332.5 billion). Thus, if U.S. agricultural trade had been balanced, labor services would have been imported. The estimate based on equation (7) shows 282 988 worker-years for the hypothetical balanced trade level of net imports of labor services in 1982.

According to factor endowment theory, if labor is a scarce resource in the U.S., domestic income per unit of that labor will be larger than the world level. Thus, in agricultural trade, we would expect that income per worker for exports would be less than that of imports. In other words, if the U.S. agricultural trade situation is such that labor-intensive agricultural products were imported while exporting capital-intensive agricultural products, then income per unit of labor in imports should be greater than that of exports. Our calculations show that average wage income per unit of labor (worker-year) for exports was \$12,889 (\$348,642/27.1) compared to average wage income per unit of labor for imports, \$13,427 (\$441,492/32.9). Thus, our finding is consistent with the factor endowment definition of factor payments: higher returns to scarce factors.

So, what have we added by including land in the analysis of Leontief's Paradox? On one level, very little. Farming is by nature heavily land-based and by any measure the U.S. is well endowed with high-quality farmland. Vanek has already emphasized the important role of natural resources in the analysis of factor content of trade.

But our results are not just a special case of previous results. The technology used to transform this natural resource, farmland, combines labor and capital in a particular and revealing manner. From 1947 to 1982 the agricultural workforce declined nearly 70% while the stock of fixed reproducible farm equipment and structures increased 200% (USDA, table 60 and USDC, table A-6). It is unlikely to be just a coincidence that U.S. farm export commodities reflect a factor content consistent with this historical trend. That is, if labor was the relatively costly factor being replaced by a relatively less costly factor, capital, then those commodities whose production technology could best combine this relative factor cost situation with abundant farmland would emerge as the U.S. commodities which best reflect U.S. comparative advantage in international trade. The production technology of corn, cotton, soybeans and cotton fit this characterization and are also the dominant U.S. bulk export commodities.

Our results differ dramatically from some previous results. When Leontief, Baldwin, and Stern and Maskus excluded natural resource-based trade, they all found less evidence of the Paradox (line 3c of Table 1). Therefore implicitly the support for the Leontief Paradox in these studies came from the factor

content of the natural resource-based traded commodities. We found agricultural exports to be more land- (natural resource-)intensive than agricultural imports, yet we were not even close to finding support for the Leontief Paradox in agricultural trade, 0.83 on the crucial ratio versus 1.3 in Leontief's original findings. This suggests agriculture was both subject to and responded to a different set of technological, market and resource-availability forces than the other resource-based sectors of the U.S. economy.

Summary and conclusions

The calculations shown in Section 3 reveal that U.S. agricultural trade would have been a net importer of labor services under Leontief's method as well as under balanced trade as shown by Brecher and Choudhri and Casas and Choi. Our result for agricultural trade contrasts with suggestions by Leontief and Brecher and Choudhri that U.S. trade (including balanced trade) would have left the U.S. a net exporter of labor services. On the other hand, our findings for characteristics of U.S. agricultural trade in 1982 are more in line with Leamer's findings. The major findings of this paper are:

(1) The Leontief paradox does not exist in U.S. agricultural trade. This conclusion holds whether Leontief's method, or more recent methods are used. This study utilized both Leontief's methods as well as more recent methods used by Leamer and others.

(2) The factor-labor ratios (the capital/labor ratio and land/labor ratio) in net exports indicate that land was the dominant factor as revealed by a high net export/consumption ratio.

(3) This analysis has reaffirmed the importance of land and agricultural capital as determinants of the U.S. comparative advantage in agricultural trade. Our findings are more in line with the expected characteristics of the U.S. trade given its relative capital, land, and labor endowments.

The results are in line with the capital and land intensiveness of U.S. farm production. Those farm subsectors, such as grains and soybeans, whose production require large quantities of land also require large quantities of capital (equipment capital in particular). They have also been export-oriented commodities and have become important to the overall U.S. balance of trade.

The scarcity of labor in the U.S. relative to other countries explains our results that the U.S. uses land- and capital-intensive production technologies to compete with foreign goods. Recent trade experience may be signaling this conclusion: the United States is relatively well endowed with land and capital so important for production of grains and soybeans and may have a comparative advantage in these crops. U.S. grains and oilseeds now enter international trade on a large scale, consistent with the patterns of trade and production suggested by the H-O theory. In sum, United States agricultural production is relatively land- and capital-abundant, that is each farmer works a larger quan-

tity of land, using more capital than does a farmer in many other trading nations, and the U.S. exports those crops which best utilize this abundance. The findings of this paper lead to powerful and interesting results that address the general question of whether factor endowments are important determinants of comparative advantage in international trade as advocated by the H-O theory. As far as U.S. agricultural trade is concerned, they are.

It is more difficult to answer the specific question of whether the H-O model is an adequate description of U.S. agricultural trade. The U.S. (as other industrialized exporters such as EEC, Canada, and Australia) has supported its agriculture with price and income programs. Therefore, trade of agricultural products is far from free. However, U.S. agricultural trade is more with countries whose factor endowments are largely different from it so that farm programs can not vitiate the factor endowments theory. In this sense, U.S. agricultural trade is still in line with the H-O theory.

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