Leontief Was Not Right After All

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Abstract

Exploiting recent international data on factor usage by sector, we provide the first direct test of Leontief's notion of factor-specific productivity differences. This test strongly rejects Trefler's [8] generalization of Leontief's idea. Hence tests of the Heckscher-Ohlin paradigm cannot be based upon such simple technological differences across countries.

1 Factor-Specific Productivity Differences

Consider two technology matrices

$$A_1 = \begin{bmatrix} 1 & 1 \\ 2 & 1 \\ 3 & 1 \end{bmatrix} \text{ and } A_2 = \begin{bmatrix} 10 & 2 \\ 20 & 2 \\ 30 & 2 \end{bmatrix},$$

where the rows correspond to goods and the columns to capital and labor respectively. The ij-th element of such a matrix is the local unit input requirement into good i of factor j. In this simple case, it is clear that capital is ten times and labor is twice as efficient in the first country as in the second.

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Leontief [6, p.344] posited factor-specific productivity differences to explain the paradox that the United States' exports in 1947 embodied considerably less capital and somewhat more labor than would be required for domestic production of competitive imports. Trefler's [8] implementation of Leontief's idea is elegant.

Let country 1 be the reference. In this example, the diagonal matrix

$$\Pi = \begin{bmatrix} \pi_K & 0 \\ 0 & \pi_L \end{bmatrix} = \begin{bmatrix} 10 & 0 \\ 0 & 2 \end{bmatrix}$$

shows an exact specification of these differences. Its inverse

$$\Pi^{-1} = \begin{bmatrix} 1/\pi_K & 0 \\ 0 & 1/\pi_L \end{bmatrix}$$

specifies the relative factor prices for which both countries are competitive in every good. Basing his empirical analysis on a simple version of the Heckscher-Ohlin model, Trefler used data on endowments and the factor content of trade to compute 32 of these matrices, each with ten different factors. His reference country was the United States, and these parameters were computed so that the measured and predicted factor contents of trade were exactly equal. Using independent data on wages, he confirmed his approach by showing a high correlation between relative wages and the productivity parameters backed out of the data.

Consider arbitrary $n \times f$ technology matrices A_1 and A_2, where n is the number of goods and f is the number of factors. Trefler's central assumption is that

$$A_2 = A_1 \Pi$$

Let W_c be the $f \times f$ diagonal matrix of factor prices in country c and P be the n-dimensional analog for international goods prices.[1] Then the factor share matrices

$$\Theta_1 = P^{-1} A_1 W_1 = P^{-1} A_2 W_2 = \Theta_2$$

are identical because $W_2 = \Pi^{-1} W_1$.

The economic intuition is simple. If labor in France is half as productive as in the United States, then French wages will be half those in America. But a French

[1]Trefler's specification implies that each good's unit cost is identical across countries, and we assume common world prices without loss of generality. But none of our arguments relies on any good being traded. Our direct tests depend upon local technology matrices only, and each industry's factor shares ought to be identical across countries even in the presence of trade costs that can vary by good.

firm will need twice as many workers as an American firm per unit of output. Hence the wage bills for firms in any industry will be identical in every country, an implication of the Procrustean postulate that technology differences are factor-specific. Thus factor shares in every local industry are identical to those in the reference country. It is unfortunate that this specification is at odds with a closer inspection of the data. There are now accurate enough data–indeed some were available at the time of Trefler's work–to reject this formulation of cross-country productivity differences.[2]

Leontief was cognizant that his assumption of factor-specific productivity differences had strong implications for disaggregated data. He stated, ' ...[T]he conventional argument must combine the foregoing observation with the implicit assumption that the *relative* productivity of capital and labor–if compared industry by industry–is the same here and abroad.' [6, p.344] Of course, consistent international data on the direct and indirect factor requirements for a wide array of economic activities did not exist in 1953. But they do now.

2 The Data and a Robust Test

Our data are the recent OECD input-output tables for 33 countries: Australia, Austria, Belgium, Brazil, Canada, China, the Czech Republic, Denmark, Finland, France, Germany, Great Britain, Greece, Hungary, Indonesia, Ireland, Israel, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Slovakia, Spain, Sweden, Switzerland, Turkey, Taiwan, and the United States.[3] These input-output tables describe the local economies near the year 2000. The raw data are in local currencies, but our technology matrices are unit-less factor shares, so we do not need to worry about converting factor flows using exchange rates. These input-output tables have data on 48 sectors. They are consistent in two ways. First, they are designed to be comparable across countries. Second, the factor shares for each industry are consistent with endowments; for example, the weighted average of capital's shares across all local industries is equal to its share in macroeconomic accounts by construction. The data have two big advantages. First, they measure the flow of factor services accurately in each industry. Second,

[2]Exploiting cross-country data on a wide sample of industries, Arrow, Chenery, Minhas, and Solow [1] estimated elasticities of substitution that were typically quite different from unity. Hence it was already well known that an industry's factor shares depended upon local factor prices. Also, scholars such as Rosefielde [7] were studying input-output matrices from other countries.

[3]The URL is: http://www.oecd.org.

we [3] show that they confirm Trefler's [9] seminal findings about missing trade and the poor power of the Heckscher-Ohlin model in predicting the direction of trade.[4]

We use these input-output tables to compute direct and indirect factor requirements in 48 industries for each of 33 countries. Our three factors capital, labor, and social capital correspond to the three entries in national accounts for value added: gross operating surplus, compensation to employees, and indirect business taxes. It is slightly unconventional to define the social capital as a factor. We do so for four reasons. First, indirect business taxes are completely analogous to payments to labor and capital in national accounts; so we define a social capital as a factor for logical and statistical consistency. Second, different long-run patterns of indirect taxation by sector affect factor prices and thus local technologies. Third, our specification is consistent with the macroeconomic literature that measures after-tax rates of return to capital and labor. Fourth, social capital, interpreted as a firm's access to a local market, is as much a fixed factor that is not traded as is labor and capital.[5]

Following Trefler [8], we use the United States as the reference country. Since it has no economic activity in "Steam and Hot Water Supply", we drop that industry. We also omit an industry in a bilateral comparison when the local economy records no activity in that sector.

Let

$$\theta(c)_{ij} - \theta(0)_{ij}$$

be the difference in sector $i \in \{1, ...48\}$ between the share of factor $j \in \{K, L, G\}$ in country $c \in \{Australia, ..., Taiwan\}$ and that in the United States, the reference country. Figure 1 is a histogram of these factor share differences. There are 4215 observations, fewer than $47 * 3 * 32 = 4512$, because a few countries record no economic activity in some sectors. The population mean is 0 by construction, and its median is -0.017. Its standard deviation is 0.15, its skewness is 0.17, and its kurtosis is 7.8.

[4]We [3] argue that consistent macroeconomic data already incorporate the correct local factor prices; so these data actually sharpen the mystery of missing trade because it still occurs even when one corrects for productivity differences using local factor prices.

[5]Our definition has a slight drawback. Factor shares always sum to unity, but there are a few subsidized sectors where payments to social capital are negative. The most striking case is "'Motor Vehicles, Trailers, and Semi-trailers" in Indonesia. Capital's share is 1.6, labor's is 0.8, and social capital's is -1.4. Some might consider it an advantage to identify rare case of highly subsidized sectors. These cases give the data fat tails.

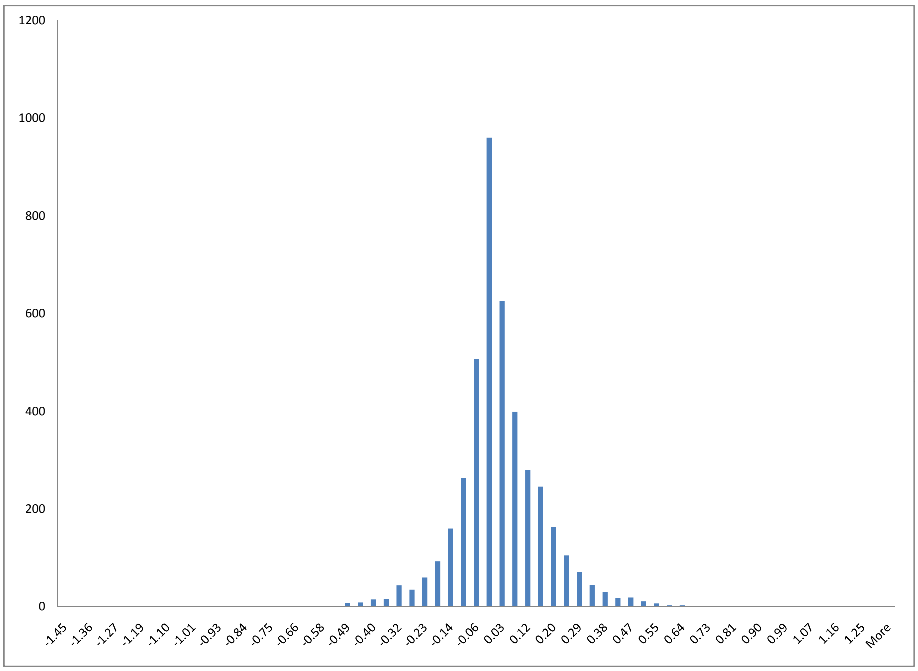

Figure 1: Factor Share Differences

If Leontief's conjecture were correct, then every difference would be identically zero. Indeed, we could follow Davis and Weinstein [2, p. 1432] and reject the theory simply by inspection, but it is worth exploiting the variability in the data.

Hence we assume that the technology matrices are measured with error. Fix a factor j and a country c, and consider

$$\theta(c)_{.j} - \theta(0)_{.j}$$

where $\theta(c)_{.j}$ is the 47×1 vector of factor shares in country c and $\theta(0)_{.j}$ is its analog in the United States. Since factor prices and goods price are fixed by assumption, these factor shares are measured with error perhaps because there is idiosyncratic local aggregation bias in each industry. For example, a different mix of firms might produce 'Rubber and Plastic Products' in Korea than in the United States.

Hence factor shares in that industry might differ across countries.

We assume only that measurement error is independent across industries. In essence, we impose that aggregation bias does not depend upon the name of the economic activity. The coefficient of variation of factor shares across countries for any one industry is almost always as great as that across industries within one country. So there is plenty of variability in these data. But we are making no parametric assumptions about any family of distributions.

We use the natural non-parametric sign test based upon the null hypothesis that each element of this vector has an equal chance of being positive or negative. There are 32 bilateral comparisons for each factor. Hence we have 96 different tests. This test uses the null hypothesis: Is Leontief's description of factor-specific technical differences correct for any given factor in a bilateral comparison between its uses in country c and those in the reference? If the hypothesis is true, then about half the industries in country c will have that factor's share above its analog in the United States. In brief, this test asks, "'For what factors and which countries does Trefler's generalization of Leontief's idea seem to be correct?"'

Almost all the p-values are near 0.[6] Table 1 reports the sixteen cases that are large enough not to reject Trefler's specification for a test of size 5%. Since there is a great deal of variability in these data, it is quite significant that we strongly reject the theory in 80 of 96 cases. It might be reassuring that France, Israel, Sweden, and Taiwan seem to use capital and labor in the ways as the United States, but the evidence is overwhelmingly against the specification of factor-specific productivity differences.

We [4] show that capital-rich countries tend to have high capital shares in every industry. Exploiting the variability of factor prices across countries, we estimate a CES production function for each sector and confirm that elasticities of substitution are typically less than unity. Hence an industry's factor shares do depend on local factor prices, and it is quite inappropriate to assume that they are identical internationally.

Why did Trefler find a strong correlation between real wages and his measures of labor productivity? Gabaix [5] gives a good answer. When the measured factor content of trade in labor is small, then Trefler's imputed labor productivities are nearly equal to a country's share in world absorption. It is not surprising that rich countries have high real wages.[7]

[6]The binomial distribution is discrete. Each marginal significance level is the two-sided probability of a more extreme value than that observed in the data.

[7]In private correspondence, Professor Trefler writes, "'If I obtained good results by combining a sound theory with a key feature of the data (missing trade), then my result can hardly be dis-

Country and Factor	p-value	N
Canada, labor	0.184	46
France, capital	0.441	42
France, labor	0.441	42
France, social capital	0.088	42
Germany, labor	0.280	42
Great Britain, capital	0.079	47
Israel, capital	0.878	42
Israel, labor	0.164	42
Japan, labor	0.243	47
Japan, social capital	0.771	47
Norway, labor	0.382	47
Spain, labor	0.771	47
Sweden, capital	0.441	42
Sweden, labor	0.280	42
Taiwan, capital	0.079	47
Taiwan, labor	0.560	47

Table 1: Marginal Significance Levels Greater than 0.05

3 A Constructive Suggestion

Trefler's generalization of Leontief's idea was theoretically elegant, but it does not survive a closer inspection of consistent disaggregated data on technologies in different countries. Trefler's [8] work was, in essence, an indirect test of Leontief's conjecture because it had to rely on corroborating evidence, such as relative wages, to argue for the plausibility of factor-specific technical differences. We have a big advantage. Our tests are direct, and we use the technology matrices themselves to show that Leontief's conjecture was misguided. Still, we do not want to end on a nihilistic note. Is there a simple specification of international

missed because it is driven by missing trade."' We are sympathetic with this view. However, in our own work [3], we show that proper productivity adjustments solve the mystery of missing trade. The logical conundrum is that missing trade can only be defined with respect to a particular theoretical benchmark, and the basic assumption that countries have identical technologies is grossly at odds with the data. Missing trade occurs for all possible theoretical predictions only if every country's net trade vector lies in the null space of the transpose of the technology matrix of the reference country. Trefler [9] did not investigate how close his net trade vectors were to this null space. In our data, this space has rank 45; this may be a fruitful avenue of future research.

productivity differences that works well?

For several years, we have advocated using factor conversion matrices. A factor conversion matrix is a linear mapping from the space of factors in an exporting country into those in the importing country. It computes the local factor content of a foreign Rybczynski matrix. We use the Moore-Penrose pseudo-inverse to calculate–not estimate–the Rybczynski matrices. Our simple technique solves Trefler's [9] mystery of missing trade and it predicts the direction of trade remarkably well. In practical applications, these matrices are far from diagonal, implying that a unit of any one local factor is really an amalgam of all the factors in a trading partner. We have a distinct advantage because we allow productivity differences to be summarized by all nine elements of the factor conversion matrices, whereas Trefler is more parsimonious and would restrict himself to its three diagonal elements. But it is now clear that factor-specific productivity differences are an empirical dead end.

Let's return to the simple example with which we began. Our factor conversion matrix is:

$$(A_2)^T(A_1^+)^T = \begin{bmatrix} 10 & 20 & 30 \\ 2 & 2 & 2 \end{bmatrix} \begin{bmatrix} -1/2 & 4/3 \\ 0 & 1/3 \\ 1/2 & -2/3 \end{bmatrix} = \begin{bmatrix} 10 & 0 \\ 0 & 2 \end{bmatrix}$$

where again $(A_1^+)^T$ is the Rybczynski matrix for the reference country. In that country, capital is the enemy of the most labor-intensive sector good 1 and the friend of the most capital-intensive industry good 3; labor is a friend of goods 1 and 2 and an enemy of good 3. On balance, the factor content of one unit of capital in the reference country corresponds to ten units of foreign capital and no foreign labor. Likewise, one unit of labor in the reference country corresponds to two units of labor and no capital abroad. Our approach is that easy.

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