Let's Take the Con Out of Factor Content

Eric O'N. Fisher
California Polytechnic State University,
University of California at Santa Barbara,
and Federal Reserve Bank of San Francisco

Kathryn G. Marshall*
California Polytechnic State University

May 22, 2009

Abstract

Factor price differences are of primary importance in explaining the factor content of trade. They reflect local scarcity, and production techniques adapt accordingly. Since capital and labor are complementary inputs in almost every industry, a country that is physically scarce in a factor may well be measured as abundant in its services.

1   Introduction

The Heckscher-Ohlin-Vanek paradigm is a theory of trade in factor services, not in factors themselves. When factor prices are equalized, this difference causes little mischief. But if local shadow values of factors are disparate, then the theory and its proper empirical applications become more subtle.

The world economy consists of many countries producing similar goods using different technologies. The OECD has assembled 33 recent input-output matrices that can be used to construct *consistent* local measures of direct and indirect factor content in 48 sectors. They are an invaluable tool for the study of international trade or open economy macroeconomics. We take full advantage of them here.

There is overwhelming evidence that factor prices are not equalized. Since production techniques depend upon factor costs, technology matrices will differ unless all sectors have Cobb-Douglas production functions. They do not. There is no simple way to aggregate the supply side of a country's economy. Attempts to define international efficiency units for factors as in [17] or to describe a world average technology matrix as in [3] may be misguided. Instead, it is better to use the technology matrices themselves to describe the local factor content of trade. These data are rich and varied. Using them properly can liberate–not hamper–the careful empiricist.

An important initial conclusion of our work is that technologies differ fundamentally across countries. Countries simply have different unit value isoquants for the same good. Hence even if there were factor price equalization, an industry might be considered capital intensive in one country and labor intensive in another. The strict implication is that theories of the factor content of trade must be recast.[1] In our penultimate section, we loosen the reins and estimate unit value isoquants, allowing countries to have the same mappings between factor prices and uses. The residuals in these regressions are perhaps best interpreted as estimates of measurement error in factor inputs. There we show that almost every industry has a low elasticity of substitution between factors. Hence, a country that is measured as scarce in physical capital will be considered abundant in its services since the local rentals rate is much higher than the world average.

2 Making the Most of Input-Output Accounts

Consider an economy with f factors and n goods. Leontief's $f \times n$ matrix is

$$B(I - A)^{-1}, \tag{1}$$

where each column of the $f \times n$ matrix B consists of direct factor inputs and each column of the $n \times n$ matrix $(I - A)^{-1}$ enumerates the infinitely many rounds of

---

[1]In particular, analyses such as [1] and [11] are only small steps in the right direction. Modern data indicate that countries have fundamentally different technologies, not just different factor prices with the same unit value isoquants for each industry.

intermediate inputs of commodities or services. Proper measurement of A insures that the matrix of direct and indirect factor requirements inherits the units of B. If the direct factor requirements are measured in person years per good and real dollars of capital per good, then so is $B(I - A)^{-1}$.

Consistent input-output accounts are available for a wide sample of countries. These data form an important part of a system of national accounts. Both A and B are in units of local currency per year. In this case, the normalized matrix

$$\begin{bmatrix} A \\ \cdots \\ B \end{bmatrix}$$

is column stochastic. Then Leontief matrix enumerates industry factor cost shares. Still, many empiricists gather data for the rows of B from disparate sources; this practice has the potential to cause no end of mischief, especially for studies of factor content in international economics.

Here's the intuition. Consider an economy with several sectors, no intermediate inputs, and only labor as a factor. It has a consistent input-output table that records value added by sector and final uses for each type of output. Let w be an $f \times 1$ matrix of factor prices and p be an $n \times 1$ vector of goods prices. Write $W = diag(w)$ and $P = diag(p)$, the corresponding diagonal matrices. For a Ricardian technology, the Leontief matrix

$$WB(I - A)^{-1}P^{-1} = \begin{bmatrix} wb_1/p_1 & \cdots & wb_n/p_n \end{bmatrix}$$

is a unit row vector. The full employment condition is

$$\sum_i p_i y_i = \sum_i (wb_i/p_i)(p_i y_i) = \sum_i wL_i$$

This *consistent* equation reflects the identity between the income and product approaches to national accounts. It is based upon the fiction that homogeneous labor is mobile and that each sector produces according to $y_i = L_i/b_i$. These assumptions are never violated in the data because the careful researcher admits forthrightly that neither L_i nor y_i is observable; industry value added wL_i and the value of its output for final demand $p_i y_i$ are.

Consider gathering data on labor inputs from a separate source. They derive perhaps from industry surveys that keep track of different types of labor that the researcher aggregates "appropriately". The economist records

$$\begin{bmatrix} L_1 & \cdots & L_n \end{bmatrix}.$$

These measures are consistent with the data on intermediate inputs from national accounts only if the transpose of this row vector is collinear with the shares of industry output in GDP:

$$\theta_y = \left[\begin{array}{ccc} p_1 y_1 / \sum p_i y_i & \cdots & p_n y_n / \sum p_i y_i \end{array} \right]'.$$

In practical applications, it never is.

This point is more general. The zero-profit conditions are:

$$(B(I - A)^{-1})'w = p. \tag{2}$$

Consider fixed prices p. Then (2) is a system of n equations in the f unknown factor prices. Since the number of sectors is typically much greater than the number of factors, there is no guarantee that any w satisfies the "over-identifying" restrictions. Exploring the relationship between the national revenue function and input-output accounts, we [6] study a typical model of the American economy with capital, five types of labor, and 63 goods. At this level of aggregation, combining data on factors from disparate sources with intermediate inputs from an input-output table may be statistically problematic.

Is this a real problem for the literature? It is obvious that using data on intermediate inputs from one source and primary inputs from another source introduces measurement error. In our own research on the American economy, we have identified two potential problems. First, the sectoral capital stocks reported by Bureau of Economic Analysis seem to introduce significant error in the measurement of factor content; in essence, assuming a common rate of return to capital in every sector introduces important aggregation bias for the factor content of capital and other factors too. Second, measuring factor usage by industry surveys taken in years different from the input-output benchmark implicitly imposes that factor prices within a country are constant across time.

We are understandably more circumspect in reporting the shortcomings of the large literature in international economics in this area. Still, we are sad to report that much of the important research on factor content in the last decade has made *ad hoc* adjustments to capital, labor, and other resources. Researchers routinely divide a factor by its sample variance and the square root of country size. They often make the same transformations on factor content too. Nothing in international trade theory justifies this procedure.

Input-output accounts in quantities–where the elements of (1) are units of apples per orange–are not in national accounts. Instead we observe

$$\Theta = W B (I - A)^{-1} P^{-1} \tag{3}$$

4

where Θ is the column stochastic matrix of factor shares. Leontief [13] reminded us that the term P^{-1} in (3) is innocuous because it entails that the input-output matrix defines unit-value isoquants for fixed (but unobservable) goods prices P. One cannot escape that Θ confounds unobservable factor prices with production techniques. This fact can liberate the careful empiricist. For example, a simple test of whether factor prices reflect differences in efficiency units compares the rows of Θ across countries. Inspection of the OECD data shows that [17] argues incorrectly that "international efficiency units" reflect factor price differences.

An economy's full employment condition is:

$$Wv = \Theta Py \tag{4}$$

where v is the vector of quantities of endowments and y is that of outputs. Dividing each row of (4) by national revenue yields:

$$\theta_v = \Theta \theta_y, \tag{5}$$

where θ_v is the vector of factor shares in national accounts. Equation (5) shows that the matrix of factor shares is a convex combination of the columns of the observable technology matrix Θ. This fact in itself is insipid. But we use it to document an interesting phenomenon in the data: countries that have large income shares for capital tend to have large costs shares of capital in every industry. A country where capital is expensive naturally substitutes labor for capital, but it can do so only imperfectly. Hence countries that seemingly lack physical capital are measured as abundant in its services. This fact alone explains an enormous amount of confusion in the large literature measuring the factor content of trade.

3   Endowments and and Factor Prices

An older strand of literature was careful in measuring factor services. The authors of [19], [4], and [8] took pains to distinguish between stocks of capital or natural resources and their flows. They enjoyed an important advantage: studying one country only. A subsequent generation of scholars has been sloppier. Bowen, Leamer, and Sveikauskas [10] mesmerized researchers with their promiscuous use of the American input-output matrix to measure the factor content of trade everywhere and their laudable collection of data on factor endowments from disparate sources. Their work was path-breaking, but it led us down a primrose path.[2] In the

---

[2]Leamer [12, pp. 985-6] gives a careful early discussion about why tests of trade theory should use consistent data on value added and better measures of endowments.

1980's, the profession had to gather data on endowments from disparate sources because there were hardly any consistent sets of international of input-output matrices.[3] Consistent measures of factor content had to wait for a new technology: personal computers and the OECD STAN database. There is no longer any excuse for taking the old shortcuts.

3.1 Endowments as Macroeconomic Factor Shares

Figure 1 gives a natural graphical representation of a country's endowment in barycentric coordinates. Each vertex represents an endowment whose value consists completely of that factor. The midpoint consists of an endowment where an equal share of national income accrues to each factor.

We are not the first to represent endowments in these coordinates. Leamer [12] beat us to the punch. But our figures have a natural coordinate system. Since we measure normalized endowments and observed technologies as factor shares, our data lie on the simplex in three-space, and they can be represented easily in barycentric coordinates. Describing his own work, Leamer [12, p. 965] admits admirably and quite candidly, "You may surmise that the "pleasant" scatter of points in figure 1 requires quite a bit of fiddling with the units in which the factors are measured." In contrast, in our Figure 1, we fiddle not at all.[4] World endowments are 33 points on the simplex, and a local technology matrix is 48 such points. The figures in this paper are a contribution in their own right; they are the best way yet devised to represent intelligibly a technology matrix consisting of $144 = 3 \times 48$ elements.

Figure 1 shows that Turkey is the most capital abundant country in the world. Having been to both New York and Istanbul, we can assure you that Turkey is not *physically* capital abundant. But cognizant of Lucas's [14] puzzle, we cannot be certain that Turkey is not capital abundant in value terms. The OECD's careful and consistent national accounts compel us to conclude that the high rentals rate in Turkey likely swamps a relative physical scarcity of capital.

Figure 1 also shows that Switzerland is the most labor abundant country in the world and that China pays the largest share of national income in net taxes on production. Again, there is no reason to believe that Switzerland has little

---

[3]Rosefielde [16] would have argued, even then, for a more cosmopolitan approach.

[4]This statement is slightly too flippant. Both Leamer [12] and we need normalizations to project $\mathbb{R}^3$ onto a two-dimensional space. We use the natural one, dividing factor payments by national income to get factor shares. The deep economic intuition behind both projections is that only the ratios of factors–not their absolute levels–matter in models with constant returns to scale.
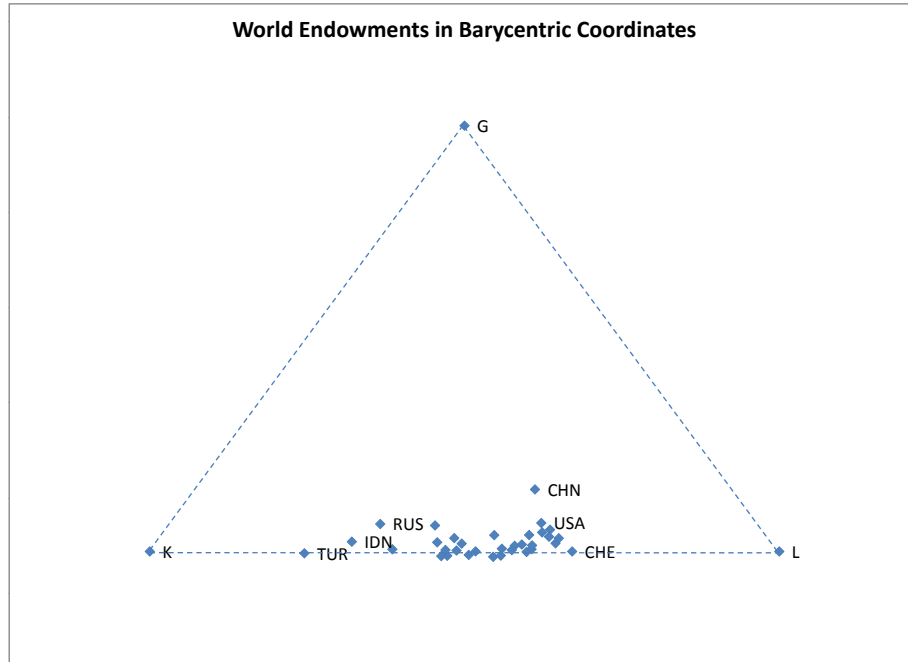
Figure 1: World Endowments

physical capital, but it is plausible that a low rentals rate makes for the lowest share of capital among the 33 countries in our sample. China has a large share of net business taxes perhaps because its government chooses to raise revenues by taxing enterprises instead of individuals.

We are sympathetic with Gollin's [7] concern that we may be underestimating labor's share in countries with many self-employed people. Turkey, Indonesia, Russia, Greece and Brazil are the five countries in our data with the lowest shares attributed to labor. Relatively poor countries may have large shares of self-employed persons. But three considerations work in our favor. First, we control for the composition of output since our data come from input output-tables; this is the basis of Gollin's first adjustment. Second, our data are consistent across countries; if we are mis-measuring the labor income of the self-employed (or the human capital income of well educated employees), we are doing so consistently by

following the OECD's accounting conventions for value added. Third, when we compare our factor shares we have in common with those in Gollin's Table 2, we find that our labor shares are generally well above the so-called "naive estimates". We are not doing growth accounting; our factor shares give good consistent measures of the local flows of services, the correct way to compute endowments when factor prices are not observable.

Caselli and Feyrer [2] would argue that we are overstating capital's shares in poor countries like Turkey, Indonesia, and Russia because capital income includes rents paid to land and other natural resources. The difference between reproducible capital and land may matter for a macro-economist, but it is less compelling for an international economist. What is the source of Russia's comparative advantage if not natural resources? What factor of production does Indonesia, a member of OPEC, really export? The input-output accounts give consistent measures of value added under three exhaustive rubrics: compensation to employees, gross operating surplus, and indirect business taxes. "Gross" refers to the fact that value added is attributed to depreciation. The gross operating surplus of a business that extracts resources is the value of the natural capital it is depleting. Capital consumption allowances form the major part of the investment flows of any advanced industrial economy, and the capital stocks macro-economists compute from the Penn World Table are geometric sums of these flows. There is no difference between a mining company that exports ore and a manufacturing company that depreciates capital in producing widgets for world markets.

3.2 Consistent Factor Prices

The flows of payments to the factors in input-output tables are as accurate as the macroeconomic accounts from which they are drawn. But they are values, confounding prices and quantities. Independent data on the stocks of capital, numbers of employed persons, and populations enable one to calculate consistent local factor prices. The Appendix describes how we calculate the quantity of each factor. The real stocks of capital are measured in international dollars in the year 2000. They are stocks; so the rentals rate we report is indeed a rate, a percentage of international dollars per international dollar. Our wage rates are measured in international dollars per employed person year. Our social capital rate is measured in international dollars per person. So it is akin to a wage rate, and it is the indirect taxes paid by local businesses in the national market. A negative shadow value implies that businesses are subsidized; presumably there are other *direct* taxes that cover the subsidies that are reported in the input-output accounts.

Table 1 reports the factor prices we computed. Much external evidence corroborates that these rentals and wage rates are reasonable. For example, macroeconomists use a rule of thumb that labor earns about 2/3 of GDP in the United States; GDP was roughly $9.8 trillion and there were about 143 million workers in 2000. Hence a computed wage of $45,920 = (2/3) \times \$9.8 \times 10^{12}/1.43 \times 10^6$ is quite consistent with our calculations.[5] Likewise, the rentals rates include the capital consumption allowance, and a rate of 13.1% for the United States would not make a macroeconomist blush.[6] Since the factor prices for private capital and labor seem reasonable, perhaps our calculations for the social capital rates are not egregious. They are per capita payments for the right to produce locally. These indirect taxes are just as much costs of production as payments to workers, and they are passed through to the final price of output. We thought it more transparent to calculate them as per capita payments rather than to construct some stocks of social capital for which they were rates of return.

We will not argue that these factor prices are the Gospel truth. But we assert adamantly that they are calculated *consistently* from macroeconomic data. They do the job they were for which they were designed: to make transparent cross-country comparisons of endowments and technologies. Look at the wage and rentals rates in Turkey and Switzerland (CHE). These factor prices go a long way in explaining the seeming anomalies in Figure 1.

4 Local Production and Global Technologies

What does it mean to say that "Real estate activities" are capital-intensive, when capital-rich countries produce everything using a lot of capital? The general definition of factor intensity is problematic. The best working definition is that industry i use factor f intensively if and only if $\theta_{fi} > \theta_f$, where the latter is the element of θ_v corresponding to factor f. We are again drawn to measuring endowments as factor shares even to understand the basic rankings of factor intensities.

This section will accomplish three goals. First, we will show that local technologies are adapted to local endowments. Second, we will explain that the mystery of missing trade occurs because [18] made the wrong theoretical prediction in a world without factor price equalization. Third, we will establish that the same

---

[5]In the OECD data, labor's share in the United States is 0.59.

[6]The rentals rates, inclusive of payments to land, are remarkably similar to those reported in [2] for countries we have in common. We corroborate the magnitude of the difference between rentals rates in poor and rich countries that Caselli and Feyrer emphasized.

Table 1: Factor Prices

Country	Rentals rate	Wage rate	Indirect tax rate
AUS	14.0%	$25,644	$854
AUT	11.7%	$30,110	$395
BEL	12.5%	$32,966	$305
BRA	20.7%	$6,867	$416
CAN	10.9%	$33,071	$1,336
CHE	7.1%	$34,013	$0
CHN	15.5%	$3,584	$553
CZE	16.1%	$13,278	-$129
DEU	9.1%	$30,852	$121
DNK	12.3%	$31,316	-$25
ESP	14.4%	$25,379	$113
FIN	11.7%	$24,627	-$255
FRA	11.5%	$34,398	$897
GBR	13.7%	$30,557	$440
GRC	18.2%	$12,158	$62
HUN	16.7%	$13,751	$2
IDN	34.5%	$3,120	$93
IRL	24.0%	$28,102	$86
ISR	13.5%	$33,211	$692
ITA	15.5%	$25,696	$456
JPN	7.9%	$26,933	$1,021
KOR	15.1%	$16,398	$35
NLD	13.0%	$27,227	$77
NOR	14.1%	$30,703	-$243
NZL	15.7%	$17,988	$542
POL	17.4%	$10,175	$145
PRT	16.7%	$17,737	-$147
RUS	34.2%	$6,350	$547
SVK	13.9%	$10,849	-$98
SWE	10.2%	$31,357	$722
TUR	44.9%	$4,507	-$24
TWN	19.4%	$26,920	$272
USA	13.1%	$43,211	$2,340

activities are generally ranked as capital-intensive or labor-intensive everywhere. One need not be worried about factor intensity reversals or about countries being in different endowment cones. Countries have quite different factor prices, but at the level of aggregation useful for studies of factor content, every country manages to produce (and trade) almost every good. Incomplete specialization everywhere is a good rule of thumb.

4.1 Technologies are Adapted to Local Conditions

Our concise visual representation of these technology matrices can really bear fruit now. If capital and labor were the only two factors, then the simplex would be the unit interval and a country's technology would be n points on that line. Since our data have three factors and 48 sectors, a country's technology is a scatter of 48 points on the generalized two-dimensional simplex. It is generalized because some sector may have a subsidy and thus its cost share of indirect taxes is negative. That industry would be graphed farther away from the G vertex than the edge that joins the K and L vertices.

Let's start on familiar turf. Figure 2 shows how each industry in the United States is adapted to the local endowments. We have labeled a few outliers. Table A1 in the Appendix gives a complete list of all industries; you should look at it to get a sense of the level of aggregation that characterize these data. "Real estate activities" are the most capital-intensive sector, "wholesale and retail trade and repairs" are quite labor-intensive, and "Medical, precision and optical instruments" are the most subsidized industry in our economy.

Turkey is the most capital-abundant country in our data, and Figure 3 shows how each industry is adapted to the local endowments. It is obvious that almost every industry has a high cost share for capital, a low cost share for labor, and almost no cost share for social capital. Switzerland is the most labor abundant country in our data, and Figure 4 stands in sharp and edifying contrast with Figure 3. We draw your attention to the fact that "Real estate activities" is the most capital-intensive industry in a country where the rentals rate is quite low. Also, Switzerland is a libertarian's dream, with no measured social capital. It is the only country whose endowments and technolgy are actually two-dimensional. China is the most social capital abundant country in our data. Figure 5 shows its technology. "Finance and insurance" pays a large cost share of indirect taxes, and "Agriculture, hunting, forestry, and fishing" is quite labor-intensive.

Russia is fairly capital-abundant and also has a large share of indirect taxes. Figure 6 shows how its technology adjusts accordingly. This figure is sparse be-
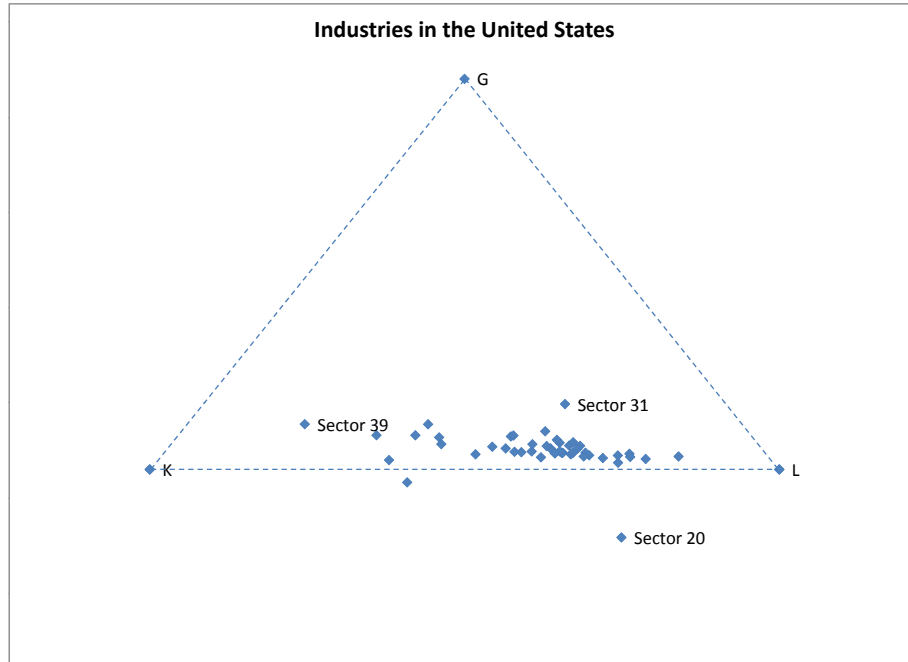
11

Figure 2: Industries in the United States

cause Russia has several sectors that record no output. The "Manufacture and distribution of gas" pays for a lot of social capital. "Research and development" is still a labor-intensive sector, well after the fall of the Soviet Union. "Wholesale and retail trade and repairs" is measured as capital-intensive! Russian retail establishments are not known for customer service. Indonesia is measured as a capital rich country; it is a member of OPEC. Figure 7 shows its technology. Indonesia subsidizes "Motor vehicles, trailers & semi-trailers" appreciably, and many of its local industries pay a high cost share for capital.

We have given a quick *tour d'horizon* of the technologies in our data.[7] It

[7]These are exactly the data that Davis and Weinstein [3] studied. We have 33 *consistent* recent observations, but they had 10 that were two decades old. Our matrices have 48 sectors and three factors, and theirs had 34 sectors and two factors. We hope you are convinced that these barycentric representations make it easy to see local technologies.
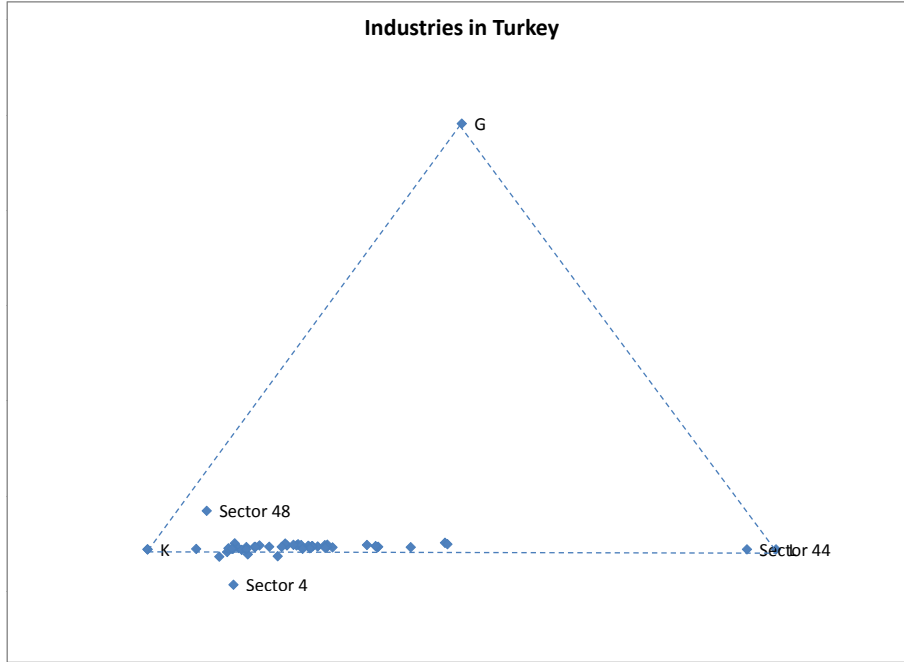
Figure 3: Industries in Turkey

is obvious that each country's Θ is adapted to its endowment θ_v. The common thread is local factor prices. Any serious study of factor content must take a stand on how factor prices affect the theory being tested. Basing theoretical predictions upon factor price equalization is a recipe for failure.

4.2 Virtual Endowments Solve the Mystery of Missing Trade

Here is the simplest example that illustrates the essence of Trefler's [18] "mystery of missing trade".

Consider two countries producing n goods with capital and labor. The first has an endowment $v^1 = (K^1, L^1)' = (2n, n)'$, and the second has a symmetrical $v^2 = (K^2, L^2)' = (n, 2n)'$. Hence the first is capital rich, and its trading partner
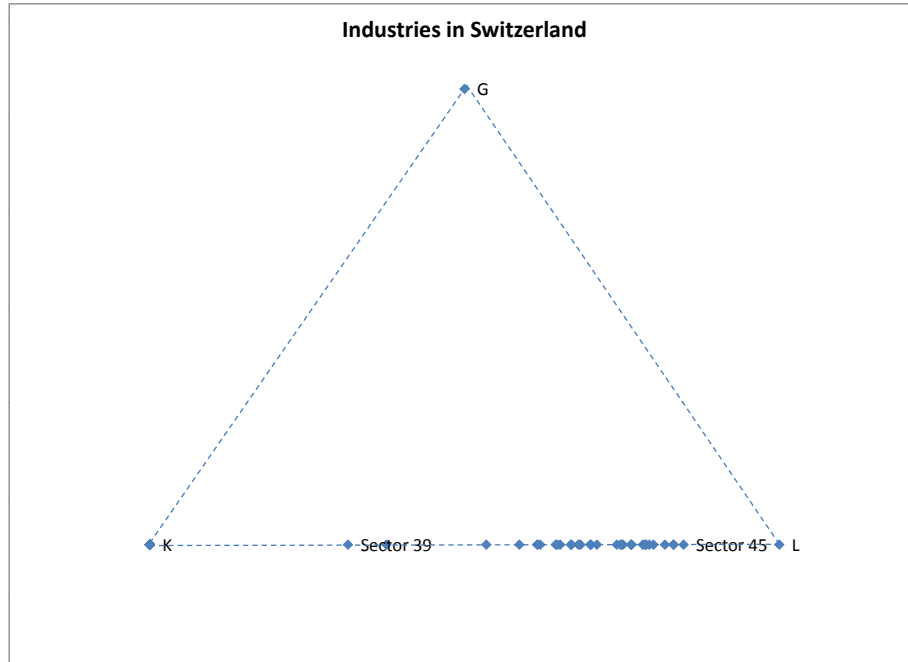
Figure 4: Industries in Switzerland

is capital poor. The first has this *physical* technology:

$$B^1(I - A^1)^{-1} = \begin{bmatrix} 2 & \cdots & 2 \\ 1 & \cdots & 1 \end{bmatrix},$$

and the second country has:

$$B^2(I - A^2)^{-1} = \begin{bmatrix} 1 & \cdots & 1 \\ 2 & \cdots & 2 \end{bmatrix}.$$

where the top row denotes inputs of capital and the bottom row those of labor. These were chosen for two reasons: (1) local techniques are adapted to local endowments; and (2) there are more goods than factors. Both facts are true in the data.
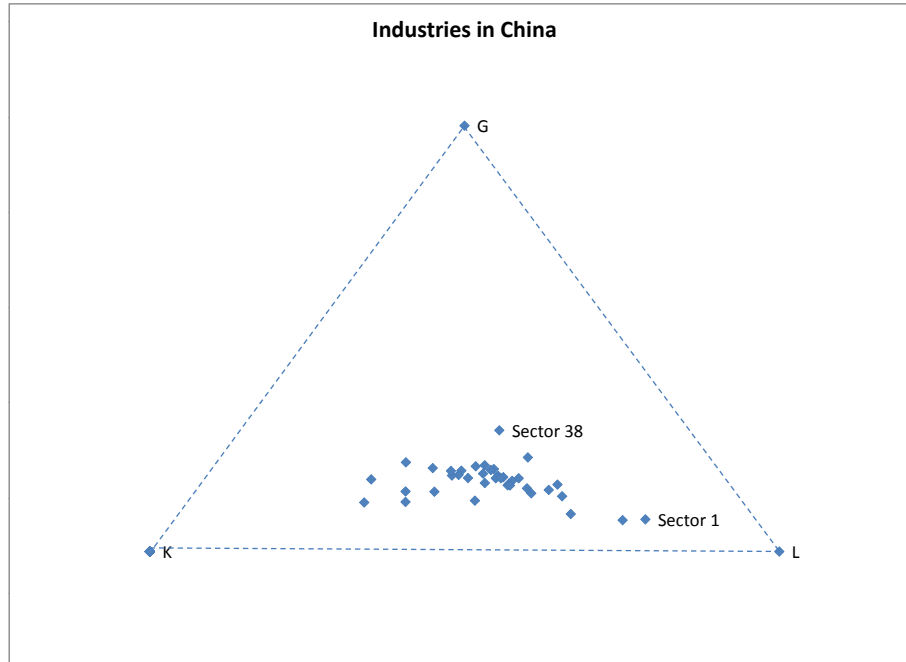
14

Figure 5: Industries in China

Factor prices are $w^1 = (1, 2)'$ and $w^2 = (2, 1)'$. These factor prices were chosen for two reasons: (1) every good can be produced anywhere; and (2) the capital-rich country has a higher wage-rentals ratio. Again, both facts are true in the data.

Assume that the outputs of the two countries are identical:

$$y^1 = y^2 = (1, ..., 1)'.$$

Assume further that countries have identical and homothetic preferences and that markets clear when prices are $p = (4, ..., 4)'$. Since both countries have identical shares of world income, the (Leontief) measured factor content of trade would be zero, no matter which country's technology is the reference. Assume that the researcher measures the physical endowments in each country without error. Then the predicted factor content of trade for the first county is $(n/2, -n/2)'$ and it the
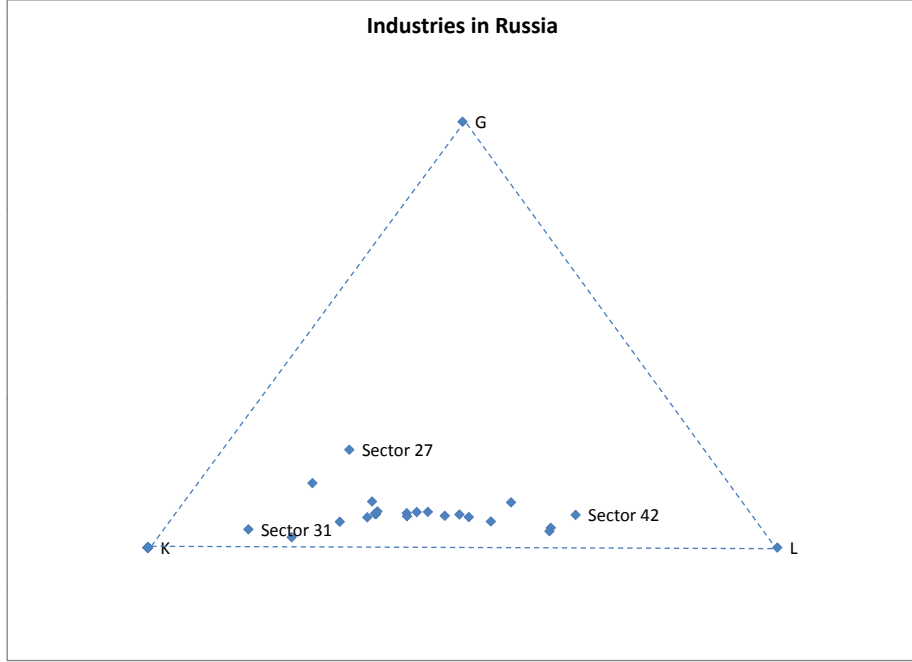
15

Figure 6: Industries in Russia

of opposite sign for the labor-rich country. So there is infinitely much missing trade.

We invented the idea of virtual endowments [5] to deal precisely with this absurdity. As we have emphasized, the physical technology matrices are not observable. Instead, the researcher sees the factor shares matrices:

$$\Theta^1 = W^1 B^1 (I - A^1)^{-1} P^{-1} = \begin{bmatrix} 0.5 & \cdots & 0.5 \\ 0.5 & \cdots & 0.5 \end{bmatrix},$$

and

$$\Theta^2 = W^2 B^2 (I - A^2)^{-1} P^{-1} = \begin{bmatrix} 0.5 & \cdots & 0.5 \\ 0.5 & \cdots & 0.5 \end{bmatrix}.$$

Let the first country be the reference. Then the virtual endowments are:

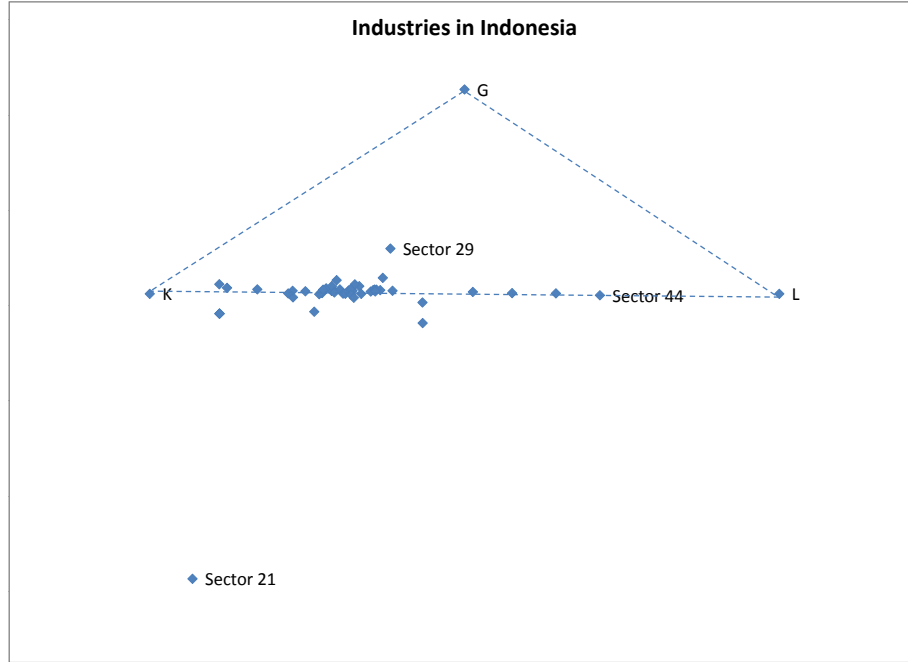$$\tilde{v}^1(1) = \Theta^1 P y^1 = (2n, 2n)'$$

16

Figure 7: Industries in Indonesia

and

$$\tilde{v}^2(1) = \Theta^1 P y^2 = (2n, 2n)'.$$

If the second country is the reference, then the virtual endowments are again:

$$\tilde{v}^1(2) = \tilde{v}^2(2) = (2n, 2n)'.$$

In either case, the two are identical. Hence the predicted factor content of trade $(0, 0)'$ is exactly correct. Our ideas are as easy as that.

There is nothing particular about our example. Countries could produce slightly different output vectors, and not every activity need have an identical capital-labor ratio. Finally, the researcher could measure each country's endowment with error. Then instead of having infinitely much missing trade, we might over predict measured factor content by only two orders of magnitude, just as in the literature. Heckscher-Ohlin-Vanek theory was developed for countries with identical factor

17

prices and technologies. These assumptions do not hold on planet Earth. If we want to give the theory a chance, then we need to make theoretical predictions that are consistent with its logical superstructure. Is it difficult to ask, "What would endowments have to be if assumptions of the theory were true?" Our notion of virtual endowments is the simple answer to this question.

Are these virtual endowments a pleasant fiction? Figure 8 shows the scatter plot of world endowments using the United States as reference. It shows the resources each country would need to produce its *observed* output vector using the *observed* technology matrix of the United States. Hence it imposes identical technologies and factor price equalization at the prices in the United States. It is obvious that there is much less variability of these virtual endowments than the actual endowments.
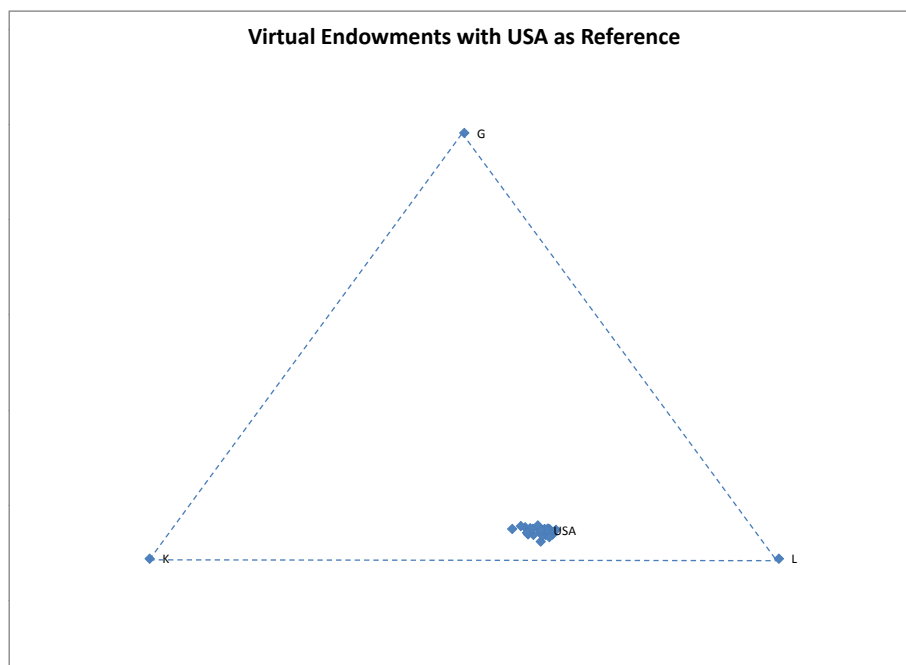

Figure 8: Virtual Endowments with the USA as Reference

We [5] show that Korea is the reference country that best fits the data on the

18

factor content of trade. Figure 9 shows those virtual endowments. Korea gives the
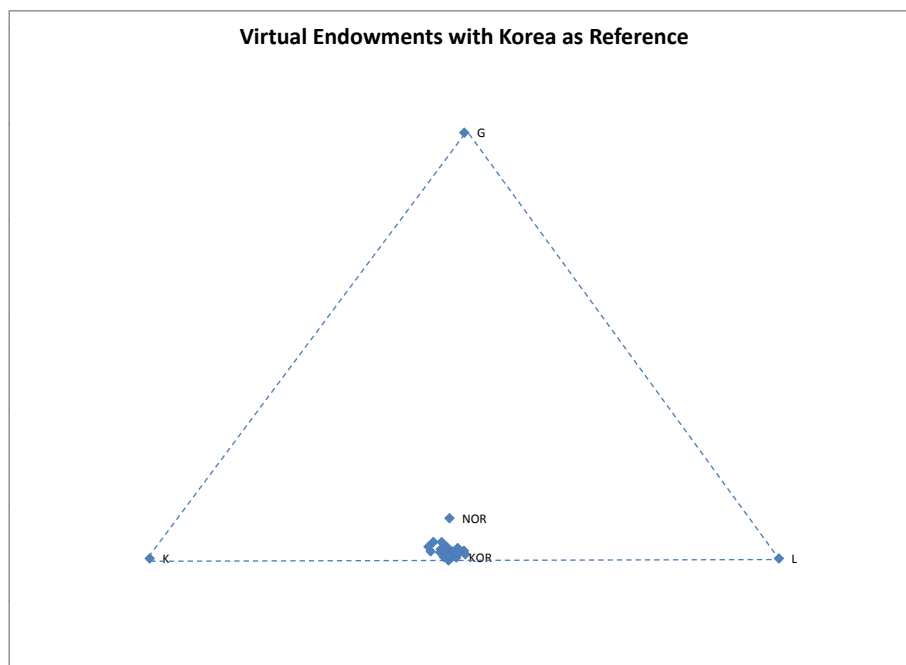
Figure 9: Virtual Endowments with Korea as Reference

best fit for a good and now obvious reason: it has the technology matrix that most closely resembles the "median" in the world economy. Theoretical predictions based upon its virtual endowments predict the (Leontief) factor content of trade (measured using Korea's input-output matrix) very well. [8]

---

[8]Norway is sufficiently different from Korea that its virtual endowment is an outlier; Norway produces some goods that are taxed heavily in Korea.

4.3 What Do These Technology Matrices Have in Common?

Figure 10 shows the sample averages of cost shares in each industry.[9] Each country's technology matrix is a unit of observation, and the United States and New Zealand are equally important. This figure is a visual representation of the simplest kind of technology matrix that [3] estimated. "Real estate activities" are the most capital intensive sector in the world, Education is the most labor intensive, and "Agriculture, Hunting, Forestry, and Fishing" are world's the most subsidized activity. These commonplaces prompt more trenchant questions. Are the same activities generally capital-intensive or labor-intensive everywhere? Which countries have idiosyncratic technologies? We have such rich data that we can explore these kinds of questions in detail in a statistically robust manner. We ran rank correlation tests for each factor and every one of the 528 country pairs in our data.

Consider the uses of capital. We reject the null hypothesis of no rank correlation for 452 country pairs; these are one-sided tests of size 5 percent because the natural alternative is that factor uses are positively rank correlated. These tests are non-parametric; the only assumption is that local factor shares are independent across activities. Since we are analyzing unit-value isoquants and every local industry faces common factor prices, we are just assuming that uses of capital by sector differ randomly. There is overwhelming evidence that country pairs use capital in similar ways in these 48 industries. The median number of rejections for these pairwise rank correlations is 29 of a possible 32. Almost every country uses capital in rank order just like everywhere else. Still, China marches most to the beat of its own drummer; its rank correlations are insignificantly different from zero in 20 of 32 pairwise comparisons.

Now consider labor. One rejects the null of no rank correlation for 450 of the 528 cases. The median number of rejections for a country is again 29, constituting overwhelming evidence of similarly ranked uses of labor everywhere in the world. New Zealand is the most typical country; its uses of labor are significantly rank correlated with every other country The United States also uses labor very typically; one fails to reject the null of no rank correlation only for the partner country Turkey. China and Turkey are the most different countries; one fails to reject the null of no rank correlation in 16 of 32 cases.

Finally, consider the uses of social capital (the sectoral patterns of indirect taxation). They tell a completely different story. Now we reject the null of no rank correlation in only 126 cases; the median number of rejections in these pairwise

---

[9]We do not always divide the sum of a factor's shares by 33. For example, Sector 1 is active in every country, but Sector 2 is active only in 32 countries because Belgium records no inputs there.
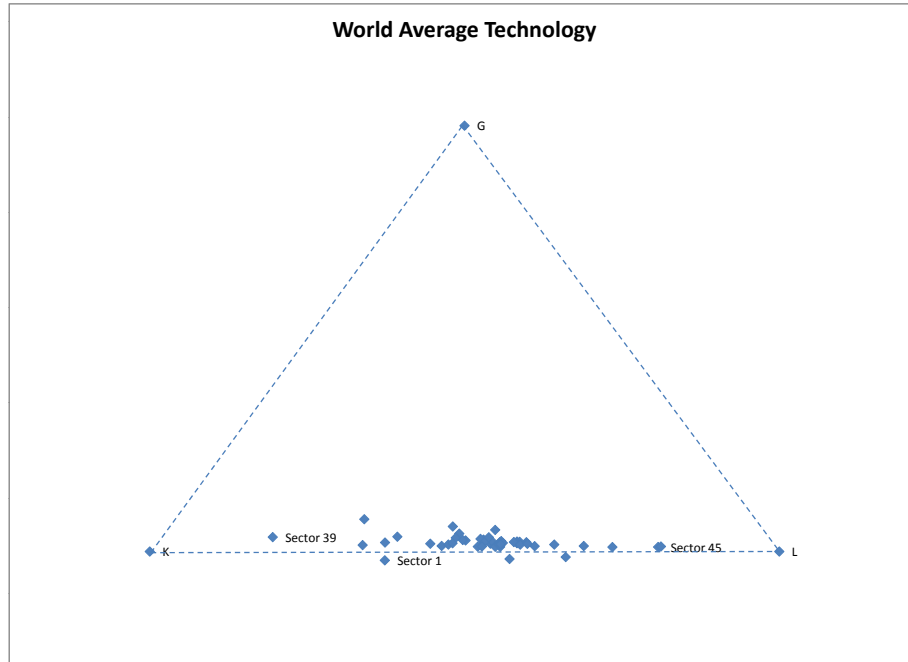
Figure 10: World Average Technology

comparisons is 8. (Since our test size is five percent, there is still some important international commonality in the patterns of indirect taxation but not *overwhelming* evidence of similarity.) The rank correlations are all over the place for this factor. But it is worth stating that Indonesia is most different in its pattern of indirect taxation, and Great Britain is most typical.

We find these rank correlation tests reassuring. First, we are not surprised that the evidence on the pair-wise correlations for the patterns of indirect taxation is relatively weak. They are determined by political economic considerations that are more varied than production techniques. We have argued elsewhere [5] that including payments for social capital is important for empirical and theoretical consistency and because they influence local factor prices. We see now that they are not fundamental determinants of international production techniques. Tip O'Neill was right, "All politics is local."

Second, we are encouraged that there are important international commonalities in the uses of capital and labor. Harrigan [9] has summarized evidence showing that countries' production techniques are adapted to local endowments. This observation is correct, but it is only half the truth. We have showed overwhelming proof that the same activities are generally ranked as capital intensive from Auckland through Beijing to London. The same fact is true for the rankings of labor intensity from Tokyo through Jakarta to New York. Of course, factor prices differences matter enormously. So if capital is expensive in Turkey, then the Turkish economy undergoes a phase shift, moving all activities towards the capital vertex.[10] Hence the whole truth is that there are important international commonalities characterizing each technology, but factor prices shift every local activity towards the values of local endowments. An approaching star has a blue shift in its spectrum, just as Turkey has a "capital" shift in the value shares of all its activities, but hydrogen has the same spectral pattern anywhere in the universe.

5 Estimating Elasticities of Substitution by Industry

We will explore the possibility that each industry may well have the same unit-value isoquants. We will show that one can plausibly represent a country's technology as a list of 48 different unit-value isoquants with constant elasticities of substitution. We will also establish that countries with high factor prices are measured properly as rich in the services of a factor that may well be physically scarce.

Consider a firm in industry i choosing inputs x_i at factor prices w and producing output y_i according to a CES production function

$$y_i = \left(\sum_f (\alpha_{fi} x_{fi})^{\rho_i} \right)^{1/\rho_i}$$

with $\rho_i \leq 1$. The firm's cost function is:

$$c_i(w, y_i) = \left(\sum_f (w_f/\alpha_{fi})^{1-\sigma_i} \right)^{1/(1-\sigma_i)} y_i \tag{6}$$

where σ_i is the elasticity of substitution. The cost share of factor f in industry i is

$$\theta_{fi} = \frac{(w_f/\alpha_{fi})^{1-\sigma_i}}{\sum_f (w_f/\alpha_{fi})^{1-\sigma_i}} \tag{7}$$

---

[10]Romalis [15] develops a model of imperfect competition that explains this phase shift in a different way. His model focuses on factor accumulation, not factor prices.

There are three canonical cases: (1) the factors are perfect substitutes and $\sigma_i = +\infty$; (2) the production function has constant factor shares and $\sigma_i = 1$; and (3) the factors are perfect complements and $\sigma_i = 0$.

The variability of factor prices across countries permits one to estimate (7). Let θ^c_{fi} be the observed cost share for factor $f \in \{1, ..., 3\}$ in country $c \in \{1, ..., 33\}$. Stacking the three factors for each industry, we estimated by nonlinear least squares:

$$\theta^c_{fi} = \frac{(w^c_f/\alpha_{fi})^{1-\sigma_i}}{\sum_f (w^c_f/\alpha_{fi})^{1-\sigma_i}} + u^c_{fi} \tag{8}$$

where the error term u^c_{fi} includes randomness, such as country-specific aggregation bias in an industry, that is orthogonal to the right hand variables in (8). We use this exact specification–not its logarithm–because it does not make sense that factor shares, which sum to unity, are measured with multiplicative error.

Table 2 reports the estimates. These are seemingly unrelated regressions, but since each has the same right hand variables, estimating each industry separately is efficient. Equation (8) suffers from five problems. First, it is not identified. Since (7) is homogeneous of degree zero in the three α_{fi}, one can estimate only two of these parameters. We deal with this issue by normalizing our estimates by per capita local taxes as a share of GDP.[11] Second, there are some missing values. For example, only five countries report output in the sector "Steam and hot water supply". We deal with this problem by reporting the number of included observations for each industry. Third, there may be heteroscedasticity in the errors, since some countries have high variability in the aggregation bias implicit in the data on cost shares. Fourth, the error terms are not independent since the sum of the factor shares in each industry in each country must be unity. We deal with these two problem by reporting Newey-West standard errors. Fifth, we are quite cognizant that we are regressing factor shares on factor prices themselves. However, the null hypothesis–the starting point for the entire literature–is that countries have identical technologies and that factor prices are exogenous. The simplest way to capture this idea is to assume that industries have different Cobb-Douglas production functions.[12] In this case, the left hand variable in (8) is independent of factor prices, and it is the null hypothesis that underlies our statistics.

---

[11]For each i, we set set the $\alpha_{3i} = \overline{w}_G/\overline{\theta}_G$ where $\overline{w}_G = \$352$ is the average per capita tax rate among the countries and $\overline{\theta}_G = .021$ is the corresponding average share of taxes in national output.

[12]Davis and Weinstein [3, p. 1434] run exactly this regression in testing their $\widehat{P}5'$; their local capital-labor ratios are observationally equivalent to our local factor prices.

Table 2 is informative.[13] First, the specification (8) fits well; these are cross-sectional regressions, and the median $\overline{R}^2$ is 0.92. Second, we can reject the null hypothesis that a sector is produced according to a Cobb-Douglas production function for a test of size five percent in 40 of 48 cases.[14] Hence, the factor share matrices–the only measures of technology that are both observable and theoretically consistent–depend fundamentally upon local factor prices. Third, one can reject the hypothesis that an industry has fixed coefficients for a test of size five percent in 47 of 48 cases.[15] Fourth, these factors are complements, not substitutes. The median of the σ_i is 0.63. There is only incomplete adjustment to factor price differences. Leontief [13] himself explained that assuming fixed coefficients was not unduly harmful because much evidence showed that production techniques adjust only slowly across time. These regressions show that they adjust only partially across space too.

Equation (7) is highly nonlinear, but a back-of-the-envelope calculation shows how important factor price differences can be. Setting $\sigma_i = 0.63$ and evaluating (7) at average factor prices $\overline{w}$ and the starting values of α_f for our estimation, we derive a hypothetical capital share of 0.75. At Turkey's factor prices, this share becomes 0.97. The values of α_f are arbitrary, but the magnitude of the effect is striking. Of course, Turkey's wage-rentals ratio is 14 times lower than that implied by our sample average wage and rent. This huge difference is quite a puzzle in itself, and it adds spice to Lucas's [14] original observation. Part of the reason that capital does not flow into Turkey is that labor flows out instead!

6 Conclusion

What will you, the reader, make of this, our philippic?

---

[13]We ran these nonlinear regression in Eviews. The starting values for the numerical algorithm was the same for each industry. Since our data come from input-output tables, we took Leontief seriously and set $\sigma_i = 0$. Then the cost share for factor f in a canonical industry is $(w_f/\alpha_f)/\sum_f (w_f/\alpha_f)$. We observe average factor prices $\overline{w}$ in Table 1 and average factors shares $\overline{\theta}_v$ in Figure 1 and use them to solve for each $\alpha_f = \overline{w}_f/\overline{\theta}_f$. This solution is also the basis for our normalization. The estimation procedure converges quickly, and it does not depend upon the initial conditions, as long as they are reasonable. The parameters α_{fi} are estimated imprecisely, but we are not interested in them. Finally, we had to take care that (7) was well defined when a factor price was negative.

[14]For industries 38 and 39 the p-values are 0.0573 and 0.0569 respectively.

[15]This is a one-sided test, and the null hypothesis is on the boundary of the parameter space.

Table 2: Elasticities of Factor Shares

Sector	σ_i	Standard error	N	$\overline{R}^2$
1	0.80	0.13	99	0.83
2	0.84	0.13	96	0.45
3	0.71	0.09	87	0.90
4	0.66	0.08	99	0.91
5	0.64	0.05	99	0.95
6	0.61	0.06	99	0.92
7	0.61	0.06	96	0.93
8	0.72	0.11	93	0.54
9	0.67	0.04	99	0.92
10	0.73	0.07	39	0.91
11	0.61	0.04	96	0.96
12	0.64	0.05	99	0.95
13	0.56	0.04	99	0.94
14	0.63	0.05	39	0.92
15	0.55	0.04	96	0.97
16	0.62	0.05	99	0.96
17	0.46	0.08	93	0.92
18	0.57	0.03	93	0.96
19	0.54	0.05	90	0.92
20	0.61	0.04	96	0.93
21	0.45	0.14	96	0.67
22	0.56	0.05	96	0.93
23	0.69	0.06	30	0.88
24	0.73	0.07	33	0.91

Table 2(cont.): Elasticities of Factor Shares

Sector	σ_i	Standard error	N	$\overline{R}^2$
25	0.56	0.06	99	0.93
26	0.81	0.08	99	0.87
27	0.85	0.12	39	0.80
28	0.71	0.19	15	0.81
29	0.89	0.08	93	0.77
30	0.56	0.06	99	0.94
31	0.44	0.09	99	0.90
32	0.59	0.09	96	0.90
33	0.62	0.07	99	0.91
34	0.72	0.07	90	0.87
35	0.62	0.06	87	0.90
36	0.54	0.07	90	0.93
37	0.62	0.05	96	0.94
38	0.81	0.10	99	0.83
39	0.74	0.14	96	0.95
40	0.65	0.15	90	0.85
41	0.46	0.09	93	0.93
42	0.66	0.14	84	0.89
43	0.67	0.09	96	0.88
44	0.88	0.13	96	0.94
45	0.44	0.11	96	0.97
46	0.65	0.06	99	0.95
47	0.66	0.07	96	0.94
48	0.00	0.31	84	0.75

We hope you come away with three important conclusions. First, international trade theory is the study of trade in factor services. Since countries have quite disparate factor prices, studies of factor content must strive for consistent measures of endowments. Second, accurate measures of value added by industry and factor services by country are widely available. Anyone not using them ought to justify why measurement error does not swamp the theory under scrutiny. Third, countries can be modeled as having identical technologies, with a common international CES production function for each industry. Since the elasticities of substitution are small, countries with relatively little physical capital may well have have high cost shares for that factor in almost all industries.

The history of the world economy in the last two centuries has been written by hundreds of millions of immigrants whose lives have been a poignant refutation of the factor price equalization equalization theorem. We international economists will just have to deal with that reality. It implies that there is no easy way to aggregate output or to measure local factors in efficiency units. The world economy is more complex than that. But it has an underlying beauty and order. Heckscher-Ohlin-Vanek theory works when you give it a chance.

References

[1] Richard A. Brecher and Ehsan U. Choudhri. The Factor Content of International Trade Without Factor-Price Equalization. *Journal of International Economics*, 12(3-4):277–283, May 1982.

[2] Francesco Caselli and James Feyrer. The Marginal Product of Capital. *Quarterly Journal of Economics*, 122(2):535–568, May 2007.

[3] Donald R. Davis and David E. Weinstein. An Account of Global Factor Trade. *American Economic Review*, 91(5):1423–1453, December 2001.

[4] Mary Locke Eysenbach. *American Manufactured Exports, 1879-1914*. Arno Press, New York, 1976.

[5] Eric O'N. Fisher and Kathryn G. Marshall. The Factor Content of Trade when Countries have Different Technologies. Unpublished manuscript http://www.calpoly.edu/ efisher/FCT.pdf, 2008.

[6] Eric O'N. Fisher and Kathryn G. Marshall. The Structure of the American Economy. CESifo Working Paper No. 2295, 2008.

[7] Douglas Gollin. Getting Income Shares Right. *Journal of Political Economy*, 110(2):458–474, April 2002.

[8] Jon Harkness. Factor Abundance and Comparative Advantage. *American Economic Review*, 68(5):784–800, December 1978.

[9] James Harrigan. Specialization and the Volume of Production: Do the Data Obey the Laws? In E. Kwan Choi and James Harrigan, editors, *Handbook of International Trade*. Blackwell, Oxford, 2003.

[10] Edward E. Leamer Harry P. Bowen and Leo Sveikauskas. Multicountry, Multifactor Tests of the Factor Abundance Theory. *American Economic Review*, 77(5):791–809, December 1987.

[11] Elhanan Helpman. The Factor Content of Foreign Trade. *Economic Journal*, 94(373):84–94, March 1984.

[12] Edward E. Leamer. Paths of Development in the Three-Factor, n-Good General Equilibrium Model. *Journal of Poltical Economy*, 95(5):961–999, 1987.

[13] Wassily Leontief. *The Structure of the American Economy, 1919-1939: An Empirical Application of Equilibrium Analysis*. Oxford University Press, Oxford, 1951.

[14] Robert E. Lucas, Jr. Why Doesn't Capital Flow from Rich to Poor Countries? *American Economic Review Papers and Proceedings*, 80(2):92–96, May, 1990.

[15] John Romalis. Factor Proportions and the Structure of Commodity Trade. *American Economic Review*, 94(1):67–97, March 2004.

[16] Steven Rosefielde. Factor Proportions and Economic Rationality in Soviet International Trade 1955-1968. *American Economic Review*, 64(4):670–681, September 1974.

[17] Daniel Trefler. International Factor Price Differences: Leontief was Right! *Journal of Political Economy*, 101(6):961–987, December 1993.

[18] Daniel Trefler. The Case of Missing Trade and Other Mysteries. *American Economic Review*, 85(5):1029–1046, December 1995.

[19] Jaroslav Vanek. *The Natural Resource Content of United States Foreign Trade, 1870-1955*. The MIT Press, Cambridge, MA, 1963.

A The Data

The input-output matrices are from the OECD. The URL is:

http://www.oecd.org/document/3/0,3343,en_2649_34263_38071427_1_1_1_1,00.html.

These data are reported in local currencies. We converted them into international dollars using the Penn World Table 6.2 (PWT) purchasing power parity exchange rates. Then we converted them into 2000 dollars using the US GDP deflator. These countries represent 75 percent of world GDP and 67 percent of world trade.

We needed independent data on the physical endowments for these 33 countries in 2000 to construct the factor prices in Table 1. The labor endowment is the number of employed person years, and its source is the International Labor Organization on-line LABORSTA series 2A at http://laborsta.ilo.org/. We used data on total population in 2000 from the PWT to construct the factor price for social capital. This factor price is measured in 2000 international dollars per person, since it is derived from our GDP data.

The real capital stocks were constructed from PWT data. We started with our measures of GDP and back-cast each country's GDP as far as the data allowed, using the growth rate of real output in the PWT. Then local real investment in each year was inferred from the series on investment share of GDP in the PWT. The initial capital stock in the first year–1950 for most countries–was determined by $I_0/(g_0 + \delta)$, where I_0 is investment in initial year, g_0 is the average rate of growth of real GDP for next decade, and $\delta = 0.04$ is the depreciation rate. For Russia, data are available only from 1990, and the initial capital stock is set equal to initial investment in 1990. After the initial capital stock is determined, the capital stock is computed using the perpetual inventory method with $\delta = 0.04$.

Table A1 gives the list of the sectors.

Table A1: Sectors

Number	Description
1	Agriculture, hunting, forestry and fishing
2	Mining and quarrying (energy)
3	Mining and quarrying (non-energy)
4	Food products, beverages and tobacco
5	Textiles, textile products, leather and footwear
6	Wood and products of wood and cork
7	Pulp, paper, paper products, printing and publishing
8	Coke, refined petroleum products and nuclear fuel
9	Chemicals excluding pharmaceuticals
10	Pharmaceuticals
11	Rubber & plastics products
12	Other non-metallic mineral products
13	Iron & steel
14	Non-ferrous metals
15	Fabricated metal products, except machinery & equipment
16	Machinery & equipment, nec
17	Office, accounting & computing machinery
18	Electrical machinery & apparatus, nec
19	Radio, television & communication equipment
20	Medical, precision & optical instruments
21	Motor vehicles, trailers & semi-trailers
22	Building & repairing of ships & boats
23	Aircraft & spacecraft
24	Railroad equipment & transport equip nec.

Table A1 (continued): Sectors

Number	Description
25	Manufacturing nec; recycling (include Furniture)
26	Production, collection and distribution of electricity
27	Manufacture of gas; distribution of gaseous fuels through mains
28	Steam and hot water supply
29	Collection, purification and distribution of water
30	Construction
31	Wholesale & retail trade; repairs
32	Hotels & restaurants
33	Land transport; transport via pipelines
34	Water transport
35	Air transport
36	Supporting and auxiliary transport activities; activities of travel agencies
37	Post & telecommunications
38	Finance & insurance
39	Real estate activities
40	Renting of machinery & equipment
41	Computer & related activities
42	Research & development
43	Other Business Activities
44	Public admin. & defence; compulsory social security
45	Education
46	Health & social work
47	Other community, social & personal services
48	Private households with employed persons & extra-territorial organisations & bodies