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Measuring Factor Abundance Across Many Factors and Countries

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Abstract

Empirical studies of factor proportion theory face the challenge of measuring factor abundance in a world with many factors of production and countries. This paper introduces a mean weighted measure of factor abundance, and using data for nine factors and 33 countries, presents the resulting factor abundance rankings. These rankings, unlike others in the literature, are quite sensible. Further, there is a positive empirical link between factor abundance and factor content for each factor except agricultural labor.

Measuring factor abundance across many factors and countries

Factor abundance is part of the foundation of factor proportions trade theory, but it has not been easy to relate the elegant theory of Vanek (1968) and Williams (1977) to data with many factors and countries. Empirical studies have cast doubt on the empirical relevance of the factor content theorem that a country exports the services of its "abundant" factors. Bowen, Leamer, and Sveikauskas (1987) find little support but are unwilling to dismiss the theory because no alternative performs better. Trefler (1995) states that the Heckscher-Ohlin-Vanek (HOV) model performs miserably, but Davis and Weinstein (1998) show that the explanatory power of the factor content theorem improves dramatically relaxing assumptions such as identical unit inputs across countries.

In the HOV model, a factor has been called "abundant" if the country's endowment of the factor, relative to the world endowment, exceeds the country's share of world income. This share definition assumes factor price equalization and balanced trade. One reason for the apparent empirical weakness of the HOV model is that this definition is based on assumptions that simply do not hold.

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Leamer (1984) points out that independent measures of factor abundance and factor intensity would be required to test factor proportion theory. This paper introduces an alternative measure of factor abundance; weighting endowments by their averages across countries. This index is directly comparable for each factor across countries and for each country across factors. A sensible abundance ranking emerges revealing a significant link between factor abundance and the factor content of trade.

1. A standardized measure of factor abundance

This study uses the data set of Trefler (1995) with 9 factors of production and 33 countries. The sample comprised 79% of world output and 76% of world exports in the year of the sample, 1983. The factors of production are capital K, six types of labor (professional P, clerical C, sales S, service R, agricultural A, production M) and two types of land (cropland T, pastureland U). Capital input is derived from investment data in the Penn World Table using the double declining balance method. Labor data come from the *Yearbook of Labour Statistics* of the International Labour Office. Data on land are from the *Production Yearbook* of the United Nations Food and Agricultural Organization.

The bilateral definition of factor abundance can be applied to any two factors i and h and any two countries c and k. Letting v denote a factor endowment, if

$$v_{ic}/v_{hc} > v_{ik}/v_{hk} \tag{1}$$

country c is abundant in factor i relative to factor h and country k. Comparing each pair of factors for each pair of countries, there are $(9^2 - 9)/2 = 36$ pairs of factors and $(33^2 - 33)/2 = 528$ different pairs of countries, resulting in $36 \times 528 = 19{,}008$ bilateral comparisons of (1). Little insight is likely to emerge with the bilateral definition of factor abundance.

Share abundance compares country c's endowments of a factor with its share of world consumption, S_c. Let v_{iw} be the world endowment of factor i. Country c is share abundant in factor i if its relative endowment of factor i exceeds its consumption share,

$$v_{ic}/v_{iw} > S_c. \tag{2}$$

A shortcoming of this definition is that countries with very low consumption shares are abundant in most factors as described by Thompson (1999).

A bilateral endowment comparison between a country c, and the rest of the world r, is written

$$v_{ic}/v_{hc} > v_{ir}/v_{hr}. \tag{3}$$

For the 33 countries and 36 pairs of the 9 factors, there are $33 \times 36 = 1188$ instances of (3). For convenience, define V_{ihc} as $v_{ic}v_{hr} - v_{hc}v_{ir}$ which by (3) is positive.

Rescaling each endowment with its mean across countries, the mean weighted endowment of factor i in country c is

$$m_{ic} \equiv v_{ic}/\mu_i .$$

Analogous to (3), $m_{ic}/m_{hc} = (v_{ic}/\mu_i)/(v_{hc}/\mu_h) = (v_{ic}\mu_h)/(v_{hc}\mu_i)$ and

$$m_{ic}m_{hr} - m_{ir}m_{hc} = (v_{ic}v_{hr} - v_{ir}v_{hc})/\mu_i\mu_h = V_{ihc}/\mu_i\mu_h \equiv M_{ihc}. \tag{4}$$

Signs of M_{ihc} and V_{ihc} are the same. There are $9^2 - 9 = 72$ different M_{ihc} values for each country and those for Bangladesh, Japan, the US, and West Germany are reported in Table 1. The M_{ihc} matrix is symmetric with reversed signs across the diagonal.

Reading across the first row for West Germany, positive numbers indicate a consistent abundance in capital, strongest relative to pastureland, cropland, and agricultural labor. In Bangladesh, negative numbers in the first row indicate capital scarcity relative to all factors. Reading down the last column for the US, every factor is scarce relative to pastureland. In complete contrast, every factor in Japan and West Germany is abundant relative to pastureland. Comparisons for cropland in those three countries are similar. Japan has an abundance of sales labor relative to every other factor.

The Leontief "paradox" that the US is a net importer of capital is anticipated because the US is scarce in capital relative to professional, clerical, and service labor, and especially cropland and pastureland. The US is abundant in capital only relative to agricultural, sales, and manufacturing labor. The US is also abundant in professional labor relative to every factor except cropland and pastureland.

The weighted abundance is a cardinal measure that can be compared across factors and countries. For example, professional labor in the US is almost five times as abundant relative to manufacturing as service labor $(101.9/21.7 = 4.7)$. Cropland is twice as abundant relative to pastureland in Bangladesh as in Japan $(22.3/11.0 = 2.0)$ and more than three times as abundant as in West Germany $(22.3/7.1 = 3.1)$. US abundance in professional labor relative to manufacturing labor is about twice as strong as the same scarcity in Japan. West Germany's scarcity in professionals P relative to production labor M is about 30% that in Japan.

Per capita income is largely explained by relative factor endowments. The US (1) has the highest per capita income. (the number in parentheses refer to each country's ranking.) Countries abundant in capital relative to every factor are Switzerland (3), Norway (4), France (7), West Germany (6), Austria (14), Italy (16), Trinidad (17), and Singapore (19). Trinidad is capital abundant because it has very small amounts of all factors and lacks any agriculture. Japan (13) is capital abundant relative to every factor except clerical and sales labor.

At the other end of the income spectrum, Bangladesh (33), Pakistan (32), Indonesia (31), Colombia (28), and Uruguay (24) are scarce in capital relative to

Table 1. Mean weighted abundance M_{ihc} for four countries.

				Bangladesh				
								Pastureland
Capital	−12.8	−9.9	−61.4	−44.5	−152.4	−30.9	−22.5	−0.2
Professional		2.8	−48.6	−31.7	−139.7	−18.1	−9.8	12.6
Clerical			−51.5	−34.6	−142.5	−21.0	−12.6	9.7
Sales				16.9	−91.1	30.5	38.8	61.1
Service					−107.9	13.6	21.9	44.3
Agriculture						121.5	129.9	152.3
Manufacturing							8.4	30.7
Cropland								22.3
				Japan				
								Pastureland
Capital	63.9	−0.0	−18.9	55.3	110.2	10.5	162.4	173.5
Professional		−63.9	−82.8	−8.6	46.3	−53.5	98.5	109.6
Clerical			−18.8	55.4	110.3	10.5	162.5	173.5
Sales				74.2	129.2	29.4	181.3	192.4
Service					54.9	−44.9	107.1	118.1
Agriculture						−99.8	52.1	63.2
Manufacturing							151.9	163.0
Cropland								11.0
				United States				
								Pastureland
Capital	−36.9	−10.6	78.8	−15.2	283.4	65.0	−185.8	−318.0
Professional		26.3	115.6	21.7	320.4	101.9	−148.9	−281.1
Clerical			89.3	−4.6	294.0	75.6	−175.2	−307.5
Sales				−93.9	204.7	−13.8	−264.6	−396.8
Service					298.7	80.2	−170.6	−302.8
Agriculture						−218.4	−469.3	−601.5
Manufacturing							−250.8	−383.0
Cropland								−132.2
				West Germany				
								Pastureland
Capital	38.4	10.5	42.5	33.6	75.8	21.9	78.8	85.9
Professional		−27.9	4.0	−4.8	37.4	−16.5	40.3	47.5
Clerical			31.9	23.1	65.3	11.4	68.2	75.4
Sales				−8.8	33.4	−20.6	36.3	43.4
Service					42.2	−11.7	45.1	52.3
Agriculture						−53.9	2.9	10.0
Manufacturing							56.9	64.0
Cropland								7.1

every factor. Panama (27) is scarce in capital relative to every factor except sales labor. Sri Lanka (30) and Portugal (25) are scarce in capital relative to every factor except pastureland. Thailand (29) is scarce in capital relative to every other factor except clerical labor and pastureland. Capital scarcity is generally associated with low per capital income.

Abundance in professional labor is also associated with higher per capita income because of the higher wages of professional labor and increased productivity of other labor. Sweden (5), Finland (9), Netherlands (10), Belgium (12), the UK (15), and Israel (20) are abundant in professional labor relative to every other factor. Norway (4), Denmark (8), and New Zealand (11) are abundant in professional labor relative to every factor except one. The US (1), Canada (2), Switzerland (3), Ireland (22), and Yugoslavia (24) are abundant in professional labor relative to every factor except two.

The M_{ihc} values can be summed to arrive at a single measure of abundance. For factor i in country c, define M_{ic} as $\Sigma_h M_{ihc}$. For instance, summing across the first row for capital in the US leads to the summary abundance -139.3. The summary value for pastureland in the US is 2723.1, which is the negative of the sum of the last row.

The entire set of M_{ic} values is presented in Table 2. Japan (557.0) is the most capital abundant country, followed by West Germany (387.5), France (272.4), and Italy (269.5). The most capital scarce countries are Indonesia (-537.2), Bangladesh (-334.6), and Thailand (-269.8). The relative scarcity of capital in the US is due to its overwhelming abundance of cropland and pastureland.

Bangladesh is abundant only in sales, service, and agricultural labor, but is share abundant in every other factor except cropland and pastureland. With the present measure, Columbia, Greece, Indonesia, Pakistan, Panama, Sri Lanka, Uruguay, and Yugoslavia are abundant in an average of only three factors, none are abundant in capital, and only Yugoslavia is abundant in professional labor. Like Bangladesh, these same eight countries are share abundant in every factor.

2. The empirical link between the mean weighted abundance and factor content

The present section examines how factor abundance is associated with factor content. The factor content of trade is derived as net exports times factor inputs, applying the US input-output scheme to all countries. With identical production functions and factor price equalization, cost minimizing factor inputs would be identical across countries. In a world with many factors, however, factor price equalization is not necessary even in the static free trade equilibrium, as described by Rassekh and Thompson (1993). In the present sample, factor prices are anything but equal.

With these qualifications in mind, consider the familiar production structure of the factor proportions model with two factors and two countries. If $m_{11}/m_{21} > m_{12}/m_{22}$, country 1 would export product 1 in exchange for product 2.

Table 2. Summary mean weighted abundance M_{ic}.

	Capital	Professional	Clerical	Sales	Service	Agricultural	Manufacturing	Cropland	Pastureland
Austria	33.1	2.8	25.5	−1.2	26.9	−45.1	16.9	−34.7	−24.4
Bangladesh	−334.6	−168.9	−245.4	166.9	65.6	1037.5	−56.4	−131.7	−332.9
Belgium	46.1	50.4	46.8	−0.3	3.3	−60.0	19.9	−51.5	−54.8
Canada	−22.4	−33.4	−29.9	−153.3	−72.1	−353.6	−170.8	675.2	160.3
Colombia	−115.9	−109.1	−108.0	−71.9	−15.7	2.8	−74.0	−46.3	538.0
Denmark	12.1	24.1	16.6	−11.8	36.5	−36.2	−1.5	8.5	−48.2
Finland	23.1	29.3	−2.8	−12.1	12.1	−21.1	7.8	7.7	−44.1
France	272.4	151.5	178.8	−83.6	73.8	−337.8	18.8	−70.2	−203.6
Greece	−10.1	−10.1	−22.4	−16.2	−15.5	13.5	1.3	13.3	46.3
Hong Kong	1.1	−10.0	10.8	13.9	49.9	−36.0	52.0	−40.9	−41.0
Indonesia	−537.2	−360.4	−494.5	544.7	−278.9	2079.0	−70.5	−352.9	−529.2
Ireland	−6.0	−4.0	−12.5	−8.7	−14.7	−17.4	−3.0	−13.4	79.8
Israel	14.6	30.8	11.9	−6.2	3.9	−24.1	−2.0	−19.2	−9.5
Italy	269.5	90.7	126.1	−46.2	48.4	−217.5	159.8	−130.2	−300.5
Japan	557.0	−1.5	557.4	710.2	58.9	−435.5	462.9	−904.9	−1004.5
Netherlands	61.5	93.6	54.8	10.2	24.5	−80.3	1.1	−86.2	−79.2
New Zealand	−29.6	−27.1	−27.5	−36.0	−39.6	−50.3	−31.0	−53.4	294.7
Norway	36.1	36.6	−7.3	−2.2	15.9	−26.7	6.4	−20.7	−38.1
Pakistan	−296.8	−135.2	−225.9	26.2	−126.1	781.4	75.5	130.0	−229.1
Panama	−4.5	−2.2	−3.7	−5.7	5.6	0.4	−4.1	0.1	14.2
Portugal	−13.2	−14.8	16.2	−1.4	22.6	0.0	34.0	13.8	−57.3
Singapore	16.9	0.6	9.7	9.3	7.0	−17.4	12.7	−19.3	−19.5
Spain	1.6	−55.0	−35.0	−44.2	−5.2	−106.0	69.3	200.9	−26.3
Sri Lanka	−34.9	−8.9	−18.7	2.4	−8.2	116.2	16.8	−11.9	−52.7
Sweden	8.2	124.1	8.7	−15.5	29.2	−65.6	−2.3	−16.8	−69.9
Switzerland	70.6	21.6	37.0	−9.6	11.5	−49.7	7.7	−59.0	−30.1
Thailand	−269.8	−167.9	−280.1	−24.2	−187.4	1325.0	−149.4	97.1	−343.3
Trinidad	4.9	0.6	1.8	−0.6	2.7	−4.0	4.4	−3.1	−6.6
United Kingdom	50.1	358.8	214.6	−116.1	248.1	−415.5	122.4	−284.2	−178.2
United States	−139.3	132.3	−44.0	−787.7	−2.6	−2690.7	−724.4	1533.2	2723.1
Uruguay	−42.8	−36.8	−34.8	−33.8	−18.6	−42.7	−34.7	−24.0	268.2
West Germany	387.5	11.4	292.8	35.4	84.8	−295.1	190.4	−321.5	−385.6
Yugoslavia	−9.1	16.8	−16.9	−61.5	−46.6	72.5	44.6	16.2	−16.0

Summary abundance measures $(M_{11}, M_{12}, M_{21}, M_{22})$ have the signs $(+ - - +)$ and the correlation between M_{ic} and the factor content of trade is perfect. With more factors and more countries, there are no straightforward theoretical predictions and the empirical issue is how well factor abundance might explain factor content. This general approach of investigating how factor abundance affects factor content has the advantage of minimizing assumptions.

Consider the polynomial specification

$$T_i = a_0 + a_1 M_i + a_2 M_i^2 + a_3 M_i^3 + a_4 X_i + \varepsilon_i, \tag{5}$$

where $T_i \equiv$ the factor content of trade for factor i, $M_i \equiv$ the summary abundance measure in Table 2, $X_i \equiv a$ vector of variables controlling for assumptions of the model, and ε_i is a random error term. The higher order polynomial terms allow for flexibility and improved estimation. Further, the underlying production functions are characterized by constant returns and homotheticity if $a_2 = a_3 = 0$. Equation (5) is estimated for each of the 9 factors across the 33 sample countries.

Three control variables are included: the balance of trade (BOT), the unemployment rate, and the coefficient of variation (CV) of factor prices. While trade is balanced in HOV theory, including the BOT as a control variable at least produces estimates holding the BOT constant across countries. Similarly, factor proportions theory assumes full employment and including the unemployment rate produces estimates holding the rate of unemployment constant across countries. Including the CV implies that the estimated coefficients can be interpreted as though there were no variations in the factor prices across countries.

Table 3 reports estimates using White's (1980) procedure, which produces consistent t-values even if the variance of the error term is heteroskedastic and correlated with regressors. The only consistently significant control variable is BOT. The unemployment rate and the coefficient of variation of factor prices are insignificant for almost every factor.

Homothetic constant returns production is revealed only for cropland and pastureland, and the BOT is significant for every factor except these two. The constant term is significant only for professional, clerical, and service labor. A zero intercept term implies that a country with the mean abundance in a factor does not effectively trade that factor.

Regressions in Table 3 are plotted in Figures 1 through 9. Minimum and maximum values of M_i set the limits of the domains. Parameter estimates in Table 3 above the 20% significance level are included in the plots. The mean value of the BOT, $-\$2.9$ billion, is added to the constant terms to generate the plots.

The expected positive relationship between factor abundance M_i and factor content T_i is found for some range of every factor except agricultural workers. For manufacturing labor and cropland there is a positive relationship over the entire domain and R-squared values are high.

For agricultural labor A, a higher endowment is associated with lower factor content. Countries with an abundance of agricultural labor may consume a large share of their own output and countries with capital intensive agriculture may export a large share of their output. Abundance of agricultural labor explains only 35% of the variation in its factor content.

Sales labor and pastureland present opposite stories. Countries scarce in sales labor export products intensive in sales labor and higher endowments

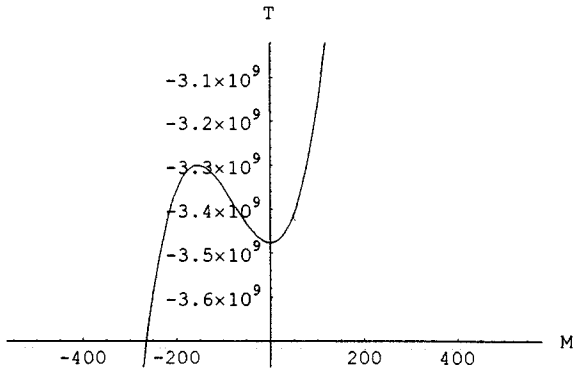

Figure 1. Capital K.

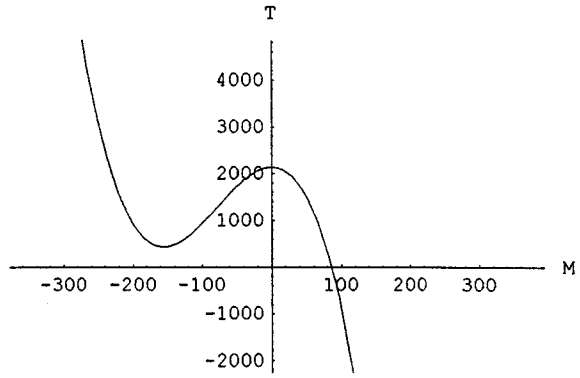

Figure 2. Professional P.

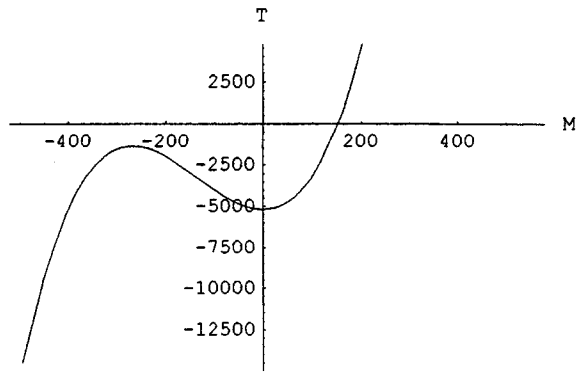

Figure 3. Clerical C.

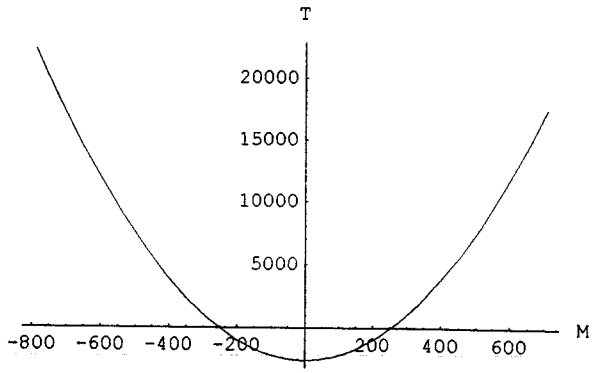

Figure 4. Sales S.

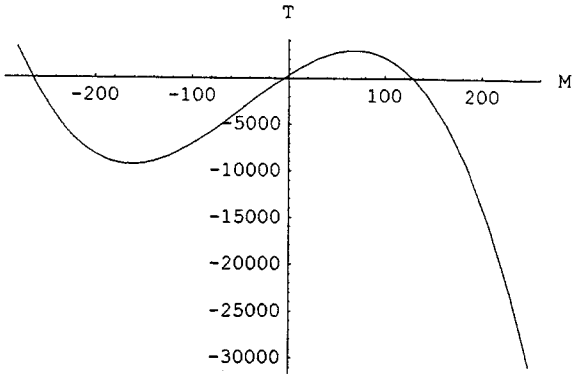

Figure 5. Service R.

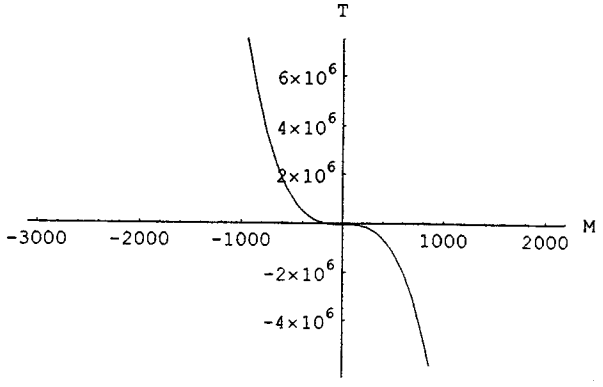

Figure 6. Agricultural A.

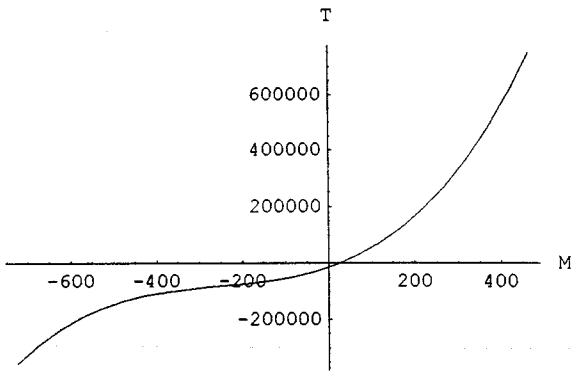

Figure 7. Manufacturing M.

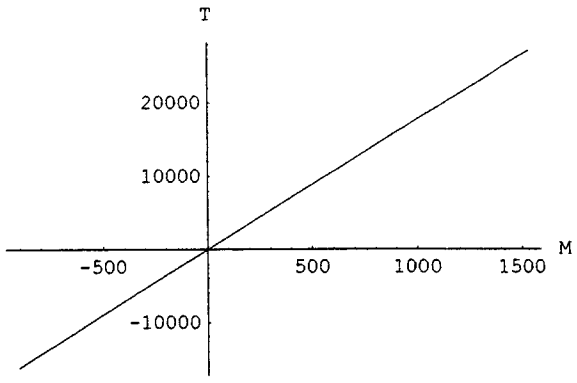

Figure 8. Cropland T.

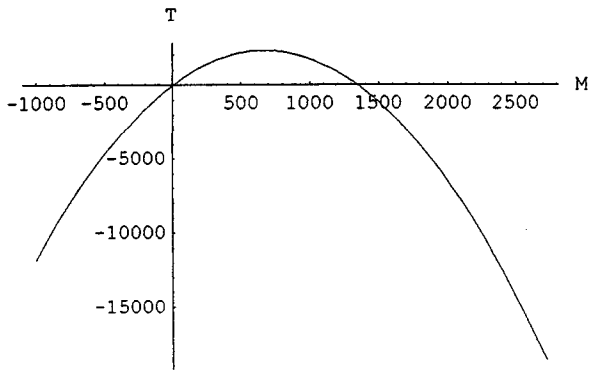

Figure 9. Pastureland U.

Table 3. Regression results of (6) dependent variable: Factor content of trade T_i.

Factor	Constant	M_i	M_i^2	M_i^3	BOT	Adj. R^2	F Value
Capital	1.06E+09	−1930597.00	22282.00	96.25	1.21	0.80	33.49
	[0.51]	[0.23]	*[1.67]	**[3.14]	**[8.72]		
Professional	10758.00	69.76	−0.21	−9.33E−04	3.30E−06	0.87	52.35
	**[2.87]	**[2.29]	**[6.56]	**[3.99]	**[6.92]		
Clerical	6319.50	20.15	0.16	3.94E−04	3.61E−06	0.91	80.68
	**[2.40]	[0.30]	**[4.60]	[1.56]	**[19.50]		
Sales	470.08	17.44	0.03	3.11E−05	9.52E−07	0.91	78.72
	[0.97]	[1.02]	**[5.85]	[0.90]	**[6.85]		
Service	6102.89	66.90	−0.28	−1.64E−03	1.67E−06	0.82	37.54
	**[2.94]	[1.46]	**[4.88]	**[2.38]	**[6.53]		
Agricultural	−21108.00	45.03	−0.05	−9.47E−03	−8.63E−06	0.35	5.31
	[1.32]	[1.10]	**[2.09]	**[4.07]	**[2.23]		
Manufacturing	14538.00	521.14	1.52	2.31E−03	1.00E−05	0.89	64.87
	[1.21]	[1.37]	**[6.13]	**[2.93]	**[2.93]		
Cropland	−733.11	17.83	3.84E−03	3.69E−06	−2.03E−07	0.87	54.44
	[1.03]	**[3.06]	[1.01]	[0.43]	[0.91]		
Pastureland	193.34	6.75	−4.77E−03	1.16E−06	−5.65E−08	0.47	8.01
	[0.30]	**[2.18]	[1.49]	[0.62]	[0.32]		

Note: Values in brackets are White's heteroskedastic-consistent t-statistics.
*Significant at 10% level.
**Significant at 5% level.

lower factor content. As the abundance of sales labor increases above zero, their factor content increases. The explanatory power of the estimate is high. For pastureland, increased endowments increase factor content up to a point, but beyond that the factor content decreases. Countries with a high abundance of pastureland must consume their own output. The estimate explains only 47% of the variation in the factor content of pastureland.

Capital and clerical labor are similar in that factor content generally increases, except when factor abundance approaches its mean value. The explanatory power of these two estimates is high.

For professional and service labor, factor content is positively associated with endowments over a limited range. At lower and higher endowments, factor content decreases with endowment, perhaps due to the nontraded production such as medical and household services.

Share abundance has lower explanatory power in a similar set of regressions with an average R-squared value of 0.55 across factors compared to 0.77 in Table 3. None of the share abundance coefficients are significant for clerical and manufacturing labor, and the qualitative shapes of the empirical relationships for share abundance are reversed for professional, sales, and service labor.

3. Conclusion

Calculating the abundance of various factors of production is a preliminary step in applying the factor proportions theory of production and trade, called "the backbone of traditional trade theory" by Leamer and Levinsohn (1995). The challenge facing empirical trade analysts is to simplify the complicated reality of a world with many countries, factors of production, and products. The mean weighted measure of factor abundance introduced in this is a step toward the application of factor proportions theory. In the present application, this abundance ranking is sensible and does a reasonable job of predicting the factor content of trade.

While the traditional theoretical assumptions sufficient to prove the HOV theorem are hardly a recipe for empirical analysis, they do provide a conceptual framework. Davis and Weinstein (1998) take the approach of relaxing the rather strict technological assumptions of HOV theory and show that share abundance explains the factor content of trade. They allow Hicks neutral differences in technology, factor price differences across countries, and production of nontraded goods, but their methodology is applied to only two factors of production. The apparently unrealistic share abundance measure might be replaced with the proposed mean weighted abundance measure in empirical studies.

As long as factors are required for production, it is reasonable to expect that their "abundance" will have an impact on international factor prices, product prices, and trade. A challenge facing empirical analysts is to gauge abundance in a world with many factors and countries. The mean weighted approach, introduced in the present paper, provides a reliable measure.

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