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James Harrigan

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# Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model

By JAMES HARRIGAN\*

*The neoclassical model of trade predicts that international specialization will be jointly determined by cross-country differences in relative factor endowments and technology levels. This paper specifies an empirical model of specialization consistent with the neoclassical explanation. In the model, a sector's share of GDP depends on relative factor supplies and relative technology differences, and the estimated parameters of the model have a clear connection to theoretical parameters. The model is estimated with panel data on manufacturing sectors in industrialized countries. Relative technology levels and factor supplies are both found to be important determinants of specialization. (JEL F1, F11)*

In the neoclassical general equilibrium model of international trade, countries trade with each other because of their differences. Countries may differ in their preferences, their technologies, or their factor supplies, and these differences jointly determine comparative advantage and, hence, trade. Technology differences as a source of comparative advantage were first studied by Ricardo, who identified different relative labor productivities as the cause of trade, while Heckscher and Ohlin assumed away technology differences and focused on differences in relative supplies of capital and labor as the causes of trade. The Ricardian and Heckscher-Ohlin explanations have been generalized by postwar trade theorists, with the general factor proportions explanation encompassing many goods and

factors, while the generalized Ricardian explanation encompasses general technology differences. Modern theorists of course recognize that general technology and factor supply differences can jointly determine comparative advantage.<sup>1</sup> This paper estimates just such a model, using data on technology, factor supplies, and production from a panel of industrialized countries.

While this has been the standard model of trade for many years, economists have spent little effort on empirical evaluation of the model, and most tests have been inconclusive and/or unfavorable to the model, beginning with Wassily Leontief's (1954) famous paper on the factor content of U.S. trade. Starting with Edward E. Leamer (1984), several researchers have used theory in a careful way to evaluate general versions of the factor proportions explanation of specialization and trade, including Keith E. Maskus (1985), Harry P. Bowen et al. (1987), Robert W. Staiger (1988), and Harrigan (1995). Each of these efforts has explicitly assumed identical technologies across countries, and the factor proportions model comes out looking to one degree or another seriously deficient in each

\* International Research Department, Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045 (e-mail: james.harrigan@ny.frb.org). The views expressed in this paper are those of the author and do not necessarily reflect the position of the Federal Reserve Bank of New York or the Federal Reserve System. This paper has benefitted from the comments of my former colleagues at the University of Pittsburgh and seminar participants at the NBER Summer Institute, Rutgers University, Purdue University, the University of British Columbia, Harvard University, the Federal Reserve Bank of New York, Penn State University, and Princeton University. James Cassing helped greatly in the development of the ideas used in this paper, and two anonymous referees were instrumental in improving it.

<sup>1</sup> While recognized as a theoretical possibility, differences in tastes have only rarely been analyzed as a source of comparative advantage. An interesting exception is James Markusen (1986) and Linda Hunter and Markusen (1988).

case. An exception is Richard Brecher and Eshan Choudhri (1993), who find that U.S.-Canadian production patterns are consistent with the factor proportions approach.

In an important recent paper, Daniel Trefler (1995) evaluated a model where there are technology differences across countries which are common across sectors (or equivalently, factors). In Trefler's model, a technological improvement increases the effective supply of all factors proportionately.<sup>2</sup> Since relative factor supplies are unchanged by neutral technological change, relative opportunity costs are not affected and, hence, the pattern of comparative advantage remains determined solely by relative factor supplies. This simple extension of the factor proportions model works remarkably well. In particular, Trefler finds that the factor content of a country's net exports is approximately equal to its effective excess factor supplies. An unappealing aspect of Trefler's model is that relative factor prices and relative factor intensities are identical everywhere. This implies, for example, that the capital/labor ratio in Brazilian manufacturing is the same as the capital/labor ratio in Japanese manufacturing. Trefler's model also conflicts with direct evidence on relative technology differences by Dale W. Jorgenson and Masahiro Kuroda (1990), David Dollar and Edward N. Wolff (1993), Bart van Ark and Dirk Pilat (1993), and Harrigan (1996a, b). Dollar and Wolff provide some evidence that these relative productivity differences are related to differences in net export performance (in particular, see their Section 7.3 pp. 144–48).

As noted above, general versions of factor proportions theory have been subject to a fair amount of empirical scrutiny. In contrast, this author is not aware of any such efforts to evaluate general technology differences as sources of comparative advantage. This impression is bolstered by the surveys by Alan V. Deardorff (1984) and Leamer and James Levinsohn (1995); neither find any studies that evaluate general Ricardian explanations for trade, never mind any studies that look at the joint impact

of technology and factor supply differences on specialization and trade. Dollar and Wolff (1993 p. 148) do not formally address the influence of factor supplies on trade, but they do note that relative factor endowments interact with relative technology differences in determining comparative advantage, and suggest that considering these sets of influences together may help to better explain the pattern of trade.

One aim of this paper is to fill this gap in the empirical literature. The paper proposes an empirical model which is flexible enough to jointly estimate the impact of differing technologies and differing factor supplies on international specialization and trade. The model comes from applying a flexible functional form to the revenue function representation of the general equilibrium of the production sector, where there are Hicks-neutral technology differences across countries and over time. The model requires a minimal number of assumptions beyond the most basic ones (exogenous prices and factor supplies, competitive market-clearing, no joint production, and constant returns to scale). This model is estimated on a data set of ten industrial countries over 20 years for seven different manufacturing sectors. Technology differences are measured by applying the theory of total factor productivity (TFP) comparisons to a data set on industry inputs and outputs, and factor endowments are measured directly. The empirical results show that technology differences are an important determinant of specialization, and that factor supplies alone cannot explain which industrial countries produce which goods. An implication of the results is that the factor proportions approach which has dominated much of the empirical and policy-oriented research in the past may need to be replaced by a model which accounts for relative technology differences in addition to relative factor supply differences.

This paper does not provide a definitive test of the neoclassical model for two reasons. First, testing against a composite alternative in the classical statistical sense is inappropriate, since the neoclassical model is known to be a simplification of a complex world and is not intended to be taken as literally true. Second, it is not possible to test the neoclassical model

<sup>2</sup> In Trefler's (1995) notation, this is model  $T_1$ .

against a well-specified alternative because there is no well-specified general equilibrium alternative model to which it can be compared. The most prominent alternative explanations for the pattern of international specialization include industry-level economies of scale (see Elhanan Helpman, 1984; Helpman and Paul Krugman, 1985) and path-dependent geographical models (e.g., Krugman, 1991). However, these more recent models have not been integrated with the neoclassical literature so it is not possible to design a statistical model which precisely pinpoints the areas of disagreement between them and the neoclassical model. For these two reasons, the strategy of this paper is to follow Leamer and Levinsohn's (1995) sensible injunction to "estimate, don't test." The estimated model turns out to be statistically successful and generally in line with the predictions of theory, so the neoclassical model comes out looking rather well.

Section I of this paper briefly explains the theory of how Hicks-neutral technology differences influence outputs in general equilibrium, and outlines the dual representation of the economy's production sector as a function of prices, technology differences, and factor supplies. Section II develops the empirical model, and Section III discusses data, measurement, and econometric issues. Section IV presents the empirical results.

### I. Theory

This section closely follows the standard treatments of Avinash Dixit and Victor Norman (1980) and A. D. Woodland (1982). Consider a small open economy characterized by fixed aggregate factor supplies, constant returns to scale, and competitive market-clearing. As is well known, the general equilibrium of this economy will maximize the value of final output. A common formulation of this maximization problem is

$$\text{Max } \mathbf{p} \cdot \mathbf{x} \text{ subject to } \mathbf{x} \in Y(\mathbf{v})$$

$$\mathbf{p}, \mathbf{x} \in \mathbb{R}^N, \mathbf{v} \in \mathbb{R}^M,$$

where  $\mathbf{x}$  is the final goods vector,  $\mathbf{p}$  is the vector of final goods prices, and  $Y(\mathbf{v})$  is the con-

vex production set for endowments  $\mathbf{v}$ . The solution to this problem gives the maximized value of GDP as  $Y = r(\mathbf{p}, \mathbf{v})$ . As long as the revenue function  $r(\mathbf{p}, \mathbf{v})$  is twice continuously differentiable, which requires smooth substitutability among factors and at least as many factors as goods ( $M \geq N$ ), the vector of net output supplies  $\mathbf{x}(\mathbf{p}, \mathbf{v})$  is given by the gradient of  $r(\mathbf{p}, \mathbf{v})$  with respect to  $\mathbf{p}$ <sup>3</sup>:

$$x_j(\mathbf{p}, \mathbf{v}) = \partial r(\mathbf{p}, \mathbf{v}) / \partial p_j \quad j = 1, \dots, N.$$

Hicks-neutral technological differences across countries and/or time can be modeled easily using an extension of the dual approach. In addition to the standard assumptions on the revenue function, suppose that there exists a production function for each good given by

$$\tilde{x}_j = \theta_j \cdot f^j(\mathbf{v}^j) = \theta_j x_j \quad j = 1, \dots, N,$$

where  $\theta_j$  is a scalar parameter relative to some base period and/or country, and  $\mathbf{v}^j \in \mathbb{R}^M$  is a vector of inputs. The assumption of the existence of distinct production functions implies that joint production is ruled out. Increases in  $\theta_j$  represent Hicks-neutral technological progress in industry  $j$ . It can be shown<sup>4</sup> that the resulting revenue function has the form  $r(\boldsymbol{\theta}\mathbf{p}, \mathbf{v})$ , where  $\boldsymbol{\theta} = \text{diag}\{\theta_1, \theta_2, \dots, \theta_N\}$ . This formulation implies that industry-specific neutral technological change can be modeled in the same way as industry-specific price increases, and the net output vector is again given by the gradient of the revenue function with respect to  $\mathbf{p}$ . Differentiation of  $r(\boldsymbol{\theta}\mathbf{p}, \mathbf{v})$  with respect to  $\boldsymbol{\theta}$  establishes that the elasticity of an industry's output with respect to technical progress in that industry is equal to one plus the own-price output elasticity.<sup>5</sup>

It is straightforward to show using revealed profit maximization logic that there is a positive correlation between technical progress and

<sup>3</sup> If there are more goods than factors, the GDP-maximizing output vector is not unique, and the gradient  $r_p(\mathbf{p}, \mathbf{v})$  needs to be reinterpreted as a set of subgradient vectors.

<sup>4</sup> See, for instance, Dixit and Norman (1980 pp. 137–39).

<sup>5</sup> A discussion of these issues in terms of the primal cost functions can be found in Ronald W. Jones (1965).

output, holding factor supplies fixed; this follows also from the convexity of  $r(\mathbf{p}, \mathbf{v})$  in  $\mathbf{p}$ . It is not generally true, however, that if we look across countries that technical advantage in an industry will be associated with greater relative output in that industry. This is because the Rybczynski effects of differences in relative factor endowments may affect outputs in the opposite direction. It is difficult to obtain useful theoretical results on the relative importance of factor supplies and technology differences in determining specialization, especially in the general case of large numbers of goods and factors. This fact is a partial motivation for this paper: only estimation tied closely to theory can shed light on the empirical importance of the different determinants of specialization.

## II. An Empirical Model

To make further progress on a model which can be used as a basis for empirical work requires that we assume a functional form for  $r(\theta\mathbf{p}, \mathbf{v})$ . Following Woodland (1982) and Uhlich Kohli (1991), suppose that we approximate the true revenue function with a translog function, in particular,

$$\begin{aligned} \ln r(\theta\mathbf{p}, \mathbf{v}) &= a_{00} + \sum_j a_{0j} \ln \theta_j p_j \\ &+ \frac{1}{2} \cdot \sum_j \sum_k a_{jk} \ln \theta_j p_j \ln \theta_k p_k \\ &+ \sum_i b_{0i} \ln v_i + \frac{1}{2} \cdot \sum_i \sum_m b_{im} \ln v_i \ln v_m \\ &+ \sum_j \sum_i c_{ji} \ln \theta_j p_j \ln v_i, \end{aligned}$$

where the summations over  $j$  and  $k$  run from 1 to  $N$  and the summations over  $i$  and  $m$  run from 1 to  $M$ . Symmetry of cross effects requires that  $a_{jk} = a_{kj}$  and  $b_{im} = b_{mi}$  for all  $j, k, i$ , and  $m$ . Linear homogeneity in  $\mathbf{v}$  and in  $\mathbf{p}$  requires

$$\begin{aligned} \sum_j a_{0j} &= 1 \quad \sum_i b_{0i} = 1 \quad \sum_j a_{kj} = 0 \\ \sum_i b_{im} &= 0 \quad \sum_i c_{ji} = 0. \end{aligned}$$

Differentiating  $\ln r(\theta\mathbf{p}, \mathbf{v})$  with respect to each  $\ln p_j$  and imposing the homogeneity restrictions  $\sum_j a_{kj} = 0$  and  $\sum_i c_{ji} = 0$  gives the share of product  $j$  in GDP,  $S_j = p_j \cdot x_j / Y$  as a function of technology parameters, prices, and factor supplies:

$$\begin{aligned} S_j &= a_{0j} + \sum_{k=2}^N a_{kj} \ln \frac{p_k}{p_1} \\ &+ \sum_{k=2}^N a_{kj} \ln \frac{\theta_k}{\theta_1} + \sum_{i=2}^M c_{ij} \ln \frac{v_i}{v_1}. \end{aligned}$$

Now suppose that each country faces the same prices in each period (that is, free trade), but that countries differ in their factor endowments and technologies. Choosing a country and a year as a reference point and using  $c$  and  $t$  subscripts to denote countries and years, we have

$$\begin{aligned} (1) \quad S_{jct} &= a_{0j} + \sum_{k=2}^N a_{kj} \ln \frac{p_{kt}}{p_{1t}} \\ &+ \sum_{k=2}^N a_{kj} \ln \frac{\theta_{kct}}{\theta_{1ct}} + \sum_{i=2}^M c_{ij} \ln \frac{v_{ict}}{v_{1ct}}. \end{aligned}$$

Defining  $d_{jt} = \sum_k a_{kj} \ln(p_{kt}/p_{1t})$ , equation (1) simplifies to

$$\begin{aligned} (2) \quad S_{jct} &= a_{0j} + d_{jt} \\ &+ \sum_{k=2}^N a_{kj} \ln \frac{\theta_{kct}}{\theta_{1ct}} + \sum_{i=2}^M c_{ij} \ln \frac{v_{ict}}{v_{1ct}}. \end{aligned}$$

With data on output shares, technology, and factor endowments, this equation can be estimated over a panel of countries and years for each industry  $j$ . If there are neutral technology differences across sectors for a particular country, so that  $\theta_{kct} = \theta_{ct}$ , then the first summation in (2) disappears and output shares depend only on relative factor supplies. In such a case cross-country technology differences determine the level, but not the composition, of GDP. This is the assumption about technology made by Trefler (1995).

A complication arises when we consider that many goods are nontraded. Denoting the

full vector of goods prices as  $P$ , partition  $P$  into

$$P = (\mathbf{p} \ \mathbf{q})$$

where  $\mathbf{p}$  is an  $N_1 \times 1$  vector of traded goods prices and  $\mathbf{q}$  is an  $N_2 \times 1$  vector of nontraded goods prices. Free trade still allows us to assume  $p_{ct} = p_t$  for all countries  $c$ , but generally  $q_{ct} \neq q_{bt}$  for two countries  $b$  and  $c$ . This implies that equation (2) becomes

$$(3) \quad S_{jct} = a_{0j} + d_{jt} + \sum_{k=2}^N a_{kj} \ln \frac{\theta_{kct}}{\theta_{1ct}} \\ + \sum_{k=N_1+1}^N a_{kj} \ln \frac{q_{kct}}{p_{1t}} + \sum_{i=2}^M c_{ij} \ln \frac{v_{ict}}{v_{1ct}}.$$

Equation (3) differs from (2) by the presence of the summation involving relative nontraded goods prices; in (3), the term  $d_{jt}$  absorbs only the traded goods prices:

$$d_{jt} = \sum_{k=2}^{N_1} a_{kj} \ln \frac{p_{kt}}{p_{1t}}.$$

Note also that the first summation in (3) includes both traded and nontraded goods relative technology parameters.

With data on nontraded goods prices and technology across countries, equation (3) can be estimated in the same way as equation (2). However, data on the prices of nontraded goods are not generally available. In addition, measurement of the output and productivity of the government and service sectors (to name the two largest nontraded sectors) is notoriously difficult even within a single country, and international comparisons are yet more difficult. Accordingly, these variables are for practical purposes unobservable. An approach which recognizes both the importance and the unobservability of the nontraded goods effects is to treat them as random with some estimable probability distribution. Define the sum of the nontraded goods price and nontraded technology terms in (3) as

$$(4) \quad \varepsilon_{jct} = \sum_{k=N_1+1}^N a_{kj} \ln \frac{q_{kct}}{p_{1t}} + \sum_{k=N_1+1}^N a_{kj} \ln \frac{\theta_{kct}}{\theta_{1t}}.$$

A simple and flexible model for the stochastic process governing  $\varepsilon_{jct}$  is

$$\varepsilon_{jct} = \eta_{jc} + \mu_{jt} + e_{jct}, \quad e_{jct} \sim N(0, \sigma_j^2).$$

That is, treat the sum of the nontraded goods effects as a random variable with country fixed effects  $\eta_{jc}$ , time fixed effects  $\mu_{jt}$ , and a random component  $e_{jct}$  with constant variance  $\sigma_j^2$ . Rewriting (3) using the definition in (4) gives the equation to be estimated:

$$(5) \quad S_{jct} = \eta_{jc} + \delta_{jt} + \sum_{k=1}^{N_1} a_{kj} \ln \theta_{kct} \\ + \sum_{i=2}^M c_{ij} \ln \frac{v_{ict}}{v_{1ct}} + e_{jct},$$

where  $\delta_{jt} = \mu_{jt} + d_{jt}$  is the combined time-specific effect of all goods prices and nontraded goods technology parameters. Note that since not all technology parameters are observed, there is no homogeneity restriction governing the sum of the observable technology effects. The only sign restriction on equation (5) that can be established by theory is that the own-TFP effect,  $a_{jj}$ , is positive: holding factor supplies and other levels of TFP constant, an increase in a sector's TFP should lead to an increase in the share of GDP accounted for by that sector. Theory also requires that the cross-TFP effects are symmetric,  $a_{kj} = a_{jk}$  for all sectors  $j$  and  $k$ ,  $k \neq j$ .

### III. Data, Measurement, and Econometrics

Empirical implementation of the model described in the previous section requires data on output shares, technology, and factor supplies. I first briefly discuss the theoretical issues involved in measuring industry technology, and then discuss data sources. Lastly, I discuss appropriate econometric techniques for dealing with the cross-equation restrictions, partial adjustment, and potential measurement error biases.

#### A. Total Factor Productivity Comparisons

The Hicks-neutral technology parameters  $\theta_{kct}$  are measured using an index of total factor

productivity. TFP calculations at the industry level require real, internationally comparable data on industry outputs and inputs of primary factors and intermediate goods. For practical purposes, information on inputs other than capital and labor is not available in internationally comparable form, so I calculate value-added TFP indexes. Value-added TFP calculations are strictly appropriate only when a well-defined, value-added function exists, which requires separability between capital and labor and other inputs. Consequently, the TFP calculations reported in this paper should be treated as approximations to true TFP.<sup>6</sup>

TFP comparisons are a classic index number problem and therefore TFP indexes have no unique optimal form, but an index proposed by Douglas W. Caves et al. (1982) is appropriate for this application. Suppose that value-added  $y$  is a function of capital  $k$  and labor  $l$ . Suppressing the industry and time subscripts for readability, the index for any two countries  $b$  and  $c$  is given by

$$(6) \quad TFP_{bc} = \frac{y_b}{y_c} \left( \frac{\bar{l}}{\bar{l}_b} \right)^{\sigma_b} \left( \frac{\bar{k}}{\bar{k}_b} \right)^{1-\sigma_b} \\ \times \left( \frac{\bar{l}_c}{\bar{l}} \right)^{\sigma_c} \left( \frac{\bar{k}_c}{\bar{k}} \right)^{1-\sigma_c},$$

where  $\bar{l}$  and  $\bar{k}$  are geometric averages over all the observations in the sample and  $\sigma_c = (s_c + \bar{s})/2$ , where  $s_c$  is labor's share in total cost in country  $c$ . To interpret (6), notice that if the value-added function is Cobb-Douglas, then the labor shares are constant and (6) reduces to the Cobb-Douglas index:

$$TFP_{bc} = \frac{y_b}{y_c} \left( \frac{l_c}{l_b} \right)^s \left( \frac{k_c}{k_b} \right)^{1-s}.$$

<sup>6</sup> On the theory of value-added functions, see W. Erwin Diewert (1978). Jorgenson and Kuroda (1990) compute U.S.-Japanese TFP comparisons using appropriately (and laboriously) constructed data on materials and intermediate goods, and their calculations of TFP levels are not too different from the value-added TFP comparisons in Harrigan (1996b).

The index (6) is superlative, meaning that it is exact for the flexible translog functional form. Furthermore, (6) is transitive:

$$TFP_{ac} = TFP_{ab} \cdot TFP_{bc},$$

which makes the choice of base country and year inconsequential. For more on the theory of TFP comparisons and its application to cross-country comparisons of industry-level data, see Harrigan (1996b).

Computation of indexes like (6) requires real, internationally comparable data on value added, labor input, and capital input. The OECD has a database called the "International Sectoral Data Base," or ISDB, which contains just such data classified according to the nine two-digit categories of the International Standard Industrial Classification (ISIC). The ISDB data reports capital stocks in addition to employment and value added for ten OECD countries (the United States, Canada, Japan, Sweden, and six European Union states: Britain, France, Germany, Italy, Belgium, and Denmark) for the years 1970 to 1990. I adjust the ISDB data on employment by average hours worked per week in manufacturing to get a measure of labor input. A problem with the ISDB data is that the share of labor in value added is very noisy, and frequently exceeds one. To control for this, I use a smoothing procedure based on the fact that, when the value-added function is given by a translog and standard market-clearing assumptions hold, labor's share in value added in industry  $j$  in year  $t$  in country  $c$  is<sup>7</sup>

$$s_{cjt} = \delta_{1cj} + \delta_{2j} \ln(k_{cjt}/l_{cjt}).$$

If observed labor shares deviate from this equation by an i.i.d. measurement error term, then its parameters can be estimated by regressing labor shares on country fixed effects and industry capital-labor ratios, with a separate regression for each industry. I use the fitted values from these regressions as the labor cost shares in constructing the TFP indexes given by equation (6).

<sup>7</sup> See Caves et al. (1982).

The ISDB uses overall GDP purchasing power parity exchange rates to convert industry outputs into internationally comparable units. This implicitly assumes that relative prices are the same in different countries; to the extent that they are not, output comparisons will be distorted. For example, suppose that country A and country B have identical technology but that the price of machinery relative to chemicals is higher in country A than in country B, perhaps due to differences in the quality mix in the two countries. Deflating industry outputs by the overall GDP price level will lead to the erroneous conclusion that country A has superior technology in chemicals and inferior technology in machinery in comparison to country B. If the structure of relative prices is fairly constant within a country over time, then this measurement procedure induces a constant country-specific multiplicative measurement error into the TFP comparisons.<sup>8</sup> The implications of this for estimation are addressed in subsection C below. For further details on the ISDB data and the computation of TFP, see the Appendix to this paper (available from the author upon request).

### B. Factor Supplies

I consider three types of factor supplies: land, labor, and capital. Data on aggregate capital stocks come from version 5.6 of the Penn-World Tables, available by anonymous ftp from [nber.harvard.edu](http://nber.harvard.edu). The Penn-World Tables classify capital stocks into producer durables, nonresidential and other construction, and residential construction. I use only the first two capital stock measures, since residential construction is most appropriately regarded as a component of consumption for the purposes of this paper. Information on arable land

comes from the World Resources database on diskette.<sup>9</sup>

I classify labor endowments according to the educational levels of workers. The data on educational attainment comes from Robert J. Barro and Jong-Wha Lee (1993), whose data are also available by anonymous ftp from [nber.harvard.edu](http://nber.harvard.edu). Barro and Lee construct estimates of the level of educational attainment in the population, and I use their data to classify workers into three categories:

1. Highly educated workers, who have at least some postsecondary education;
2. Medium-educated workers, who have at least some secondary education but no higher education, and
3. Low-educated workers, who have no secondary education (almost all of this category consists of workers with at least some primary education).

This education-based classification is probably preferable to the occupational-based classification used by (among others) Leamer (1984) and Harrigan (1995) for two reasons. The first is that educational levels are more likely to be exogenous with respect to output shares than occupational classifications, since growth in some industries might induce workers to shift their occupations. The second is that education is probably more closely related to skill than is occupation.

### C. Estimation: Cross-Equation Restrictions, Partial Adjustment, and Measurement Error

As noted at the end of Section II, the translog functional form implies that there are linear cross-equation symmetry restrictions among the system of output share equations (5) for a group of industries. These restrictions are imposed by using a restricted SURE estimator, which is an asymptotically efficient GLS estimator if the restrictions are valid.<sup>10</sup>

<sup>8</sup> It is possible to compare the structure of relative prices across countries by examining the source documents for the construction of the OECD's purchasing power parities. Harrigan (1996b) does this, and shows that relative prices vary much less over time within a country than across countries at a point in time. This supports the view that a constant multiplicative factor will capture most of the error in the TFP calculations in this paper.

<sup>9</sup> It would be desirable to use data on other natural resources. Arable land is the only natural resource variable that I use in the empirical work because of gaps in the coverage of other natural resource stocks.

<sup>10</sup> See William Greene (1993 Ch. 17) for a clear exposition of estimating a system of translog share equations. As Greene notes, if data on all sectors is available,



The neoclassical model assumes free movement of factors among sectors. If reallocation of factors occurs with a lag in response to changes in technology, prices, and aggregate factor supplies, then equation (5) will hold only after adjustment has taken place. With slow adjustment to equilibrium, output shares in the short run can be modeled as

$$(7) \quad S_{jct} = \lambda_j S_{jct-1} + \eta_{jc} + \delta_{jt} + \sum_{k=1}^{N_1} a_{kj} \ln \theta_{kct} \\ + \sum_{i=2}^M c_{ij} \ln \frac{v_{ict}}{v_{1ct}} + e_{jct},$$

where  $\lambda_j$  is the speed of adjustment, and the long-run effect of a change in  $\theta_k$  is given by  $a_{kj}/(1 - \lambda_j)$ . Because symmetry requires  $a_{kj} = a_{jk}$ , it also requires  $\lambda_j = \lambda_k$ . Therefore, the coefficient on the lagged output share will be constrained to be the same for each equation when (7) is estimated. As noted in Cheng Hsiao (1986 Section 4.2), for short panels the OLS estimator of  $\lambda_j$  is biased downward and inconsistent. A consistent estimator uses a two-period lag of the dependent variable to instrument for the lagged dependent variable, and this is the procedure that is followed in the results reported below.

A problem with the estimation of (5) and (7) is the severe measurement error in all of the right-hand-side variables. It is likely that there are two types of measurement error that infect observed factor supplies and relative TFP. The first is systematic, and is a result of differences in measurement procedures and factor quality across countries and over time. For example, differences in soil quality are country specific and will infect the measurement of arable land, while exchange rate fluctuations and imperfections in the calculation of purchasing power parity exchange rates are both country and time specific and will affect the comparisons of capital stocks and TFP. The second type of error is classical random measurement error which arises due to imper-

fect application of any given measurement technique. A model of this dual type of measurement error for explanatory variable  $i$  in country  $c$  at time  $t$  is

$$z_{ict} = a_c \cdot b_t \cdot z_{ict}^* \cdot \exp\{e_{ict}\},$$

where

$z_{ict}$  = observed value of variable  $i$  in country  $c$  at time  $t$ ,

$z_{ict}^*$  = actual value of variable  $i$  in country  $c$  at time  $t$ ,

$a_c, b_t$  = country-specific and time-specific systematic measurement errors,

$e_{ict}$  = normally distributed classical measurement error with mean 0 and variance  $\sigma_i^2$ .

Taking logarithms of both sides of the above equation gives

$$(8) \quad \ln z_{ict} = \alpha_c + \beta_t + \ln z_{ict}^* + e_{ict},$$

where  $\alpha_c \equiv \ln a_c$  and  $\beta_t \equiv \ln b_t$ . Substituting (8) into (5) or (7) and collecting terms, it becomes apparent that the systematic measurement errors  $\alpha_c$  and  $\beta_t$  will be absorbed into the country and time fixed effects  $\eta_{jc}$  and  $\delta_{jt}$ , leaving only the classical measurement errors  $e_{ict}$  on the right-hand side. Of course, the ideal solution to classical measurement error is to use an instrumental variables estimator. It seems reasonable to assume that true technology levels are correlated across countries while technology measurement errors are uncorrelated across countries, which means that one country's TFP level is a valid instrument for another country's TFP level. Consequently, I instrument industry  $k$  TFP in country  $c$  in year  $t$  by the average of all other countries' industry  $k$  TFP in year  $t$ . In other words, the instrument for  $\theta_{kct}$  is

$$\frac{1}{C-1} \sum_{d \neq c}^C \theta_{kdt}, \quad k = 1, \dots, N,$$

where  $C$  is the number of countries in the sample.

Unfortunately, there are no good instruments available for factor supplies. As shown by Steven Klepper and Leamer (1984), the

then the system is singular and maximum likelihood is the recommended estimator. Since I do not estimate shares for all sectors, restricted GLS is appropriate.

degree of inconsistency caused by classical measurement error in multiple right-hand-side variables can be bounded, and the tightness of the bounds is a function of the  $R^2$  of the regression equation. The  $R^2$ s of the regressions of the share equations (5) and (7) vary between 0.92 and 0.98, so that the degree of inconsistency due to classical measurement error in the factor endowment variables is very small. Consequently, I do not pursue the calculation of the measurement error bounds as outlined by Klepper and Leamer.

#### D. Data Summary

Table 1 summarizes the coverage and organization of the data. The sample includes all of the largest developed countries as well as a number of smaller European economies and covers the period 1970 to 1988, with a number of countries having data up to 1990. Table 2 gives an indication of how the ten countries differ in what they produce. The first column of Table 2 gives the share of manufacturing value added in each country's total GDP in 1970 and 1988. Each country saw a drop in manufacturing's share of GDP over the period. The other columns of the table give the share of each industry in total manufacturing value added. By far the largest sector is Machinery, which accounted for over a third of total manufacturing value added in most countries. The sector which saw the largest decline in its share of manufacturing was Textiles and Apparel. After Machinery, the next two largest sectors were generally Food and Chemicals, with Paper an important sector in the heavily forested countries of Canada and Sweden. The variability in these output shares across countries and over time is what the empirical model in the next section is designed to explain.

The explanatory variables of the model are summarized in Tables 3 and 4. Table 3 shows the levels of factor endowments at the end of the sample as well as the average annual growth rates of the endowments over the sample. The type of systematic measurement error discussed in the previous section is evident in this table, particularly in the education variables. For example, Germany has a very small number of college-educated workers relative to the United States, but far more low-

educated workers, which may have more to do with differences in the educational systems in the two countries than with differences in the skill levels of the two workforces. Most countries saw small declines in arable land and somewhat larger declines in low-educated workers over the period, while the other types of labor and both types of capital generally grew.

The total factor productivity data are summarized in Table 4. Not surprisingly, there is generally strong growth over time in TFP, although there are some exceptions, particularly in the Food sector. The United States was the leader in TFP in most sectors both at the beginning and at the end of the sample, an observation which accords with Dollar and Wolff (1993) and Harrigan (1996a, b), among other researchers. Careful scrutiny of this table uncovers a number of apparent anomalies (for example, was Japanese TFP in Food really 23 percent higher in 1970 than U.S. TFP in 1988?), so these comparisons should be taken as fairly noisy indicators of true technology differences.

#### IV. Empirical Results

Equations (5) and (7) are estimated as a system of restricted seemingly unrelated regressions, and the results are reported in Tables 5 and 6 respectively, with hypothesis tests reported in Table 8. Standardized coefficients for equations (5) and (7) are reported in Table 7. The estimates in Table 5 are computed subject to the symmetry and homogeneity constraints, while the Table 6 results have the additional restriction that the coefficient on the lagged dependent variable is the same in each equation. For each sector, the dependent variable is the percentage share of that sector's output in GDP, and the explanatory variables are the log of TFP in all sectors and the log of six different types of factor endowments. Since the dependent variable is a percentage, the estimated parameters have the interpretation of a semielasticity. For example, a parameter estimate of 2.0 means that a 10-percent increase in the independent variable will raise the output share by 0.20 percentage points. Country and time fixed effects are included in each equation but are not reported for space

TABLE 1—DATA SET DESCRIPTION

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*Years 1970–1990 (many series stop in 1988).*

*Countries:* Ten OECD countries: Canada, the United States, Japan, Belgium, Britain, France, Denmark, West Germany, Italy, and Sweden.

*Product classification system:* Seven of the nine categories of the two-digit level of the International Standard Industrial Classification (ISIC). The categories, and their three-digit constituent parts, are listed below. ISIC 33, Products of Wood, and ISIC 39, Other Manufacturing, are excluded from the analysis because of missing data.

<b>Food</b>	311/2	Food manufacturing
	313	Beverage industries
	314	Tobacco manufactures
<b>Apparel</b>	321	Manufacture of textiles
	322	Manufacture of wearing apparel, except footwear
	323	Manufacture of leather products, except footwear and apparel
	324	Manufacture of footwear, except rubber or plastic
<b>Paper</b>	341	Manufacture of paper and paper products
	342	Printing, publishing, and allied industries
<b>Chemicals</b>	351	Manufacture of industrial chemicals
	352	Manufacture of other chemical products
	353	Products of petroleum refineries
	354	Miscellaneous products of petroleum and coal
	355	Rubber products
	356	Plastic products not elsewhere classified
<b>Glass</b>	361	Pottery, china and earthenware
	362	Glass and glass products
	369	Other nonmetallic mineral products
<b>Metals</b>	371	Iron and steel basic industries
	372	Nonferrous metal basic industries
<b>Machinery</b>	381	Fabricated metal products, except machinery and equipment
	382	Manufacture of machinery, except electrical
	383	Electrical machinery, apparatus, appliances, and supplies
	384	Transport equipment
	385	Professional, scientific, measuring, and control equipment

*Shares of each industry in GDP*

Source: the OECD's International Sectoral Database (ISDB).

*Total factor productivity*

Author's calculation of total factor productivity uses data on real value added, capital stocks, and employment by industry, country, and year from the ISDB. For details, see the text and the Appendix (available from the author upon request).

*Factor endowments*

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<b>Capital</b>	Using version 5.6 of the Penn-World Tables (PWT 5.6), capital is classified into two categories: (1) durable goods capital, and (2) nonresidential construction and other capital. Units: millions of 1985 international dollars. See Robert Summers and Alan Heston (1991) for details.
<b>Labor</b>	The economically active population (from PWT 5.6) is classified according to education level: (1) low—workers with at most primary education; (2) medium—workers with at most secondary education; and (3) high—workers with at least some higher education. Units: thousands of workers. The educational classification for 1970, 1975, 1980, and 1985 comes from Barro and Lee (1993); intervening years are interpolated, and years after 1985 are projected using the 1980–85 trend.
<b>Land</b>	Arable land. Units: thousands of hectares. The source is the World Resources Data Base on diskette.

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TABLE 2—SHARE OF MANUFACTURING IN GDP AND SHARE OF INDUSTRIES IN TOTAL MANUFACTURING, 1970 AND 1988

		All	Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery
<b>Belgium</b>	<b>1988</b>	23.3	14.6	6.7	6.2	23.2	5.5	10.3	28.3
	<b>1970</b>	32.1	15.4	11.4	5.2	15.9	7.1	11.9	27.0
<b>Canada</b>	<b>1988</b>	19.7	13.2	5.4	16.2	13.0	3.5	8.3	31.2
	<b>1970</b>	22.5	14.9	8.3	14.0	9.9	3.5	9.0	31.5
<b>Germany</b>	<b>1988</b>	32.1	10.2	4.1	4.5	18.7	3.9	7.3	47.6
	<b>1970</b>	40.2	12.9	7.9	4.5	16.4	5.0	9.6	39.6
<b>Denmark</b>	<b>1988</b>	18.8	21.0	5.2	11.0	12.9	4.7	1.2	36.3
	<b>1970</b>	21.1	21.0	8.9	11.4	9.9	7.4	1.8	32.0
<b>France</b>	<b>1988</b>	22.5	12.5	6.6	7.4	19.6	4.3	5.6	39.5
	<b>1970</b>	28.5	12.6	10.1	6.5	17.1	4.6	9.3	35.0
<b>Britain</b>	<b>1988</b>	23.0	19.4	5.9	9.7	13.7	5.2	3.9	38.0
	<b>1970</b>	33.8	19.0	9.2	7.4	9.3	4.0	5.6	40.9
<b>Italy</b>	<b>1988</b>	23.9	10.4	16.3	6.0	13.2	7.1	4.7	35.8
	<b>1970</b>	27.6	13.8	14.6	4.9	12.0	6.9	8.1	33.1
<b>Japan</b>	<b>1988</b>	27.4	11.5	2.4	2.8	12.1	3.9	8.3	43.5
	<b>1970</b>	34.8	10.6	5.5	2.6	13.1	4.2	11.3	40.0
<b>Sweden</b>	<b>1988</b>	23.2	10.3	2.8	16.1	11.5	3.2	4.3	43.9
	<b>1970</b>	27.6	10.0	6.6	14.4	8.4	4.5	8.1	39.2
<b>U.S.</b>	<b>1988</b>	18.6	10.4	5.1	11.7	17.6	3.0	4.8	41.0
	<b>1970</b>	24.7	12.2	7.8	9.0	13.2	3.2	7.3	41.4

Notes: The column labeled "All" gives the percentage share of manufacturing value added in total GDP in 1970 and 1988. The other columns give the percentage share of each industry's value added in manufacturing value added.

reasons; they are reported in an Appendix, which is available upon request. The fixed effects alone account for the large majority of the variation in the data.

For each estimated equation, the TFP variable corresponding to the industry output share being explained is highlighted to make the table easier to read. According to the theory, this parameter is the own-price output effect and should be nonnegative. In most cases, this own-TFP parameter is estimated to be positive and statistically significant: in Table 5, five of the seven sectors have positive own-TFP effects, while in Table 6 all seven sectors have positive own-TFP effects.<sup>11</sup> The largest positive effect is in the Machinery sector: a 10-

percent improvement in relative TFP raises Machinery's share of GDP by 0.2 or 0.3 percentage points. The Chemicals sector has an own-TFP effect of over 1, while the Apparel, Glass, and Metals sectors have relatively small own-TFP effects of less than 1. The Paper sector has a small positive own-TFP effect which is significant only in Table 6, while the Food category has an own-TFP effect ambiguous sign: it is negative in Table 5 and positive in Table 6. This failure of the theory for the Food sector is in itself an interesting result which hints that the output of this sector depends more on factors such as government policy than on purely economic considerations. Students of agricultural policy in the world economy may find this particularly unsurprising.

As the theory suggests, the cross-TFP effects are a mix of positive and negative, although the signs and statistical significance are somewhat fragile across the two tables. Of the 21 cross-TFP effects, only three are statistically

<sup>11</sup> The covariance matrix of the restricted GLS estimator is asymptotically normal. Here and in what follows, my cutoff for "statistical significance" is  $|t| \geq 1.64$ , which is the 10-percent cutoff point for the standard normal.

TABLE 3—FACTOR ENDOWMENTS: LEVELS IN 1988 AND AVERAGE ANNUAL PERCENTAGE GROWTH RATES, 1970–1990

		Workers, 1000's	Producer durables per worker, 1985 \$	Nonresidential construction per worker, 1985 \$	Low- educated workers, percent of total	Medium-educated workers, percent of total	High- educated workers, percent of total	Arable land per worker, hectares
<b>Belgium</b>	Level, 1988	4,113	9,624	24,747	47	42	11	0.20
	Growth rate	0.69	1.81	3.75	-0.85	1.71	6.62	-0.60
<b>Canada</b>	Level, 1988	12,973	7,319	31,405	23	39	38	3.54
	Growth rate	2.19	6.90	4.80	-0.90	1.78	6.07	0.34
<b>Germany</b>	Level, 1988	28,375	14,042	37,021	73	19	8	0.26
	Growth rate	0.57	3.61	3.75	0.07	1.37	4.60	-0.08
<b>Denmark</b>	Level, 1988	2,830	8,941	23,105	46	36	18	0.91
	Growth rate	0.93	3.61	3.33	-0.41	2.34	2.34	-0.16
<b>France</b>	Level, 1988	25,437	11,084	22,402	63	26	11	0.70
	Growth rate	0.89	3.97	4.10	-0.86	5.09	7.76	0.29
<b>Britain</b>	Level, 1988	28,077	8,798	10,370	49	38	13	0.24
	Growth rate	0.49	2.68	3.18	-1.07	1.86	5.13	-0.19
<b>Italy</b>	Level, 1988	23,114	10,179	19,672	63	31	7	0.39
	Growth rate	0.51	4.36	3.46	-1.13	4.39	5.45	-0.62
<b>Japan</b>	Level, 1988	77,281	8,473	23,990	42	42	16	0.05
	Growth rate	0.83	6.70	7.04	-1.32	1.95	6.88	-0.73
<b>Sweden</b>	Level, 1988	4,344	11,665	24,338	40	43	17	0.66
	Growth rate	0.80	5.01	2.90	-1.43	2.16	4.90	-0.34
<b>U.S.</b>	Level, 1988	120,891	10,956	21,749	7	60	32	1.54
	Growth rate	1.79	4.57	3.12	-6.51	2.81	3.84	-0.03

Notes: The first row under each heading is the level of the economywide factor supply in 1988. Capital is expressed as 1985 U.S. dollars per worker, education levels are expressed as percentages of the labor force, and land is expressed as hectares per worker. The second row under each heading is the average annual percentage growth rate of the factor from 1970 to 1990. Growth rates are 100 times the regression coefficients from log-linear trend regressions by factor and country. Changes in relative factor endowments over time can be inferred by comparing the growth rates; for example, growth in producer durables per worker in Belgium from 1970 to 1990 was  $1.81 - 0.69 = 1.12$  percent per year.

significant and of the same sign in both tables: negative Machinery-Chemicals, Glass-Foods, and Apparel-Chemicals cross-effects. The strongest cross-TFP effect is between TFP in Chemicals and Machinery: TFP growth in one of these sectors evidently draws resources out of the other sector. These are also the two sectors with the largest own-TFP effects.

Turning to the effect of factor supplies on GDP shares, I first focus on Table 5. The two types of capital tend to have different effects. Abundance in producer durables is generally associated with larger output in most sectors, while greater supplies of nonresidential construction are associated with lower output shares: this pattern holds in the Apparel, Chemicals, Glass, and Machinery sectors and, in addition, producer durables have a positive

effect in the Food sector. Abundance in highly educated workers has a uniformly negative or negligible effect on the output shares of all industries, medium-educated workers have a positive or negligible effect on the output shares of all but the Chemicals sector, and low-educated workers have large effects only in the Chemicals (negative) and Machinery (positive) sectors. The effects of land are mixed, with a surprising negative effect in the Food sector, although it should be recognized that this sector is the output of processed food and beverages and not agricultural production per se.

To summarize, the most reliable inferences across sectors about the effects of factor abundance on output shares are: (1) producer durables and medium-educated workers are

TABLE 4—RELATIVE TOTAL FACTOR PRODUCTIVITY, 1970 AND 1988

		Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery
<b>Belgium</b>	<b>1988</b>	96	99	99	135	98	125	78
	<b>1970</b>	73	53	53	39	43	46	36
<b>Canada</b>	<b>1988</b>	77	90	69	53	85	83	81
	<b>1970</b>	80	52	60	40	61	76	47
<b>Germany</b>	<b>1988</b>	76	87	79	89	84	87	73
	<b>1970</b>	75	61	63	71	61	63	54
<b>Denmark</b>	<b>1988</b>	70	65	62	58	51	67	50
	<b>1970</b>	41	36	55	31	57	36	37
<b>France</b>	<b>1988</b>	74	91	88	86	86	84	72
	<b>1970</b>	65	67	71	59	50	52	43
<b>Britain</b>	<b>1988</b>	96	64	86	114	80	61	52
	<b>1970</b>	88	45	69	68	59	32	37
<b>Italy</b>	<b>1988</b>	81	100	87	71	78	72	72
	<b>1970</b>	41	54	52	30	38	54	34
<b>Japan</b>	<b>1988</b>	86	37	52	89	65	111	69
	<b>1970</b>	123	31	40	54	61	83	28
<b>Sweden</b>	<b>1988</b>	55	67	55	53	57	50	51
	<b>1970</b>	55	54	42	39	49	30	36
<b>U.S.</b>	<b>1988</b>	100	100	100	100	100	100	100
	<b>1970</b>	89	63	90	74	79	95	57

*Notes:* The TFP indexes are calculated as described in the text, and are expressed (arbitrarily) relative to the United States in 1988 for each industry. Numbers are directly comparable within industries, and relative TFP for any two countries or years can be calculated by dividing one number by another. For example, Belgian TFP in Food in 1970 was 73 percent of the U.S. level in 1988, Belgian TFP in Food in 1970 was  $73/89 = 82$  percent of the U.S. level in 1970, and Belgian TFP in Food in 1988 was 96 percent of U.S. TFP in Food in 1988.

associated with larger shares; and (2) non-residential construction and high-educated workers are associated with lower shares. These findings suggest a simple story: the service sector is intensive in nonresidential construction (office buildings and retail stores) and college-educated workers (managers, professionals, educators), so that abundance in these factors draws other resources out of manufacturing and into the service sector. By contrast, the manufacturing sectors are intensive in producer durables and medium-educated workers, so that abundance in these factors draws resources out of services and into manufacturing sectors. While plausible, confirmation of this explanation would require data on direct factor shares which are not easily available in internationally comparable form.

The results about factor abundance are roughly consistent with Harrigan (1995). That paper used a somewhat different model, data set, and set of factor endowment variables, and found that capital abundance was associated with larger output in most manufacturing industries and skilled labor abundance was associated with lower output in most industries. The results are also roughly consistent with Leamer's (1984) findings about the net export effects of factor abundance.

Turning to Table 6, it is much more difficult to sign the effects of factor supplies on output shares. For example, nonresidential construction has a significant effect in only one sector, and medium-educated workers have no significant effects. Evidently, the slow adjustment (the estimated coefficient on the lagged output share is 0.699) of output shares to the movement

TABLE 5—ESTIMATES OF THE GDP SHARE EQUATIONS, EQUATION (5)

	Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery
TFP Food	<b>-0.457</b> (-2.01)	0.672 (4.74)	0.144 (1.09)	-0.067 (-0.48)	-0.327 (-3.21)	0.381 (3.55)	0.005 (0.02)
TFP Apparel	0.672 (4.74)	<b>0.371</b> (2.40)	0.360 (3.14)	-0.485 (-4.25)	-0.057 (-0.65)	-0.157 (-1.92)	0.597 (3.39)
TFP Paper	0.144 (1.09)	0.360 (3.14)	<b>0.184</b> (1.06)	-0.104 (-0.93)	0.012 (0.13)	-0.003 (-0.04)	0.387 (2.34)
TFP Chemicals	-0.067 (-0.48)	-0.485 (-4.25)	-0.104 (-0.93)	<b>2.025</b> (11.9)	-0.060 (-0.72)	-0.029 (-0.29)	-1.198 (-5.32)
TFP Glass	-0.327 (-3.21)	-0.057 (-0.65)	0.012 (0.13)	-0.060 (-0.72)	<b>0.369</b> (3.96)	-0.107 (-1.82)	-0.174 (-1.26)
TFP Metals	0.381 (3.55)	-0.157 (-1.92)	-0.003 (-0.04)	-0.029 (-0.29)	-0.107 (-1.82)	<b>0.618</b> (4.88)	-0.583 (-3.00)
TFP Machinery	0.005 (0.02)	0.597 (3.39)	0.387 (2.34)	-1.198 (-5.32)	-0.174 (-1.26)	-0.583 (-3.00)	<b>3.583</b> (6.06)
Prod. durables	1.305 (6.90)	0.940 (6.57)	-0.016 (-0.14)	1.186 (5.78)	0.358 (3.89)	0.193 (0.96)	0.913 (1.91)
Nonres. const.	-0.195 (-0.68)	-0.353 (-1.68)	0.157 (0.90)	-1.530 (-5.26)	-0.244 (-1.70)	-0.066 (-0.24)	-1.754 (-2.44)
High-ed. workers	-0.170 (-1.34)	-0.663 (-7.16)	-0.219 (-2.98)	-0.002 (-0.02)	-0.190 (-3.18)	-0.503 (-3.93)	-2.114 (-6.60)
Medium-ed. workers	0.682 (3.47)	0.688 (4.88)	-0.035 (-0.31)	-0.889 (-4.44)	0.378 (4.20)	-0.210 (-1.10)	1.013 (2.11)
Low-ed. workers	-0.020 (-0.14)	0.102 (0.99)	-0.148 (-1.78)	-0.397 (-2.68)	-0.103 (-1.53)	-0.224 (-1.55)	1.820 (5.22)
Arable land	-1.602 (-5.27)	-0.714 (-3.09)	-0.261 (1.43)	1.631 (5.10)	-0.200 (-1.32)	0.809 (2.64)	0.123 (0.14)

Notes: Estimation results are listed columns, with *t*-statistics in parentheses. The dependent variable is the percentage share of the industry in GDP. All explanatory variables are in logarithms, and are listed as rows. Country and year fixed effects are not shown. There are 203 observations in regression. For further details on this table, see the text.

of relative factor supplies obscures the equilibrium relationship that was apparent when adjustment was assumed to be immediate, as it is in Table 5.

To help understand the size of the effects reported in Tables 5 and 6, Table 7 reports standardized coefficients, which are transformations of the regression coefficients into units of sample standard deviations.<sup>12</sup> For ex-

ample, a standardized coefficient of 1.3 means that a one-standard-deviation increase in the explanatory variable will increase the dependent variable by 1.3 standard deviations. The standardized coefficients corresponding to Table 5 are reported in columns A of Table 7. Columns B of Table 7 report long-run standardized coefficients, where each slope is first divided by  $1 - \lambda$  to convert it into a long-run effect. Numbers are in boldface if the corresponding slope in Table 5 or 6 is significantly different from zero at the 10-percent level. The estimated long-run, own-TFP effects in columns B are invariably larger than the effects in columns A; generally, a one-standard-

<sup>12</sup> Standardized coefficients are often known as "beta" coefficients. Standardized coefficients are formed by multiplying the regression slope by the standard deviation of the explanatory variable and dividing by the standard deviation of the dependent variable.

TABLE 6—ESTIMATES OF THE GDP SHARE EQUATIONS, EQUATION (7)

	Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery
TFP Food	<b>0.458</b> (2.13)	0.065 (0.55)	0.028 (0.20)	-0.099 (-0.71)	-0.143 (-1.70)	-0.056 (-0.54)	-0.264 (-1.26)
TFP Apparel	0.065 (0.55)	<b>0.253</b> (2.11)	0.013 (0.12)	-0.167 (-1.76)	-0.003 (-0.05)	0.029 (0.45)	0.147 (1.09)
TFP Paper	0.028 (0.20)	0.013 (0.12)	<b>0.233</b> (1.23)	-0.006 (-0.05)	0.039 (0.46)	-0.031 (-0.39)	0.133 (0.77)
TFP Chemicals	-0.099 (-0.71)	-0.167 (-1.76)	-0.006 (-0.05)	<b>1.205</b> (6.69)	-0.093 (-1.38)	0.001 (0.01)	-1.063 (-4.76)
TFP Glass	-0.143 (-1.70)	-0.003 (-0.05)	0.039 (0.46)	-0.093 (-1.38)	<b>0.265</b> (3.40)	0.045 (1.04)	-0.040 (-0.39)
TFP Metals	-0.056 (-0.54)	0.029 (0.45)	-0.031 (-0.39)	0.001 (0.01)	0.045 (1.04)	<b>0.509</b> (3.99)	-0.143 (-0.77)
TFP Machinery	-0.264 (-1.26)	0.147 (1.09)	0.133 (0.77)	-1.063 (-4.76)	-0.040 (-0.39)	-0.143 (-0.77)	<b>2.086</b> (3.92)
Prod. durables	0.230 (1.43)	0.138 (1.40)	-0.197 (-1.73)	0.370 (1.83)	0.099 (1.58)	0.190 (1.03)	-0.610 (-1.54)
Nonres. const.	0.736 (2.22)	0.091 (0.45)	0.239 (0.97)	0.444 (1.18)	0.003 (0.02)	-0.168 (-0.50)	0.509 (0.64)
High-ed. workers	0.035 (0.24)	-0.203 (-2.15)	-0.236 (-2.17)	-0.044 (-0.23)	-0.104 (-1.79)	-0.078 (-0.46)	-0.959 (-2.48)
Medium-ed. workers	0.075 (0.34)	-0.045 (-0.34)	-0.115 (-0.73)	-0.178 (-0.65)	-0.112 (-1.29)	-0.292 (-1.18)	-0.461 (-0.83)
Low-ed. workers	-0.048 (-0.37)	0.038 (0.47)	-0.103 (-1.07)	-0.364 (-2.25)	-0.047 (-0.90)	-0.089 (-0.58)	0.567 (1.74)
Arable land	-1.027 (-2.89)	-0.018 (-0.10)	0.412 (1.59)	-0.229 (-0.53)	0.160 (1.13)	0.438 (1.12)	0.954 (1.03)

Notes: Estimation results are listed columns, with *t*-statistics in parentheses. The specification in this table differs from that of Table 5 by the inclusion of a lagged dependent variable, whose estimated coefficient (slope = 0.699, *t* = 22.9) is restricted to be the same for all seven equations. There are 183 observations in each regression. For further details on this table, see the text.

deviation increase in own-TFP has a moderate-to-large effect on the GDP share. The cross-TFP effects are almost all negligible except for the Machinery-Chemicals effect. Where statistically significant, the factor endowment effects are generally large, with many standardized coefficients greater than one in absolute value and most greater than 0.5.

Table 8 reports some hypothesis tests relating to the results in Tables 5 and 6. The symmetry restrictions (Hypotheses A1, B1, and B2) are rejected, while the homogeneity of the factor supply effects is generally not rejected (Hypotheses A3 and B3). The TFP and factor

supply effects are jointly significant for each equation in Table 5, but the picture is less clear for Table 6: the TFP variables are not significant in the Food sector, and factor supplies do not have significant effects in the Glass and Metals sectors.

Because the results of Tables 5 and 6 are computed using a fixed effects estimator, cross-country variation in TFP and factor supplies is not used in estimation; in other words, only time-series variation within countries is used to identify the parameters. Mechanically, the estimator proceeds in two steps: first, country and time means are subtracted by regressing



TABLE 7—ESTIMATES OF THE GDP SHARE EQUATIONS, STANDARDIZED COEFFICIENTS

		Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery
TFP Food	A	<b>-0.12</b>	<b>0.17</b>	0.04	-0.01	<b>-0.20</b>	<b>0.10</b>	0.00
	B	<b>0.40</b>	0.05	0.03	-0.06	<b>-0.29</b>	-0.05	-0.08
TFP Apparel	A	<b>0.21</b>	<b>0.11</b>	<b>0.13</b>	<b>-0.10</b>	-0.04	<b>-0.05</b>	<b>0.07</b>
	B	0.07	<b>0.25</b>	0.02	<b>-0.12</b>	-0.01	0.03	0.05
TFP Paper	A	0.04	<b>0.08</b>	0.05	-0.02	0.01	0.00	<b>0.03</b>
	B	0.02	0.01	0.23	0.00	0.07	-0.03	0.04
TFP Chemicals	A	<b>-0.02</b>	<b>-0.16</b>	-0.04	<b>0.49</b>	-0.05	-0.01	<b>-0.15</b>
	B	-0.11	<b>-0.18</b>	-0.01	<b>0.96</b>	-0.25	0.00	<b>-0.45</b>
TFP Glass	A	<b>-0.07</b>	-0.01	0.00	-0.01	<b>0.18</b>	<b>-0.02</b>	-0.01
	B	<b>-0.10</b>	0.00	0.03	-0.04	<b>0.42</b>	0.03	-0.01
TFP Metals	A	0.16	<b>-0.06</b>	0.00	-0.01	<b>-0.11</b>	<b>0.28</b>	<b>-0.09</b>
	B	-0.08	0.04	-0.05	0.00	0.15	<b>0.76</b>	-0.07
TFP Machinery	A	0.00	<b>0.16</b>	<b>0.13</b>	<b>-0.22</b>	-0.11	<b>-0.17</b>	<b>0.35</b>
	B	-0.24	0.13	0.14	<b>-0.66</b>	-0.08	-0.14	<b>0.68</b>
Prod. durables	A	<b>1.69</b>	<b>1.16</b>	<b>-0.02</b>	<b>1.06</b>	<b>1.07</b>	0.26	<b>0.43</b>
	B	0.99	0.57	<b>-1.01</b>	<b>1.10</b>	0.98	0.86	-0.95
Nonres. const.	A	<b>-0.24</b>	<b>-0.42</b>	0.23	<b>-1.29</b>	<b>-0.69</b>	-0.09	<b>-0.78</b>
	B	<b>3.02</b>	0.36	1.17	1.25	0.03	-0.72	0.75
High-ed. workers	A	-0.25	<b>-0.92</b>	<b>-0.38</b>	0.00	<b>-0.63</b>	<b>-0.77</b>	<b>-1.11</b>
	B	0.17	<b>-0.93</b>	<b>-1.36</b>	-0.14	-1.15	-0.40	-1.67
Medium-ed. workers	A	<b>0.90</b>	<b>0.86</b>	-0.06	<b>-0.80</b>	<b>1.14</b>	-0.29	<b>0.48</b>
	B	0.33	-0.19	-0.60	-0.53	<b>-1.12</b>	-1.34	-0.73
Low-ed. workers	A	-0.02	0.12	<b>-0.21</b>	<b>-0.33</b>	-0.28	-0.28	<b>0.79</b>
	B	-0.19	0.14	-0.49	<b>-0.99</b>	-0.43	-0.37	<b>0.81</b>
Arable land	A	<b>-2.46</b>	<b>-1.05</b>	-0.48	<b>1.72</b>	-0.71	<b>1.31</b>	0.07
	B	<b>-5.25</b>	-0.09	2.52	-0.80	1.88	2.36	1.76

Notes: This table reports standardized or "beta" coefficients based on the slope estimates in Tables 5 and 6. A standardized coefficient of (for example) 1.3 means that a one-standard-deviation increase in the explanatory variable will increase the dependent variable by 1.3 standard deviations. The numbers in rows A are equal to the corresponding slopes in Table 5, multiplied by the standard deviation of the explanatory variable, divided by the standard deviation of the GDP share. The numbers in rows B are computed in two steps. First, each slope in Table 6 is divided by  $1 - 0.699 = 0.301$ , where 0.699 is the estimated coefficient on the lagged dependent variable, to get the long-run effect of each explanatory variable. The long-run effects are then multiplied by the standard deviation of the explanatory variable, divided by the standard deviation of the GDP share. Numbers are in boldface if the corresponding slope from Table 5 or 6 is significantly different from zero at the 10-percent level.

each variable on country and time-period dummies; second, the restricted SURE estimator is applied to the residuals from these regressions. To see how the estimated model does in predicting cross-country variation in GDP shares, I constructed predicted values using the estimated coefficients multiplied by variables with only time means removed. These predicted values are compared to the actual GDP shares in Table 9. Not surprisingly, given the large

magnitude of cross-country variation in GDP shares (see Table 2), the results are mixed: for equation (5) the correlation between predicted and actual is positive in five of seven sectors, while Chemicals and Metals have negative correlations. Equation (7) does much better, with high positive correlations in all sectors; this is surely due to the lagged dependent variable in equation (7). Better cross-country measurement of TFP and factor supplies, as

TABLE 8—HYPOTHESIS TESTS

Panel A: No lagged dependent variable, equation (5), Table 5

A1. Symmetry of cross-TFP effects: 0.000

	Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery	All
A3. Homogeneity	0.471	0.498	0.823	0.290	0.512	0.308	0.098	0.041
Significance tests (conditional on A1 and A3 imposed)								
A4. TFP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A5. Factors	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000
A6. TFP & factors	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Panel B: Lagged dependent variable, equation (7), Table 6

B1. Symmetry of cross-TFP effects: 0.019

B2. Equality of lagged effects: 0.000

	Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery	All
B3. Homogeneity	0.026	0.230	0.224	0.975	0.138	0.002	0.112	0.001
Significance tests (conditional on B1, B2, and B3 imposed)								
B4. TFP	0.086	0.227	0.638	0.000	0.004	0.013	0.000	0.000
B5. Factors	0.025	0.109	0.068	0.030	0.071	0.623	0.009	0.000
B6. TFP & factors	0.021	0.076	0.177	0.000	0.008	0.009	0.000	0.000

Notes: This table reports the marginal significance levels of hypothesis tests of the specifications reported in the previous two tables. Each test is calculated by computing the appropriate Wald statistic, which has a  $\chi^2$  distribution with degrees of freedom equal to the number of restrictions being tested.

A1, B1 Hypothesis: Cross-TFP effects are equal,  $a_{kj} = a_{ji}$ ,  $k, j = 1, \dots, 7$ ,  $i \neq j$ , which amounts to 21 cross-equation linear restrictions. The test statistics are  $\chi^2$  (21).

B2 Hypothesis: Coefficients on lagged dependent variables are equal,  $\lambda_j = \lambda_k$ ,  $j, k = 1, \dots, 7$ , which amounts to six cross-equation linear restrictions. The test statistic is  $\chi^2$  (6).

A3, B3 Hypothesis: Sum of the factor endowment terms is zero. For each industry separately, the test statistic is  $\chi^2$  (1). For the hypothesis that homogeneity holds for all seven industries, the statistic is  $\chi^2$  (7).

A4–6, B4–6 Hypothesis: The indicated coefficients are all zero. For each industry separately, the test statistics are:

A4, B4:  $\chi^2$  (7)

A5, B5:  $\chi^2$  (5)

A6, B6:  $\chi^2$  (12).

For all seven industries together, the test statistics are:

A4, B4:  $\chi^2$  (49)

A5, B5:  $\chi^2$  (35)

A6, B6:  $\chi^2$  (84).

well as modeling of cross-country differences in the size of the nontraded goods sector, would probably lead to a smaller amount of unexplained cross-country variation in GDP shares.

## V. Conclusion

This paper is the first to estimate a model where technology and factor supply differences jointly determine international specialization. This methodology is consistent with, but less restrictive than, the even model of

Leamer (1984) and Harrigan (1995), and also encompasses the modified factor price equalization approach of Treffer (1993, 1995). The estimated effect of technology differences is generally large and in accord with the theory, suggesting that Ricardian effects are an important source of comparative advantage. Factor endowment differences are also found to have large effects on output shares, and the pattern of estimated effects is informative, although the factor supply effects are elusive when a lagged dependent variable is included in the specification.

TABLE 9—COMPARISON OF PREDICTED AND ACTUAL GDP SHARES

Industry	Predicted values from equation (5)			Predicted values from equation (7)		
	Corr.	Intercept	Slope	Corr.	Intercept	Slope
Food	0.285	0.098 (1.52)	0.144 (4.22)	0.659	-0.044 (-0.88)	0.417 (12.10)
Apparel	0.315	0.116 (1.74)	0.288 (4.71)	0.976	-0.041 (-2.67)	1.168 (62.1)
Paper	0.378	-0.046 (-0.89)	0.682 (5.78)	0.886	-0.006 (-0.22)	0.764 (26.42)
Chemicals	-0.323	0.182 (1.96)	-0.306 (-4.83)	0.933	-0.024 (-0.67)	0.953 (35.9)
Glass	0.521	0.059 (2.30)	0.698 (8.66)	0.768	-0.012 (-0.62)	0.944 (16.6)
Metals	-0.235	-0.033 (-0.54)	-0.296 (-3.43)	0.698	-0.033 (-0.72)	0.941 (13.5)
Machinery	0.339	0.170 (0.96)	0.457 (5.10)	0.742	-0.005 (-0.04)	0.960 (15.3)

Notes: Fitted values  $\hat{S}_{jct}$  are formed by applying the estimated coefficients from Tables 5 and 6 to the explanatory variables after each explanatory variable has had time means removed. Actual GDP shares  $S_{jct}$  also have time means removed. Time means are removed by keeping the residuals from regressions of each variable on the set of year dummies. The column "corr." reports the correlation between  $\hat{S}_{jct}$  and  $S_{jct}$  for each industry  $j$ , and the columns "intercept" and "slope" report the estimated coefficients and  $t$ -statistics from the regression of  $S_{jct}$  on  $\hat{S}_{jct}$  for each industry  $j$ .

While the paper does not explicitly address trade, the implications for trade are immediate: to the extent that countries have similar tastes, the inferences about the determinants of a country's production pattern found here will translate into inferences about the country's trade pattern.<sup>13</sup> The results of this paper do not necessarily conflict with Treffer's (1995) result that the factor content of a country's net trade is approximately equal to its effective excess factor supplies. Treffer showed that for aggregate calculations about the factor content of trade it is reasonable to abstract from non-neutral technology differences by assuming that each country's factor requirement matrix<sup>14</sup> is a scalar multiple of the U.S. matrix. What the current paper shows is that nonneu-

tral technology differences *are* important for explaining specialization. One difficulty in comparing Treffer's paper to this one is that the effective factor content of trade is not well defined when there are nonneutral technology differences across sectors: when a country's factor requirements matrix cannot be expressed as a scalar multiple of the U.S. matrix, the measured factor content of trade will depend on which factor requirements matrix is used in the calculation.

This paper has been primarily concerned with testing the neoclassical theory of international specialization, but it has implications for empirical modelers and policy makers as well as theorists. For empirical modelers using the neoclassical framework, the message is that some of the defects of the Heckscher-Ohlin model can be remedied by consideration of Hicks-neutral technology differences. For policy makers, the message is that both factor supply and technology differences have important impacts on a country's pattern of specialization in the global economy, and that these factors must be considered jointly when

<sup>13</sup> Similarity in tastes may explain why the results of this paper are consistent with Leamer's (1984) estimates of the effects of factor endowments on net exports, as noted in the previous section.

<sup>14</sup> That is, the  $A$  matrix in the usual statement of the factor market-clearing conditions,  $Ax = v$ .

formulating policies intended to effect the structure of production and trade.

A final contribution of the paper is that it has demonstrated that the dual approach to general equilibrium theory can greatly simplify cross-country empirical analysis in trade models, especially when panel data is available. The dual approach has been used extensively in time-series analysis of trade models, especially by Kohli (1991), but has not been applied to a panel of countries before.

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### **The Case of the Missing Trade and Other Mysteries**

Daniel Trefler

*The American Economic Review*, Vol. 85, No. 5. (Dec., 1995), pp. 1029-1046.

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