WP/04/23

IMF Working Paper

Trade Patterns Among Industrial Countries: Their Relationship to Technology Differences and Capital Mobility

Mika Saito

INTERNATIONAL MONETARY FUND

 WP/04/23

IMF Working Paper

IMF Institute

Trade Patterns Among Industrial Countries: Their Relationship to Technology Differences and Capital Mobility

Prepared by Mika Saito[1]

Authorized for distribution by Sunil Sharma

February 2004

Abstract

This paper compares two alternative measures of technology differences across industrial countries during 1970-92: one measures differences in labor productivity (the Ricardian measure), and the other differences in total factor productivity (the Hicksian measure). The distinction between the two measures is important to the extent that trade patterns are inconsistent with comparative advantage revealed by the Hicksian measure, but not necessarily with that by the Ricardian measure. The distinction becomes more important in the period with high capital mobility across countries.

JEL Classification Numbers: F11, F14, C51, C52, D24

Keywords: comparative advantage, total factor productivity, labor productivity, capital mobility, neoclassical trade model.

Author's E-Mail Address: msaito@imf.org

[1] I would like to thank Jeffrey Bergstrand, George Jakubson, Ronald Jones, Keith Maskus, Peter Pedroni, Erik Thorbecke, Ichiro Tokutsu, Henry Wan, Jr., Ping Wang, and participants at the Western Economic Association Meeting in San Diego, the Empirical Investigation in International Trade Conference at Purdue University, the World Congress of the Econometric Society, and seminars at Cornell University, and the IMF Institute for their support and comments. All remaining errors are mine.

Contents Page

I. Introduction

Recent papers such as Bowen, Leamer, and Sveikauskas (1987), Trefler (1993, 1995), Harrigan (1997), Davis and others (1997), and Davis and Weinstein (2001) have emphasized the importance of cross-country differences in technology in explaining trade patterns within the Heckscher-Ohlin framework. Despite the growing interest in technology differences across countries, the choice of the measure of technology differences has received little attention in the literature. In particular, one has a choice between cross-country differences in total factor productivity (the *Hicksian measure*) and those in labor productivity (the *Ricardian measure*).[2]

Although it has been more standard to measure technology differences with the former than the latter, if capital is allowed to move across countries in a two-factor model of the Heckscher-Ohlin type, then the latter, which is more easily measured, can be used as an alternative measure to summarize the supply side of the economy. For example, Kemp (1966) and Jones (1967) showed that if capital is mobile across countries and technology differs across countries, then trade patterns can be summarized by cross-country differences in labor productivity (see Ruffin, 1984, for more discussions). Given the well-established evidence of high capital mobility across industrial countries since the mid-1980s (Graham and Krugman, 1993), examining the role of the Ricardian measure in comparison with the Hicksian measure in explaining trade patterns is an important exercise.

This paper shows that trade patterns are inconsistent with comparative advantage revealed by the Hicksian measure, but not necessarily with that by the Ricardian measure. This result holds regardless of the different estimators used to obtain the total factor productivity (TFP) differences; two estimators used in this paper are the panel fully modified ordinary least squares (panel FMOLS) estimator of Pedroni (2000) and the three-stage least squares (3SLS) estimator of Boskin and Lau (1992).

II. Literature Review

Recent papers in the international trade literature have found that one of the key requirements for finding evidence supportive of the Heckscher-Ohlin model is to allow for cross-country differences in technology. For example, Bowen, Leamer, and Sveikauskas (1987), using data on 12 resources and the trade of 27 countries in 1967, showed that the Heckscher-Ohlin-Vanek (HOV) equations are rejected in favor of weaker models that allow for technological differences and measurement error. Trefler (1993) allowed for factor-augmenting international productivity differences in the HOV model and showed that this modification can explain much of the factor content of trade. Trefler (1995), using 1983 data for 33 countries and 9 factors, rejected the Heckscher-Ohlin model in favor of alternative models that took account of

---

[2] A difference in labor productivity is called the *Ricardian measure* in this paper since it is the concept offered by Ricardo (1817). A difference in total factor productivity is called the *Hicksian measure* since the "neutrality" of technological differences discussed here is the one offered by Hicks (1932), in which the capital-labor ratio remains unaltered at a constant ratio of factor prices. See Jones (1965) for more discussions on different concepts of "neutrality" in technological change.

international technology differences and home bias in consumption. Maskus and Webster (1995) looked at differences in technology and consumption behavior between two countries (the United States and the United Kingdom), but for a finer disaggregation of factors; they also rejected the Heckscher-Ohlin theorem in favor of alternative models. Harrigan (1997) found differences in both relative technology and endowment differences to be important determinations of specialization. He used TFP to capture cross-country differences in technology among industrial countries. Davis and others (1997) showed that, when one controls for technology differences across countries, the Heckscher-Ohlin model performs much better empirically; they showed this using interregional trade in Japan. Most recently, Davis and Weinstein (2001) demonstrated in the most comprehensive manner that the HOV theory, when modified to permit technical differences, a breakdown in factor price equalization, and the existence of nontraded goods and costs of trade, is consistent with data from 10 OECD member countries and a rest-of-world aggregate. In all of these studies, one of the key elements in explaining the pattern of trade is cross-country differences in technology.

III. Two Measures of Technology Differences

A. The Ricardian Measure

Denote the price of a good in a given country by p_{it}^m, where superscript m (or n) represents countries and subscript i (or j) stands for goods. The law of comparative advantage says that if

$$\frac{p_{it}^m}{p_{jt}^m} < \frac{p_{it}^n}{p_{jt}^n}, \tag{1}$$

then country m must export good X_i, if trade exists at time t.[3]

The Ricardian model (Ricardo, 1817) assumes that production is a function of a single factor, labor. Therefore, if $p_{it}^m = c_{it}^m$, where c_{it}^m is a unit cost of producing good i in country m, then

$$p_{it}^m = c_{it}^m = w_{it}^m \frac{l_{it}^m}{X_{it}^m}, \tag{2}$$

where w_{it}^m, l_{it}^m, and X_{it}^m are the wage rate, labor, and output, respectively. The Ricardian theorem of comparative advantage says that if

$$\frac{w_{it}^m \frac{l_{it}^m}{X_{it}^m}}{w_{jt}^m \frac{l_{jt}^m}{X_{jt}^m}} < \frac{w_{it}^n \frac{l_{it}^n}{X_{it}}}{w_j^n \frac{l_{jt}^n}{X_{jt}^n}}, \tag{3}$$

then country m exports good X_i, if trade exists. Typically, the Ricardian model treats a labor input requirement, $\frac{l_i^m}{X_i^m}$, as a constant, a_{Li}^m. It also assumes that the labor market clears in each country, and hence that wage rates are equal across sectors; for example, $w_i^m = w_j^m$. Thus equation (3) is often expressed as $\frac{a_{Li}^m}{a_{Lj}^m} < \frac{a_{Li}^n}{a_{Lj}^n}$. Since factor prices are not necessarily equalized in the real world,

[3]Of course, in the case of more than two goods and two factors, only a much weaker law, the general law of comparative advantage (Deardorff, 1980) holds. The general law states that the relationship between the relative autarkic prices and trade holds only *on average*.

we define and compute *the Ricardian measure of technology differences* as follows:

$$\mathbf{RICARDO}_{ijt}^{mn} = \ln \frac{w_{it}^{m} \frac{l_{it}^{m}}{X_{it}^{m}}}{w_{j}^{m} \frac{l_{j}^{m}}{X_{j}^{m}}} - \ln \frac{w_{it}^{n} \frac{l_{it}^{n}}{X_{it}}}{w_{jt}^{n} \frac{l_{jt}^{n}}{X_{jt}^{n}}}. \tag{4}$$

If $\mathbf{RICARDO}_{ijt}^{mn}$ is negative, then country m has comparative advantage in producing goods in sector i and thus exports good X_i to country n.

This *Ricardian measure* is computed for every bilateral combination of 14 OECD member countries m and n for 10 sectors at the two-digit International Standard Industrial Classification (ISIC) level for 1970-92 using production data from the International Sectoral Data Base.[4] Details of the data used in this study are discussed in Section V.

B. The Hicksian Measure

A component that is attributed to Hicks-neutral technological progress, called the *Hicksian measure*, is extracted from the Ricardian measure.

The extraction takes two steps. First, the Ricardian measure is decomposed into a relative labor productivity component and a relative wage component:

$$\begin{aligned} \mathbf{RICARDO}_{ijt}^{mn} &= \left(\ln \frac{\frac{X_{jt}^{m}}{l_{jt}^{m}}}{\frac{X_{jt}^{n}}{l_{jt}^{n}}} - \ln \frac{\frac{X_{it}^{m}}{l_{it}^{m}}}{\frac{X_{it}^{n}}{l_{it}^{n}}} \right) + \left(\ln \frac{w_{it}^{m}}{w_{it}^{n}} - \ln \frac{w_{jt}^{m}}{w_{jt}^{n}} \right) \qquad (5) \\ \text{or} \quad &= \left(\Delta \ln \frac{X_{jt}}{l_{jt}} - \Delta \ln \frac{X_{it}}{l_{it}} \right) + \left(\Delta \ln w_{it} - \Delta \ln w_{jt} \right), \end{aligned}$$

where $\Delta \ln \frac{X_{it}}{l_{it}} \left(= \ln \frac{X_{jt}^{m}}{l_{jt}^{m}} - \ln \frac{X_{jt}^{n}}{l_{jt}^{n}} \right)$ is the cross-country difference in labor productivity in sector i expressed in percentage terms at time t, and $\Delta \ln w_{it}\,(= \ln w_{it}^{m} - w_{it}^{n})$ is the cross-country difference in wage rates in sector i expressed in percentage terms at time t. Notice that the first term captures the *relative* labor productivity differences across countries and the second term the *relative* wage rate differences across countries.

To extract the Hicksian measure $\mathbf{HICKS}_{ijt}^{mn}$ from the first term of equation (5), we estimate the production function described as follows:

$$\ln \frac{X_{it}^{c}}{l_{it}^{c}} = \ln X_{0i} + \ln A_{i}^{c} + \lambda_{i}^{c} \cdot t + \alpha_{ki} \ln \frac{k_{it}^{c}}{l_{it}^{c}} + \ln u_{it}^{c}, \tag{6}$$

where $c = m$ or n. Notice that A_i^c and λ_i^c are *country-specific* technological parameters, respectively. A_i^c captures differences in the initial level of technology across countries (relative

---

[4]The two-digit ISIC is certainly not the finest disaggregation available. Particularly in recent years, trade data at the three-digit classification have become more common. This paper, however, faces a data constraint in the sector-level capital input data, which are needed to estimate production functions and thus to obtain the Hicksian measure of technology differences. Harrigan (1997, 1999) faces the same data constraints. This paper, therefore, will not be able to address issues related to product mix changes or quality mix changes that most likely have taken place within the two-digit classification among countries and across time.

to that of a particular country X_{0i}), and λ_i^c captures differences in the rate of technical progress across countries. k_{it}^c and l_{it}^c are *country-specific* capital and labor inputs, respectively. α_{ki} is without a country superscript, indicating that this technological parameter is commonly shared across countries.[5] $\ln u_{it}^c$ is the disturbance term, capturing unobservable productivity shocks.

This specification makes two implicit assumptions. First, technological progress is Hicks-neutral across factors (capital and labor) within each sector. This assumption is implied by the common shift parameter A_i^c and the common rate of technical progress λ_i^c for both factors, capital and labor. Second, technological progress is not necessarily Hicks-neutral across sectors. This assumption is revealed by allowing for $A_i^c \neq A_j^c$ and $\lambda_i^c \neq \lambda_j^c$.

With the estimates of parameters, the cross-country difference in labor productivity $\Delta \ln \frac{X_{it}}{l_{it}}$ for each sector i at time t (in percentage terms) can be decomposed as follows:

$$\Delta \ln \frac{X_{it}}{l_{it}} = \Delta \ln A_i + \Delta \lambda_i \cdot t + \alpha_{ki} \Delta \ln \frac{k_{it}}{l_{it}} + \Delta \ln u_{it}. \tag{7}$$

Notice that $\Delta \ln A_i (= \ln A_i^m - \ln A_i^n)$ and $\Delta \lambda_i (= \lambda_i^m - \lambda_i^n)$ together capture cross-country differences in technology. $\Delta \ln \frac{k_{it}}{l_{it}} (= \ln \frac{k_{it}^m}{l_{it}^m} - \ln \frac{k_{it}^n}{l_{it}^n})$ represents cross-country differences in factor intensity, and $\Delta \ln u_{it} (= \ln u_{it}^m - \ln u_{it}^n)$ represents cross-country differences in unobservables.

Together with the first step of the decomposition in equation (5), the Ricardian measure (aside from the unobservables) is decomposed into the following two components:

$$\mathbf{RICARDO}_{ijt}^{mn} = \mathbf{HICKS}_{ijt}^{mn} + \mathbf{CAP}_{ijt}^{mn}, \tag{8}$$

where

$$\mathbf{HICKS}_{ijt}^{mn} = (\Delta \ln A_j - \Delta \ln A_i) + (\Delta \lambda_j - \Delta \lambda_i) \cdot t \tag{9}$$

$$\mathbf{CAP}_{ijt}^{mn} = \left(\alpha_{kj} \Delta \ln \frac{k_{jt}}{l_{jt}} - \alpha_{ki} \Delta \ln \frac{k_{it}}{l_{it}} \right) + (\Delta \ln w_{it} - \Delta \ln w_{jt}). \tag{10}$$

IV. Relationships Between the Two Measures: Theory

When there is an *exogenous* and *observable* change in technology in a world with capital mobility across countries, one can show that the Hicksian measure captures cross-country differences in *relative productivity,* whereas the Ricardian measure captures those in *relative prices*, which reflect differences in both relative productivity and relative factor intensity across countries.

Consider a $2 \times 2 \times 2$ model with capital mobility and technology differences across countries. That is, there are two countries, home country m and foreign country n; two factors, labor and capital; and two goods, a labor-intensive good X_i (a numeraire good) and a capital-intensive good X_j.

[5] This assumption is tested in Section V.

Suppose that two countries are identical initially, so that neither has comparative advantage in either sector. We focus on a one-period change in the home country by assuming that the foreign country remains unchanged.[6]

Let $a_{Li}(=\frac{l_i}{X_i})$ and $a_{Ki}(=\frac{k_i}{X_i})$ denote the labor and capital requirements, respectively, for good i. When two goods are both produced, we know that competitive pricing requires

$$\begin{aligned} a_{Li}w + a_{Ki}r &= 1 \\ a_{Lj}w + a_{Kj}r &= p, \end{aligned} \tag{11}$$

where w and r are wage rates and rental rates, respectively. Note that w and r no longer have sector subscripts as in the earlier section. p is the price of the capital-intensive good X_j relative to that of the labor-intensive good X_i.

Let θ_{Li} and θ_{Ki} be the labor cost share and the capital cost share, respectively. For example, $\theta_{Li} = a_{Li}w$ and $\theta_{Lj} = \frac{a_{Lj}w}{p}$. By totally differentiating equation (11) and letting carets indicate a proportionate change in a variable, we obtain

$$\begin{aligned} \theta_{Li}\hat{w} + \theta_{Ki}\hat{r} &= \pi_i \\ \theta_{Lj}\hat{w} + \theta_{Kj}\hat{r} &= \pi_j + \hat{p}, \end{aligned} \tag{12}$$

where $\pi_i = -(\theta_{Li}\hat{a}_{Li} + \theta_{Ki}\hat{a}_{Ki})$ is the factor-weighted rate of technical progress in sector i.[7]

Provided that both goods are produced before and after, the evolution in factor returns can be obtained by solving equation (12) for $\hat{w}$ and $\hat{r}$, and therefore the percentage change in the wage-rental ratio $\frac{\hat{w}}{r}$ and that in the price of capital-intensive goods $\hat{p}$ take the form

$$\frac{\hat{w}}{r} = \frac{\pi_i - \pi_j - \hat{p}}{\theta} \tag{13}$$

$$\hat{p} = \frac{\theta_{Lj}\pi_i - \theta_{Li}\pi_j}{\theta_{Li}}, \tag{14}$$

where $\theta = \theta_{Li} - \theta_{Lj} = \theta_{Kj} - \theta_{Ki} > 0$.[8]

In this simple framework, the Hicksian measure in equation (9), the capital-intensity component in equation (10), and therefore the Ricardian measure in equation (8) can be expressed as follows:[9]

$$\mathbf{HICKS}_{ij} = \pi_j - \pi_i, \tag{15}$$

$$\mathbf{CAP}_{ij} = \pi_i - \pi_j - \hat{p}, \tag{16}$$

$$\mathbf{RICARDO}_{ij} = \mathbf{HICKS}_{ij} + \mathbf{CAP}_{ij} = -\hat{p}. \tag{17}$$

[6]These assumptions are made so that a comparison of relative productivity differences (for example, productivity in the capital-intensive goods sector relative to the labor-intensive goods sector) between the home and the foreign countries at a given time can be equivalently carried out by focusing on changes in the level of technology in the home country relative to the initial level (that is, the level of technology in the foreign country).

[7]If we assume Hicks-neutral technical progress (that is, assume the same technical progress in both factors, $\hat{a}_{Li} = \hat{a}_{Ki}$), then we have $\pi_i = -\hat{a}_{Li} = -\hat{a}_{Ki}$.

[8]See Appendix II for the derivation.

[9]See Appendix II for the derivation.

Equation (15) shows that the Hicksian measure captures comparative advantage through cross-country differences in *relative productivity*. If an increase in the rate of technical progress is higher in the capital-intensive good sector ($\pi_j > \pi_i$) in country m (and country n remains unchanged), then the Hicksian measure will be positive, implying that country m has comparative advantage over country n in producing the capital-intensive good X_j.

Equation (16), which can also be expressed as $\mathbf{CAP}_{ij} = \frac{\theta}{\theta_{Li}}\pi_i$, shows that the sign of the capital-intensity component depends only on the rate of technical progress in the labor-intensive goods sector (the sector that uses the immobile factor more intensively).[10] The intuition is as follows. When capital is mobile across countries, the cost of capital inputs is constant. Thus, even if the capital-intensive good sector becomes more productive, the relative price of factors (and therefore the factor intensity) remains unchanged. When the labor-intensive goods sector becomes more productive, however, labor inputs become relatively more expensive, and hence both sectors become more capital intensive.

Finally, equation (17) shows that the Ricardian measure captures comparative advantage through cross-country differences in *relative prices*, which reflect both cross-country differences in relative productivity and those in relative capital intensity. For example, when the relative price of the capital-intensive good falls ($\hat{p} < 0$) in country m (and that in country n remains unchanged), the Ricardian measure is positive, implying that the home country has comparative advantage over the foreign country in producing the capital-intensive good.

Notice that the sign of the Ricardian measure (which is given by $-\hat{p} \gtreqless 0$ or, alternatively, $\frac{\pi_j}{\theta_{Lj}} \gtreqless \frac{\pi_i}{\theta_{Li}}$) and that of the Hicksian measure (which is given by $\pi_j \gtreqless \pi_i$) do not necessarily coincide. For example, when the sectoral bias in technical progress is toward the capital-intensive goods sector ($\pi_j > \pi_i > 0$), the Ricardian and the Hicksian measures both take a positive value because $\theta_{Lj} < \theta_{Li}$. When the sectoral bias in technical progress is toward the labor-intensive goods sector ($\pi_i > \pi_j > 0$), however, it is not clear whether both measures take a negative value. The Hicksian measure would always be negative, but the Ricardian measure would be negative if and only if the relative price of the labor-intensive good is actually falling.[11]

V. Issues in the Empirical Analysis

A. Econometric Issues

The econometric estimation of the technological parameters of production functions is necessary to extract the Hicksian measure from the Ricardian measure as discussed in Section II. A problem arises in estimating the industry-level production function in equation (6) because of the possible correlation between the regressor $\ln \frac{k_{it}^c}{l_{it}^c}$ and the disturbance term $\ln u_{it}^c$.[12] Such correlation is likely for two reasons: measurement error especially in capital inputs k_{it}^c, and a

[10]See Appendix II for the derivation.
[11]Other possibilities besides $\pi_j > \pi_i > 0$ and $\pi_i > \pi_j > 0$ are discussed in Appendix II.
[12]Harrigan (1999) discusses this issue.

possible simultaneity between unobservable productivity shocks u_{it}^c and the choice of factor inputs k_{it}^c and l_{it}^c.

Two solutions will be implemented. One is to use an instrumental variable (IV) estimator. Specifically, the three-stage least squares (3SLS) estimator used in Boskin and Lau (1992), which introduces instrumental variables into a system of equations, is used.[13] The other is to use the panel fully modified ordinary least squares (FMOLS) estimator (Pedroni, 2000). This estimator is the panel version of the Phillips and Hansen (1990) procedure.[14] Although the parameter estimates obtained from these two estimators are somewhat different, the qualitative results of the paper do not change with the choice of estimators.

B. Difficulties in Testing the Law of Comparative Advantage

To compare the Ricardian and the Hicksian measures in terms of how well they can explain trade patterns, this paper attempts to test the law of comparative advantage using these two measures. There are two difficulties in doing so.

First, applying the law of comparative advantage in a higher dimension than the $2 \times 2 \times 2$ world is difficult; see Drabicki and Takayama (1979) and Dixit and Norman (1980). We therefore refer to the general law of comparative advantage suggested by Deardorff (1980). This weaker version of the law is unable to predict the direction of movement of a particular good or factor or a particular country, but it is able to predict the direction of trade *on average*. Specifically, the null hypothesis to test is

$$H_0 : correlation(P^a, E) \leqslant 0, \tag{18}$$

where P^a is a column vector containing *autarky prices* (normalized to a unit simplex) for all countries and industries, and E is a column vector containing net exports for all countries and industries arranged in the same order as in P^a.

Second, a more serious limitation is in finding data in autarky.[15] As a second-best solution,

[13] The standard shortcoming with the family of IV estimators is lack of valid instruments. Input prices (for example, energy prices) are good candidates for instruments for the aggregate production function, since they are typically correlated with the choice of capital and labor inputs at the country level but are independent of unobservable productivity shocks. Such instruments become harder to obtain as the data become more disaggregated. For example, input prices that vary across firms are virtually impossible to find. Thus, for studies using firm-level data, the literature suggests an alternative method of IV estimation, where a proxy (which controls for part of the error correlated with input choices) is included in the estimation equation, see Olley and Pakes (1996) and Levinsohn and Petrin (2000). For the estimation of the industry-level production functions, however, the IV estimator with instruments proposed by Boskin and Lau (1992) can be a valid solution.

[14] More specifically, this method fully modifies the OLS estimates (and hence eliminates the possible simultaneity biases) by transforming the residual term in equation (6) and subtracting off a parameter that can be constructed from the estimated nuisance parameters and a term from the original data; see Pedroni (2000) for more details.

[15] Bernhofen and Brown (2001) use data from the postliberalization (autarky) period of Japan,

we test the following condition:

$$H_0 : correlation(P^c, E) \leqslant 0, \tag{19}$$

where P^c is a column vector containing the prices paid (if importing) or received (if exporting) by domestic traders (normalized to a unit simplex).[16]

A rejection of equation (19) implies a rejection of equation (18) since the latter holds if and only if condition (19) and the remaining feasibility, maximal, and preferred assumptions made in Deardorff (1980) are satisfied. Not rejecting condition (19), however, does not imply not rejecting condition (18) and hence the test results must be interpreted cautiously.

C. Data

Industry data at the two-digit ISIC level are taken from the International Sectoral Data Base. The 14 OECD member countries included are Australia, Belgium-Luxembourg, Canada, Denmark, France, Finland, (West) Germany, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the United States. The abbreviations and descriptions of the data are given in Table 1. This table also shows how trade data at the two-digit Standard International Trade Classification (SITC) taken from the OECD's International Trade by Commodities Statistics are matched with the production data. The details of the data used for each variable in this study are given in Appendix I (see p.15).

To use the panel FMOLS estimator, both variables in equation (6), $\ln \frac{X_{it}^c}{l_{it}^c}$ and $\ln \frac{k_{it}^c}{l_{it}^c}$, must be nonstationary. Results of unit root tests on these variables are reported in Tables 2 and 3, respectively. The group mean unit root test of Im, Pesaran, and Shin (1997) is used, since it has an advantage over the pooled unit root test in that, under the alternative hypothesis, the autoregressive parameter is not required to be the same among different countries in the panel. The t-bar statistics reported in Tables 2 and 3 show that the null of a unit root cannot be rejected for $\ln \frac{X_{it}^c}{l_{it}^c}$ and $\ln \frac{k_{it}^c}{l_{it}^c}$ in all sectors, except for $\ln \frac{X_{it}^c}{l_{it}^c}$ in agriculture.

In addition to the nonstationarity of $\ln \frac{X_{it}^c}{l_{it}^c}$ and $\ln \frac{k_{it}^c}{l_{it}^c}$, there must be a cointegrating relationship between the two in order to apply the panel FMOLS estimator. The cointegration between the two variables is therefore tested using the group mean cointegration tests (Pedroni, 1999), and the test results are reported in Table 4. As with the group mean unit root tests, the group

1868-1872, to test the general law of comparative advantage. We, however, do not observe data in autarky.

[16]Alternatively, condition (19) can be rewritten as

$$\sum_{cc' \in COMB} \left(\sum_{i=1}^{10} p_i^{cc'} nx_i^{cc'} \right) \leqslant 0,$$

where $nx_i^{cc'}$ are bilateral net exports from country c to country c', $p_i^{cc'}$ are cross-country differences in relative prices between two countries, which will be proxied by the Ricardian and Hicksian measures, and $COMB$ is a set of bilateral country combinations, where the number of elements is given by the binomial coefficient $\binom{14}{2}$ for the sample of 14 industrial countries.

mean cointegration tests have an advantage over pooled tests in that they allow the autoregressive parameter in the estimated residuals to be heterogeneous under the alternative. The group mean test statistics in Table 4 show that the null of no cointegration is rejected by at least one test statistic in all industries, except for textiles and machinery and equipment.[17] The cointegration relationship between the left-hand side and the right-hand side of equation (6) confirms that we can use the FMOLS estimator to take care of the endogeneity problem.[18]

The instrumental variables, provided by Boskin and Lau (1992), are the relative price of cotton to wheat, the relative price of oil to wheat, the relative price of iron to wheat, world population, male population, female population, arable land, permanent crops, male life expectancy, and female life expectancy.

Finally, our sample size (14 countries, 10 industries, and 23 years) implies that the Ricardian measure $\mathbf{RICARDO}_{ijt}^{mn}$ is computed for $\binom{14}{2}$ combinations of countries for each of $\binom{10}{2}$ combinations of industries for 23 years. That is, there are $94,185 = 91 \times 45 \times 23$ observation points. Each of them is decomposed into three components: the Hicksian measure $\mathbf{HICKS}_{ijt}^{mn}$, the capital-intensity component $\mathbf{CAP}_{ijt}^{mn}$, and the residuals. Moreover, to avoid choosing an arbitrary sector as a numeraire, for each sector i we compute $\mathbf{RICARDO}_{it}^{mn}$ by taking an average over all $j \neq i$, that is, $\mathbf{RICARDO}_{it}^{mn} = \frac{1}{14-1}\sum_{j \neq i}\mathbf{RICARDO}_{ijt}^{mn}$ (which reduces the observation points to $20,930 = 91 \times 10 \times 23$). $\mathbf{HICKS}_{it}^{mn}$ and $\mathbf{CAP}_{it}^{mn}$ are computed in the same manner.

VI. Empirical Findings

A. Estimates of Structural Parameters

The panel FMOLS estimates of the structual parameters are presented in Table 5. There are a few points to note on these estimates. First, the mean of the rate of technical progress λ_i is 0.006, which is relatively low for the industrialized countries during this period.

Second, the average of the group mean FMOLS estimates for α_{ki} across 10 sectors is 0.50, which seems to represent a reasonable capital cost share. Individual estimates for α_{ki} however are hard to interpret. For example, in the mining and basic metals products industries, estimates for α_{ki} exceed 1, and that in the nonmetallic mineral products industry takes a negative value.

Third, the assumption that α_{ki} is common to all the countries in the sample is tested for the panel FMOLS estimates. The null hypothesis cannot be rejected for all sectors except the agriculture and nonmetallic mineral products industries.

---

[17]Pedroni (1999) shows that, in short samples, the group mean augmented Dickey-Fuller (ADF) test often has the most power, which explains why the group mean ADF test is able to reject the null more often than the others.

[18]One needs to be careful in interpreting estimates for the textiles and machinery and equipment industries since the null of no cointegration is not rejected in these industries.

The parameter estimates using the 3SLS estimator (Boskin and Lau, 1992) are presented in Table 6. The estimates for the rate of technical progress (the average of λ_i^c for each industry i) are on average 4.0 percent. These estimates are much more reasonable than in the case of the FMOLS estimates. Some of the individual estimates, however, are again hard to interpret.

B. Case Study: Japan Versus the United States

To provide an example of the actual values computed for the Ricardian and the Hicksian measures, Table 7 presents these measures for the Japanese industries relative to the corresponding U.S. industries for 1970 and 1990. In other words, $\mathbf{RICARDO}_{it}^{mn}$ in this particular case study is computed for $m =$ Japan, $n =$ the United States, $i =$ industries listed in the first column of the table, and $t = 1970$ or 1990.

The Ricardian measure The Japanese textile and basic metals industries (such as steel) became competitive and began to enjoy comparative advantage over the United States in the 1960s. This phenomenon can be observed in the negative signs on the Ricardian measure in 1970: the Ricardian measure for the textile industry is -0.241, and that for the basic metals industry is -0.113. The magnitude is expressed in natural logarithms, so that these values imply that the corresponding relative unit labor costs in Japan were 78 and 89 percent of those in the United States, respectively. Machine tools, autos, videos, semiconductors, and other products belonging to the machinery and equipment industry still had comparative disadvantage in the early 1970s. The Ricardian measure in the machinery industry in 1970, 0.517, indicates that the relative unit labor cost in Japan was approximately 1.677 times as high as that in the United States.

During the 1970s and 1980s, some Japanese industries such as the food products and the textile industries lost comparative advantage. The Ricardian measures for these industries in 1990 are 0.171 and 0.241, respectively. These values imply that the relative unit labor cost in the food products and the textile industries in Japan were approximately 1.186 and 1.273 times as high as those in the United States, respectively. On the other hand, the machinery and equipment industry began to enjoy comparative advantage by the beginning of the 1990s. The negative value, -0.070, indicates that the relative unit labor cost in Japan was 93.2 percent of that in the United States in this industry.

Two Subcomponents of the Ricardian measure Japan's comparative advantage in the textile industry in 1970 is not revealed in the Hicksian measure, indicating that the United States had comparative advantage over Japan as far as technology was concerned. Japan's comparative advantage in this industry in 1970 is, however, revealed in the capital-intensity component: the value of -0.523 for this component reveals that had technology been the same in the two countries, the relative unit labor cost in Japan would have been 59.3 percent of that in the United States because of the heavy use of capital inputs. The relatively higher allocation of capital in this industry is consistent with the industrial policies implemented during this period (Komiya, Okuno, and Suzumura, 1988).

In the case of the machinery and equipment industry in 1970, Japan's comparative disadvantage is also revealed in the Hicksian measure: the value of 0.992 implies that the relative unit labor cost in Japan was more than twice that in the United States, had capital intensity been the same in the two countries. What is revealed in the Ricardian and the Hicksian measures, however, is not revealed in the capital-intensity component. The relative capital intensity indicated by the capital-intensity component value of -0.475 reveals that had technology been the same in the two countries, the relative unit labor cost in Japan would have been 62.2 percent of that in the United States. This is again consistent with the industrial policies implemented during this period.

C. Relationships Between the Two Measures: Empirical Evidence

Here we examine the general tendency in the relationships between the Ricardian measure and the Hicksian measure. Specifically, we classify each observation into one of three cases. Case 1 is the case where the signs of $\mathbf{RICARDO}$, $\mathbf{HICKS}$, and $\mathbf{CAP}$ are the same (for example, when $\pi_j > \pi_i > 0$, the signs of all three are positive). Case 2 is the case where the signs of $\mathbf{RICARDO}$ and $\mathbf{HICKS}$ are the same, but not the sign of $\mathbf{CAP}$ (for example, when $\pi_j > 0 > \pi_i$, the two technology measures are positive, but because of the negative productivity in the labor-intensive good sector, the capital-intensity component is negative). Case 3 is the case where the two measures of technology differences are of opposite sign (for example, when $\pi_i > \pi_j > 0$, but $\frac{\pi_i}{\theta_{Li}} < \frac{\pi_j}{\theta_{Lj}}$, or $\hat{p} < 0$, the Hicksian measure is negative but the Ricardian measure is positive).[19]

Table 8 shows that approximately two-thirds of observations for the whole sample period belong to either case 1 or 2. That is, in two-thirds of the cases, comparative advantage revealed by the Ricardian measure and that by the Hicksian measure are not the same. With the panel FMOLS estimates the corresponding share is 61 percent, and with the 3SLS estimates it is 56 percent. Moreover, these shares tend to fall toward the period when capital becomes more mobile; with the panel FMOLS estimates, it falls from 65 percent in 1970 to 58 percent in 1990, and with the 3SLS estimates, it falls from 74 percent in 1970 to 52 percent in 1990.

D. Correlations Between the Two Measures and Net Exports

The fact that comparative advantage revealed by the two measures of technology differences coincide at most two-thirds of the time raises the question of which of the two is more closely related to trade patterns.

Table 9 presents the correlation coefficients between the technology measures and net exports. The first column presents the correlation coefficients between $\mathbf{RICARDO}$ and net exports. The second and third columns present those between $\mathbf{HICKS}$ and net exports (the difference between the two is the estimator used to obtain the parameters of the production functions). The sample period becomes 1970-90 instead of 1970-92 because the OECD trade data we use end in 1990.

The correlation coefficients in the first row in Table 9 are computed using the whole sample (that is, 91 bilateral country combinations, 23 years, and 10 industries). An asterisk next to a correlation coefficient indicates that it is statistically significant at the 5 percent level.

[19] See Appendix II for the full set of outcomes and of classifications.

The correlation coefficient between the Hicksian measure and net exports is positive and statistically significant at the 5 percent level. We therefore reject the general law of comparative advantage, since the rejection of condition (19) implies the rejection of condition (18). The correlation coefficient between the Ricardian measure and net exports, however, is negative with statistical significance at the 5 percent level and therefore we cannot reject condition (19). The rejection of the general law of comparative advantage therefore becomes questionable. What we find in the whole sample period (1970-90) is also found in 1990 but not in 1970 (see the second and third rows of Table 9).

Empirical evidence found in this paper implies that the weak relationship between comparative advantage revealed by TFP differences (the Hicksian measure) and trade patterns may not necessarily mean that the supply side of the economy cannot explain trade patterns. It may instead mean that comparative advantage should be captured by labor productivity differences (the Ricardian measure), especially in the period with high capital mobility across countries.

VII. Conclusion

We first showed that, in the simple $2 \times 2 \times 2$ model with capital mobility and technology differences across countries, the Ricardian measure exactly captures the change in the relative price of capital-intensive goods. Moreover, we showed that in theory the Hicksian measure does not have to coincide with the Ricardian measure. Empirically, we found that the two measures coincide only in half of the cases in the period when capital has become highly mobile across countries. The distinction between Hicksian and Ricardian is important to the extent that the general law of comparative advantage is rejected with the Hicksian measure, but not necessarily with the Ricardian measure.

Data

Industry-level output, X_{it}; capital, k_{it}^{c}; labor, l_{it}^{c}; labor share, $\frac{w_{it}^{c} l_{it}^{c}}{p_{it}^{c} X_{it}^{c}}$; and industry aggregate capital stock, K_{it}^{c}; for each industry *i*, country *c*, and time *t* are directly taken or computed from the International Sectoral Data Base. The variables used are as follows: value added at 1990 prices $GDPD_{it}^{c}$; gross capital stock at 1990 prices $KTVD_{it}^{c}$, number of employees EE_{it}^{c}, compensation of employees at current prices in national currency $WSSS_{it}^{c}$, and value added at current prices in national currency GDP_{it}^{c}. The variables, X_{it}, k_{it}^{c}, and l_{it}^{c} correspond to $GDPD_{it}^{c}$, $KTVD_{it}^{c}$, and EE_{it}^{c}, respectively. Labor cost shares are given by $\frac{WSSS_{it}^{c}}{GDP_{it}^{c}}$.

Net exports $nx_{it}^{cc'}$ is computed as the log difference of exports and imports between two countries *c* and *c'* from International Trade by Commodities Statistics, Rev. 2 Historical Data. Exports from country *c* to country *c'* are not necessarily the same as imports of country *c'* from country *c*. We therefore consistently use import data: $nx_{it}^{cc'} = \ln(imp_{it}^{cc'}) - \ln(imp_{it}^{c'c})$, where $imp_{it}^{cc'}$ is imports from *c* to *c'*. Moreover, trade data by two-digit SITC are matched with two-digit ISIC data as described in Table 1. For the trade data between SITCs 01 and 07, we use the three-digit SITC to separate nonprocessed and processed food products into agricultural products and food products, respectively.

The Kemp-Jones Model

The Wage-Rental Ratio and the Relative Price: The evolution in factor returns can be obtained by solving equation (12) for $\hat{w}$ and $\hat{r}$:

$$\hat{w} = \frac{\theta_{Kj}\pi_i - \theta_{Ki}(\pi_j + \hat{p})}{\theta} \tag{20}$$

$$\hat{r} = \frac{\theta_{Li}(\pi_j + \hat{p}) - \theta_{Lj}\pi_i}{\theta}, \tag{21}$$

where $\theta = \theta_{Kj}\theta_{Li} - \theta_{Ki}\theta_{Lj} = \theta_{Li} - \theta_{Lj} = \theta_{Kj} - \theta_{Ki} > 0.$

Equation (13) is derived by subtracting equation (21) from equation (20). Equation (14) is derived by setting $\hat{r} = 0$ in equation (21) under the perfect capital mobility assumption.

The Hicksian Measure: When two countries $c = m$ and n are identical initially at $t = 0$, we have $\Delta \ln A_j = \Delta \ln A_i = 0$ in equation (9). Moreover, when country m experiences technical progress in both sectors by π_j and π_i while country n experiences no technical progress at $t = 1$, we have $\Delta\lambda_j = \pi_j$ and $\Delta\lambda_i = \pi_i$ in equation (9). The Hicksian measure **HICKS**$_{ij}$ can therefore be expressed as in equation (15).

The Capital-Intensity Component: The capital-intensity component **CAP**$_{ij}$ (equation (10)) has two subcomponents, but the relative wage subcomponent is zero when labor is fully mobile across sectors. We therefore have **CAP**$_{ij} = \alpha_{kj}\Delta\ln\frac{k_{jt}}{l_{jt}} - \alpha_{ki}\Delta\ln\frac{k_{it}}{l_{it}}$ or alternatively **CAP**$_{ij} = \alpha_{kj}\frac{\hat{k}_{jt}}{l_{jt}} - \alpha_{ki}\frac{\hat{k}_{it}}{l_{it}}$. The percentage change in the capital-labor ratio equals the percentage change in the wage-rental ratio in both sectors; that is, $\frac{\hat{k}_i}{l_i} = \frac{\hat{k}_j}{l_j} = \frac{\hat{w}}{r} = \frac{\pi_i - \pi_j - \hat{p}}{\theta}$ (see equation (13)). Therefore, we have **CAP**$_{ij}$ **=** $\frac{\left(\alpha_{kj} - \alpha_{ki}\right)\left(\pi_i - \pi_j - \hat{p}\right)}{\theta}$. Notice that parameters α_{kj} and α_{ki} in equation (6) are capital cost shares, and therefore $\alpha_{kj} - \alpha_{ki}$ in the numerator and $\theta\left(= \theta_{Kj} - \theta_{Ki}\right)$ in the denominator cancel out, and we therefore have equation (16). By substituting $\hat{p}$ in equation (16) with $\hat{p}$ in equation (14), **CAP**$_{ij}$ can also be expressed as **CAP**$_{ij} = \frac{\theta}{\theta_{Li}}\pi_i$.

Relationships Between the Two Measures: A full set of relationships between the Ricardian and the Hicksian measures of technology differences is presented in Table 10. The last two columns indicate the correlation coefficients between **RICARDO** and **HICKS** and those between **RICARDO** and **CAP**, respectively.

Table 1. Concordance Between Industry Data (ISDB) and Trade Data (ITCS)

International Sectoral Data Base (ISDB) at the two-digit ISIC level				International Trade by Commodities Statistics (ITCS) at the two-digit SITC level	
1	Agriculture, hunting, forestry, and fishing (AGR)	11	Agriculture	00	Live animals chiefly for food
				01	Meat and meat preparations 1/
				02	Dairy products and birds' eggs 1/
				04	Cereals and cereal preparations 1/
				05	Vegetables and fruit 1/
				06	Sugar, sugar preparations, and honey 1/
				07	Coffee, tea, cocoa, spices, and manufactures thereof 1/
				29	Crude animal and vegetable materials, n.e.s.
		12	Forestry and lodging		
		13	Fishing	03	Fish, crustaceans, molluscs, and preparations thereof 1/
2	Mining and quarrying (MID)	21	Coal mining	32	Coal, coke, and briquettes
		22	Crude petroleum and natural gas production	33	Petroleum, petroleum products, and related materials
				34	Gas, natural and manufactured
		23	Metal ore mining and other mining	35	Electric current
31	Manufacturing of food, beverages, and tobacco (FOD)	311/312	Food manufacturing	01	Meat and meat preparations 1/
				02	Dairy products and birds' eggs 1/
				03	Fish, crustaceans, molluscs, and preparations thereof 1/
				04	Cereals and cereal preparations 1/
				05	Vegetables and fruit 1/
				06	Sugar, sugar preparations, and honey 1/
				07	Coffee, tea, cocoa, spices, and manufactures thereof 1/
				08	Feeding stuff for animals, excluding unmilled cereals
				09	Miscellaneous edible products and preparations
				22	Oil seeds and oleaginous fruit
				4	Animal and vegetable oils, fats, and waxes
		313	Beverage industries	11	Beverages
		314	Tobacco manufactures	12	Tobacco and tobacco manufactures
32	Textiles, wearing apparel, and leather industries (TEX)	321	Manufacture of textiles	21	Hides, skins and fur skins, raw
		322	Manufacture of wearing apparel except footwear	26	Textile fibers (except wool tops) and their wastes
				65	Textile yarn, fabrics, made-up articles, and related products
				84	Articles of apparel and clothing accessories
		323	Manufacture of leather and products of leather	61	Leather, leather manufactures, n.e.s., and dressed fur skins
		324	Manufacture of footwear	85	Footwear
34	Manufacturing of paper, and paper products (PAP)	341	Manufacture of paper and paper products	25	Pulp and waste paper
				64	Paper, paperboard, articles of paper, and paper-pulp/board
		342	Printing and publishing		

Source: Created by author.

Table 1. (Continued) Concordance Between Industry Data (ISDB) and Trade Data (ITCS)

International Sectoral Data Base (ISDB) at the two-digit ISIC level			International Trade by Commodities Statistics (ITCS) at the two-digit SITC level
35 Manufacturing of chemicals and of chemical, petroleum, coal, rubber, and plastic rubber products (CHE)	351/352	Manufacture of industrial chemicals and other chemical products	27 Crude fertilizers and crude materials (excluding coal)
	353/354	Petroleum refineries and manufacture of miscellaneous products of petroleum, and coal	5 Chemicals and related products, n.e.s.
	356	Manufacture of plastic products	
	355	Manufacture of rubber products	23 Crude rubber (including synthetic and reclaimed) 62 Rubber manufactures, n.e.s.
36 Manufacturing of nonmetallic products, except petroleum and coal products (MNM)	361	Manufacture of pottery, china, and earthenware	66 Nonmetallic mineral manufactures, n.e.s.
	362	Manufacture of glass and glass products	
	369	Manufacture of other nonmetallic mineral products	
37 Basic metal industries (BMI)	371	Iron and steel basic industries	28 Metalliferous ores and metal scrap 67 Iron and steel
	372	Nonferrous metal basic industries	68 Nonferrous metals
38 Manufacturing of fabricated metal products, machinery, and equipment (MEQ)	381	Manufacture of fabricated metal products, except machinery and equipment	69 Manufactures of metal, n.e.s.
	382	Manufacture of machinery except electrical	71 Power-generating machinery and equipment 72 Machinery specialized for particular industries 73 Metalworking machinery 74 General industrial machinery and equipment, and parts
	383	Manufacture of electrical machinery, apparatus, appliances, and supplies	76 Telecommunications and sound recording apparatus 77 Electrical machinery, apparatus, and appliances, n.e.s. 81 Sanitary, plumbing, heating, and lighting fixtures
	384	Manufacture of transport equipment	78 Road vehicles (including air-cushion vehicles) 79 Other transport equipment
	385	Manufacture of professional and scientific, and measuring and controlling equipment	75 Office machines and automatic data processing equipment 87 Professional, scientific, and controlling instruments 88 Photographic apparatus, optical goods, and watches
39 Other manufacturing industries (MOT)	39	Other manufacturing industries	82 Furniture and parts thereof 83 Travel goods, handbags, and similar containers 89 Miscellaneous manufactured articles, n.e.s.

1/ Subcategories in these sectors are divided between ISIC categories 1 (AGR) and 31 (FOD).

Table 2. Heterogeneous Panel Unit Root Tests on the Left-Hand-Side Variable, ln(X/l) 1/

Industry (ISIC)		AUS	BEL	CAN	DNK	FRA	FIN	DEU	ITA	JPN	NLD	NOR	SWE	GBR	USA	Group-t statistic
1. AGR	ADF	-4.39	-2.98	-3.55	-2.92	-1.54	-3.00	-3.72	-3.15	-1.04	-0.53	-3.40	-2.81	-2.94	-1.93	-2.64 *
	No. of lags	3	3	0	0	0	0	0	0	0	0	0	4	0	0	
2. MID	ADF	-2.72		-1.08		-3.07	-2.90	-3.48		-2.89	-2.05		-2.79	-1.56	-1.49	-0.94
	No. of lags	0		0		0	0	0		0	0		0	0	0	
31. FOD	ADF		-2.19	-1.34	-2.30	-3.07	-2.40	-4.15	-3.51	-1.91		-2.41	-1.82	-2.34	-1.87	-1.21
	No. of lags		0	0	3	4	2	0	0	0		0	0	0	0	
32. TEX	ADF		-5.25	-3.01	-0.76	-1.50	-3.31	-2.47	-3.63	-0.16		-1.44	-2.01	-2.09	-2.66	-0.82
	No. of lags		4	3	0	0	0	1	0	4		0	0	0	0	
34. PAP	ADF		-3.92	-3.26	-1.54	-2.36	-2.95	-4.04		-1.50		-1.86	-0.53	-1.38	-3.18	-1.03
	No. of lags		1	0	0	3	3	3		2		0	2	1	3	
35. CHE	ADF		-1.50	-1.98	-2.81	-3.06	-1.71	-2.25	-0.78	-3.19		-2.16	-0.07	-1.33	-1.00	1.67
	No. of lags		2	0	4	2	3	0	4	0		0	0	0	3	
36. MNM	ADF		-4.84	-1.90	-1.79	-2.84	-2.55	-1.76	-2.20	-5.13			-1.44	-1.73	-1.36	-1.44
	No. of lags		4	4	0	0	0	0	0	4			0	0	0	
37. BMI	ADF		0.61	-1.62	-3.91	-2.81	-4.10	-1.65	-2.40	-2.18		-2.44	-3.37	-1.60	-3.28	-1.00
	No. of lags		4	0	1	0	0	0	0	0		4	4	1	0	
38. MEQ	ADF		-0.42	-2.34	-1.81	-3.72	-1.19	-1.56	-7.21	-2.36		-1.30	-2.08	-1.26	-2.11	-0.45
	No. of lags		0	0	0	2	4	0	4	3		0	0	0	1	
39. MOT	ADF		-2.69	-1.49	-2.29		-2.99	-2.15	-2.97	-2.56			-2.77	-1.48	-2.91	-1.06
	No. of lags		0	2	0		0	0	0	0			3	3	0	

Source: Author's calculations.

1/ Heterogeneous panel unit root tests of Im, Pesaran, and Shin (1997) are implemented for each industry indicated in the first column (see Table 1 for explanation of industry abbreviations). For example, in agriculture (AGR), there are 14 members in the panel. Each member's augmented Dickey-Fuller (ADF) test statistic is reported in the first row. Here, heterogeneous trends are included. Also heterogeneous lag truncation (up to the maximum lag of 4) is allowed (see the second row for the number of lags). The null hypothesis is that the time-series has a unit root. The t-bar (group-t) statistic is reported in the last column (for example, the group-t statistic for agriculture is -2.64). An asterisk indicates that the null is rejected.

Table 3. Heterogeneous Panel Unit Root Tests on the Right-Hand-Side Variable, ln(k/l) 1/

Industry (ISIC)		AUS	BEL	CAN	DNK	FRA	FIN	DEU	ITA	JPN	NLD	NOR	SWE	GBR	USA	Group-t statistic
1. AGR	ADF	-3.77	-2.61	-0.17	-2.57	0.05	-1.98	-0.78	-1.01	-0.54	-2.69	-4.86	-2.81	-1.90	-3.20	0.61
	No. of lags	3	1	4	1	0	3	0	3	0	4	1	0	0	1	
2. MID	ADF	-1.48		-1.44		-2.62	-3.01	-1.18		-1.66	-0.43		-3.63	-6.47	-0.82	-0.39
	No. of lags	1		0		1	1	0		4	4		1	4	0	
31. FOD	ADF		-3.16	-1.39	-2.23	-1.37	-2.35	-2.71	-2.10	-4.25		-3.68	-2.69	-2.64	-0.38	-1.08
	No. of lags		4	0	1	0	0	1	1	1		0	1	0	0	
32. TEX	ADF		-2.81	-1.68	-3.13	-1.83	1.02	-4.43	-3.46	-2.59		-2.31	-1.46	-1.95	-1.03	0.19
	No. of lags		2	0	3	0	0	2	2	0		1	1	1	0	
34. PAP	ADF		-3.81	-0.04	-1.89	-3.02	-1.99	0.32		-1.47		-1.71	-1.00	-1.60	-2.96	1.94
	No. of lags		1	3	0	0	0	0		0		3	0	0	0	
35. CHE	ADF		-4.19	-2.85	-1.72	-2.26	-1.06	-3.33	-3.98	-0.20		-3.13	1.62	-2.05	-1.71	0.50
	No. of lags		4	4	0	1	0	0	3	0		1	0	1	0	
36. MNM	ADF		-1.41	-2.35	-3.10	-1.99	0.96	-3.02	-2.16	-2.77			-1.99	-0.41	-2.61	1.26
	No. of lags		0	0	1	1	4	1	0	4			1	4	0	
37. BMI	ADF		-3.43	-0.92	-0.87	-3.52	-2.38	-3.89	-1.41	-3.10		-0.57	-1.36	-1.77	-1.68	0.48
	No. of lags		3	0	0	1	0	2	1	4		3	1	2	0	
38. MEQ	ADF		-2.16	1.19	-2.77	-2.59	-1.89	-2.54	-4.17	-3.31		-3.12	0.44	-3.62	-3.71	-0.81
	No. of lags		0	4	4	1	1	3	3	3		1	0	3	1	
39. MOT	ADF		-0.62	-1.14	-2.65		-1.50	-2.79	-2.41	-4.63			-3.12	-3.95	-0.96	-0.84
	No. of lags		0	3	4		0	0	0	1			3	4	0	

Source: Author's calculations.

1/ Heterogeneous panel unit root tests of Im, Pesaran, and Shin (1997) are implemented for each industry indicated in the first column (see Table 1 for explanation of industry abbreviations). As in Table 2, heterogeneous trends are included and heterogeneous lag truncation (up to the maximum lag of 4) is allowed (see the second row for the number of lags). The t-bar (group-t) statistic is reported in the last column (for example, the group-t statistic for agriculture is 0.61). There is no asterisk next to the group-t statistics. This indicates that the null of unit root cannot be rejected in any of the industries at the two-digit ISIC level.

Table 4. Heterogeneous Panel Cointegration Tests Between ln(X/l) and ln(k/l) 1/

Cointegration Test Statistic	Industry (ISIC)									
	1.AGR	2.MID	31.FOD	32.TEX	34.PAP	35.CHE	36.MNM	37.BMI	38.MEQ	39.MOT
The within-dimension-based statistics										
1. Panel *v*-statistic (analogous to variance ratio statistic)	2.404	0.725	1.043	0.351	-0.009	3.472	1.772	0.622	1.728	1.092
2. Panel ρ-statistic (analogous to Phillips-Perron ρ-statistic)	-2.000 *	0.407	0.499	1.190	0.107	-0.723	-0.636	0.030	0.888	-0.744
3. Panel *t*-statistic (non-parametric) (analogous to Phillips-Perron *t*-statistic)	-4.129 *	-0.665	-0.532	0.209	-1.248	-2.166 *	-2.175 *	-1.545	0.273	-2.051 *
4. Panel *t*-statistic (parametric) (analogous to ADF *t*-statistic)	-6.615 *	-0.755	-1.103	0.217	-2.465 *	-2.090 *	-3.231 *	-2.569 *	0.269	-2.189 *
The between-dimension-based statistics										
5. Group ρ-statistic (analogous to Phillips-Perron ρ-statistic)	-1.538	0.832	0.834	1.470	0.853	0.307	0.344	0.815	1.632	0.304
6. Group *t*-statistic (non-parametric) (analogous to Phillips-Perron *t*-statistic)	-5.003 *	-1.051	-0.962	-0.013	-1.159	-1.628	-2.023 *	-1.264	0.651	-1.586
7. Group *t*-statistic (parametric) (analogous to ADF t-statistic)	-10.112 *	-2.375 *	-4.291 *	-1.185	-5.495 *	-1.869	-5.308 *	-3.564 *	0.792	-1.978 *

Source: Author's calculations.

1/ Heterogeneous panel cointegration tests of Pedroni (1999) are implemented for each industry indicated in the first row (see Table 1 for explanation of industry abbreviations). The null hypothesis is that there is no cointegration between the left-hand-side variable ln(X/l) and the right-hand-side variable ln(k/l). An asterisk next to the various test statistics indicates that the null is rejected. Except for the textile and machinery and equipment industries, at least one test statistic rejects the null of no cointegration.

Table 5. Structural Parameters Estimated with the Panel FMOLS Estimator

Parameter and country	Industry (ISIC) 1/									
	1.AGR	2.MID	31.FOD	32.TEX	34.PAP	35.CHE	36.MNM	37.BMI	38.MEQ	39.MOT
Heterogeneous trend parameter (λ) 2/										
United States	0.017	-0.032	-0.014	0.036	-0.006	0.020	0.020	-0.009	-0.024	0.031
Australia	0.010	-0.034								
Belgium	0.010		-0.010	0.021	-0.026	0.082	0.069	-0.058	0.146	-0.005
Canada	0.002	-0.068	-0.010	0.020	0.005	0.007	-0.020	-0.019	0.020	0.002
Denmark	0.023		-0.024	-0.012	-0.026	-0.005	-0.013	0.032	-0.021	-0.015
France	0.034	0.041	-0.024	0.056	0.004	0.030	0.012	-0.109	0.033	
Finland	0.004	0.072	0.005	0.044	0.034	0.046	0.046	0.020	0.054	0.029
Germany	0.020	-0.028	0.005	0.014	0.002	0.003	0.016	0.029	0.006	0.019
Italy	-0.012		0.031	0.039		0.051	0.035	0.013	0.039	-0.035
Japan	0.026	-0.052	-0.046	-0.074	0.001	0.016	0.060	-0.019	0.087	0.058
Netherlands	0.016	0.009								
Norway	-0.011		0.031	-0.029	0.002	0.015		-0.053	0.015	
Sweden	0.051	-0.047	-0.046	0.023	0.007	0.010	0.015	-0.024	0.027	-0.001
United Kingdom	0.055	-0.014	-0.030	0.015	-0.002	-0.002	0.019	-0.078	-0.038	-0.032
Coefficient on a regressor, ln(k/l) (α_k) 3/										
Individual FMOLS										
United States	-0.279	1.491 *	1.089 *	0.072	0.443	0.148	-0.317	0.196	1.145 *	-0.102
Australia	0.894 *	1.388								
Belgium	0.752 *		0.650 *	0.433	1.080 *	0.475	-0.423	2.480 *	-2.000	0.656 *
Canada	0.051	1.670 *	0.650 *	0.651 *	0.003	0.438 *	-1.455	0.916 *	0.111	0.399
Denmark	0.516 *		1.278 *	0.887 *	1.224 *	1.750 *	0.388 *	0.294	1.058 *	0.543 *
France	0.381 *	-0.179	1.278 *	-0.607	0.315	-0.197	0.471 *	3.643 *	-0.087	
Finland	0.564 *	1.422 *	0.347	-0.089	0.200	-0.258	-0.284	0.872	-0.337	0.125
Germany	0.500	0.606	0.347	0.401 *	0.544 *	0.635 *	0.251	-0.128	0.478 *	-0.016
Italy	0.773 *		0.110	-0.023		1.356 *	-0.004	0.601	0.165	1.328 *
Japan	-0.413	1.322 *	0.946	2.033 *	0.572 *	0.217	-0.436	0.880 *	-0.314	-0.638
Netherlands	0.573 *	1.463 *								
Norway	0.632 *		0.110	0.830 *	0.232	0.284		2.310 *	-0.061	
Sweden	-0.229 *	1.176 *	0.946	-0.029	0.508	0.623	0.104	1.807 *	-0.020	-2.042
United Kingdom	-0.360	0.934	1.465 *	0.239	0.516	1.159 *	0.082	1.956 *	1.301 *	1.159 *
Group-mean FMOLS										
	0.311 *	1.129 *	0.683 *	0.400 *	0.513 *	0.553 *	-0.148	1.319 *	0.120 *	0.141 *
Heterogeneous intercept term (lnA) 2/										
United States	14.16	-7.60	-1.39	8.75	5.96	9.08	13.96	8.65	-1.78	11.26
Australia	-0.40	-5.69								
Belgium	2.07		3.70	4.97	-1.29	3.68	14.37	-18.01	30.17	3.29
Canada	9.97	-9.717	3.70	3.18	10.54	5.25	28.02	-0.33	8.98	6.17
Denmark	3.82		-3.71	0.78	-2.76	-9.66	6.02	5.93	-0.85	4.97
France	6.20	11.67	-3.71	15.85	7.08	12.97	4.96	-32.04	11.00	
Finland	3.81	-9.16	6.73	9.94	7.41	12.92	12.89	-0.61	13.03	8.27
Germany	4.15	3.78	6.73	5.50	4.37	3.58	7.47	11.43	5.22	10.27
Italy	1.16		9.19	9.99		-5.96	10.10	3.09	8.04	-7.52
Japan	15.68	-3.42	1.17	-11.12	3.61	8.66	14.49	0.47	12.32	15.80
Netherlands	4.00	-7.67								
Norway	2.96		9.19	1.15	7.57	6.60		-16.91	10.60	
Sweden	12.75	-2.31	1.17	9.89	4.29	3.29	8.97	-11.22	9.92	26.34
United Kingdom	13.97	-0.14	-5.56	7.14	4.89	-2.68	9.15	-11.50	-3.10	-3.59

Source: Author's calculations using the panel FMOLS estimator (Pedroni, 2000).

1/ See Table 1 for explanation of industry abbreviations.

2/ No inferences are done on the estimate of these parameters.

3/ A group-mean estimate for the parameter α_k is obtained by averaging the estimates for individual countries. An asterisk indicates that the estimate is significant at the 5 percent level.

Table 6. Structural Parameters Estimated with the 3SLS Estimator

Parameter and country	Industry (ISIC) 1/									
	1.AGR	2.MID	31.FOD	32.TEX	34.PAP	35.CHE	36.MNM	37.BMI	38.MEQ	39.MOT
Heterogeneous trend parameter (λ) 2/										
United States	-0.092 *	-0.070 *	-0.067 *	0.066 *	0.065 *	-0.207 *	0.029 *	0.079 *	-0.032 *	0.372 *
Australia	0.782 *	-0.024								
Belgium	-0.028 *		0.002	0.074 *	-0.021 *	-0.066 *	-0.167 *	-0.061 *	-0.225 *	-0.005
Canada	0.182 *	-0.157 *	0.037 *	0.015	0.159 *	0.004	0.009	0.132 *	-0.068 *	0.193 *
Denmark	0.473 *		0.091 *	0.050 *	-0.079 *	0.125 *	0.005	-0.102 *	-0.103 *	-0.011
France	0.098 *	0.279 *	-0.027 *	-0.010 *	0.061 *	0.036 *	0.021 *	0.094 *	0.001	
Finland	-0.033 *	-0.073 *	0.013 *	0.056 *	-0.006	0.127 *	-0.084 *	-0.309 *	0.161 *	-0.050 *
Germany	0.363 *	0.367 *	-0.128 *	-0.054 *	0.197 *	0.194 *	0.017 *	0.031 *	-0.196 *	0.088 *
Italy	0.274 *		0.021 *	0.061 *		0.276 *	-0.011	-0.082 *	-0.366 *	0.094 *
Japan	-0.421 *	-0.052 *	-0.078 *	0.125 *	0.214 *	0.104 *	-0.125 *	-0.524 *	0.000	0.045 *
Netherlands	0.142 *	0.073 *								
Norway	0.337 *		0.057 *	0.041 *	0.015 *	-0.447 *		-0.238 *	-0.060 *	
Sweden	0.396 *	0.006	0.060 *	0.065 *	0.082 *	0.011 *	-0.045 *	-0.182 *	0.190 *	0.485 *
United Kingdom	0.646 *	0.276 *	0.008 *	-0.017 *	0.385 *	0.000	-0.054 *	0.067 *	0.017 *	0.168 *
Coefficient on a regressor, ln(k/l) (α_k) 2/										
	0.938 *	0.790 *	0.554 *	0.250 *	0.417 *	0.458 *	0.256 *	0.381 *	0.219 *	0.388 *
Heterogeneous intercept term (lnA) 3/										
United States	-0.88	1.64	4.50	6.98	6.11	5.40	7.49	6.39	8.07	6.30
Australia	-0.92	1.58	.	.	.	.	.	.	.	.
Belgium	-0.36	.	4.35	6.85	5.65	3.94	7.07	5.56	7.66	5.90
Canada	-0.95	1.519	4.67	6.97	5.80	4.96	7.82	6.04	7.77	6.08
Denmark	-1.59	.	3.52	6.79	5.72	4.74	7.44	5.22	7.57	6.38
France	-0.12	3.63	4.34	7.30	6.04	5.31	7.35	5.75	7.79	.
Finland	-0.78	0.46	3.83	6.70	5.05	4.87	7.14	5.34	7.33	5.85
Germany	-1.57	1.81	4.44	7.06	5.71	5.51	7.38	5.89	7.88	6.29
Italy	-0.64	.	4.36	7.13	.	4.26	7.05	6.10	7.54	4.84
Japan	-0.08	1.99	4.98	6.72	5.26	5.79	7.46	6.22	7.16	6.41
Netherlands	-0.46	2.51	.	.	.	.	.	.	.	.
Norway	-0.90	.	4.11	6.80	5.57	4.54	.	5.19	7.77	.
Sweden	-0.50	1.51	4.33	7.05	5.34	5.10	7.31	5.24	7.55	4.58
United Kingdom	-0.57	1.34	4.20	6.97	5.91	5.05	7.44	6.35	7.38	5.88

Source: Author's calculations using the 3SLS estimator (Boskin and Lau, 1992).
1/ See Table 1 for explanation of industry abbreviations.
2/ The asterisk indicates that estimates are significant at the 5 percent level.
3/ Heterogeneous intercept term is estimated as a residual for the initial period.

Table 7. Measures of Technology Differences Between Japan and the United States, 1970 and 1990 1/

Industry (ISIC) 2/	**RICARDO** 3/		**HICKS** 4/ 5/		**CAP** 6/	
	1970	1990	1970	1990	1970	1990
1.AGR	-0.080	-0.035	-0.895	0.523	0.815	-0.557
2.MID	1.587	0.455	-0.404	-0.697	1.991	1.152
31.FOD	-0.623	0.171	-0.543	-0.051	-0.080	0.222
32.TEX	-0.241	0.241	0.282	0.563	-0.523	-0.323
34.PAP	0.201	-0.133	0.933	0.375	-0.733	-0.508
35.CHE	-0.617	-0.337	-0.437	-0.388	-0.180	0.052
36.MNM	-0.351	-0.125	0.028	-0.046	-0.379	-0.080
37.BMI	-0.113	-0.517	0.178	-0.475	-0.291	-0.042
38.MEQ	0.517	-0.070	0.992	-0.003	-0.475	-0.067
39.MOT	-0.279	0.350	-0.135	0.199	-0.144	0.151

Source: Author's calculations.
1/ The Ricardian measure (**RICARDO**) is decomposed to two subcomponents, the Hicksian measure (**HICKS**) and the capital-intensity component.
2/ See Table 1 for explanation of industry abbreviation.
3/ A positive value indicates a higher unit labor cost in Japan than in the United States in the indicated industry and period.
4/ A positive value indicates a higher unit labor cost in Japan than in the United States had capital intensity been the same in the two countries in the indicated industry and period.
5/ Includes the residuals (unobservables) so that the sum of two subcomponents equals the Ricardian measure in each industry.
6/ A positive value indicates a higher unit labor cost in Japan than in the United States had technology been the same in the two countries in the indicated industry and period.

Table 8. Empirical Relationships Between the Two Technology Measures 1/

Period	Case 1 or 2				Case 3			
	Panel FMOLS		3SLS		Panel FMOLS		3SLS	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
1970-92	6,963	0.61	6,959	0.56	4,442	0.39	5,378	0.44
1970	320	0.65	455	0.74	175	0.35	157	0.26
1975	300	0.63	302	0.58	176	0.37	217	0.42
1980	281	0.59	279	0.54	193	0.41	238	0.46
1985	313	0.62	269	0.52	188	0.38	244	0.48
1990	298	0.58	281	0.52	217	0.42	263	0.48

Source: Author's calculations.
1/ Cases 1, 2, and 3 are classified as follows: Case 1, the signs of **RICARDO**, **HICKS**, and **CAP** are the same; Case 2, the signs of **RICARDO** and **HICKS** are the same, but not the sign of **CAP**; Case 3, the signs of **RICARDO** and **CAP** are the same, but not the sign of **HICKS**.

Table 9. Pearson Correlation Coefficient 1/

Period	Between **RICARDO** and Net Exports	Between **HICKS** and Net Exports	
		Panel FMOLS	3SLS
1970-90 2/	-0.019 *	0.082 *	0.103 *
No. of observations	13,398	12,873	12,873
1970 only	-0.010	0.215 *	0.252 *
No. of observations	638	613	613
1990 only	-0.160 *	0.065	0.097 *
No. of observations	638	613	613

Source: Author's calculations.

1/ An asterisk indicates statistical significance at the 5 percent level.

2/ The sample period is 1970-90 instead of 1970-92 because the trade data used in this study end in 1990.

Table 10. A Complete Set of Possible Outcomes

Possible outcome	Sign on Technology Measure			Category
	RICARDO (-%Δp)	**HICKS** (π_j - π_i)	**CAP** (π_i - π_j - %Δp)	
$\pi_j > \pi_i > 0$	+	+	+	Case 1
$\pi_j = \pi_i > 0$	+	0	+	Case 1
$\pi_i > \pi_j > 0$	+	-	+	Case 3
	-	-	+	Case 2
$\pi_i > 0 > \pi_j$	-	-	+	Case 2
$0 > \pi_i > \pi_j$	-	-	-	Case 1
$0 > \pi_i = \pi_j$	-	0	-	Case 1
$0 > \pi_j > \pi_i$	-	+	-	Case 3
	+	+	-	Case 2
$\pi_j > 0 > \pi_i$	+	+	-	Case 2

Source: Author's analysis.

References

Bernhofen, Daniel, and John Brown, 2001, "A Direct Test of the Theory of Comparative Advantage: The Case of Japan" (unpublished: Clark University).

Boskin, Michael J., and Lawrence J. Lau, 1992, "Capital, Technology, and Economic Growth," in *Technology and the Wealth of Nations*, ed. by N. Rosenberg, R. Landau, and D. C. Mowery (Palo Alto, California: Stanford University Press).

Bowen, Harry P., Edward E. Leamer, and Leo Sveikauskas, 1987, "Multicountry, Multifactor Tests of the Factor Abundance Theory," *American Economic Review*, Vol. 77, No. 5, pp. 791–809.

Davis, Donald R., David E. Weinstein, Scott C. Bradford, and Kazushige Shimpo, 1997, "Using International and Japanese Regional Data to Determine When the Factor Abundance Theory of Trade Works," *American Economic Review*, Vol. 87, pp. 421–46.

Davis, Donald R., and David E. Weinstein, 2001, "An Account of Global Factor Trade," American Economic Review, Vol. 91, pp. 1423–53.

Deardorff, Alan V., 1980, "The General Validity of the Law of Comparative Advantage," *Journal of Political Economy*, Vol. 88, No. 5, pp. 941–57.

Dixit, Avinash, and Victor Norman, 1980, *Theory of International Trade: A Dual, General Equilibrium Approach* (Cambridge: Cambridge University Press).

Drabicki, John G., and Akira Takayama, 1979, "An Antinomy in the Theory of Comparative Advantage," *Journal of International Economics*, Vol. 9, pp. 211–23.

Graham, Edward M., and Paul R. Krugman, 1993, "The Surge in Foreign Direct Investment in the 1980s," in *Foreign Direct Investment*, ed. by Kenneth A. Froot (Chicago: University of Chicago Press).

Harrigan, James, 1997, "Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model," *American Economic Review*, Vol. 87, pp. 475–94.

———, 1999, "Estimation of Cross-Country Differences in Industry Production Functions," *Journal of International Economics*, Vol. 47, pp. 267–94.

Hicks, John R., 1932, "The Theory of Wages" (reprinted, London: Macmillan).

Im, Kyung S., Hashem M. Pesaran, and Yongcheol Shin, 1997, "Testing for Unit Roots in Heterogeneous Panels," Discussion Paper (Cambridge: University of Cambridge).

Jones, Ronald W., 1965, ""Neutral" Technological Change and the Isoquant Map," *American Economic Review*, Vol. 55, No. 4., pp. 848–55.

———, 1967, "International Capital Movements and the Theory of Tariffs and Trade," *Quarterly Journal of Economics*, Vol. 81, pp. 1–38.

Kemp, Murray C., 1966, "The Gain from International Trade and Investment: A Neo-Heckscher-Ohlin Approach," *American Economic Review*, Vol. 56, pp. 788–809.

Komiya, Ryutaro, Masahiro Okuno, and Kotaro Suzumura, 1988, *Industrial Policy of Japan* (Tokyo: Academic Press).

Levinsohn, James, and Amil Petrin, 2000, "Estimating Production Functions Using Inputs to Control for Unobservables," NBER Working Paper No. 7819 (Cambridge, Massachusetts: National Bureau of Economic Research).

Maskus, Keith E., and Allan Webster, 1995, "Factor Specialization in U.S. and U.K. Trade: Simple Departures from the Factor-Content Theory," *Swiss Journal of Economics and Statistics*, Vol. 131, No. 3, pp. 419–39.

Olley, Steven, and Ariel Pakes, 1996, "The Dynamics of Productivity in the Telecommunications Equipment Industry," *Econometrica*, Vol. 64, No. 6, pp. 1263–98.

Pedroni, Peter, 1999, "Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors," *Oxford Bulletin of Economics and Statistics*, Vol. 61, pp. 653–70.

———, 2000, "Fully Modified OLS for Heterogenous Cointegrated Panels," in *Advances in Econometrics, vol. 15, Nonstationary Panels, Panel Cointegration and Dynamic Panels*, ed. by B. Baltagi (Amsterdam: JAI Press).

Phillips, Peter C. B., and Bruce E. Hansen, 1990, "Statistical Inference in Instrumental Variables Regression with I(1) Processes," *Review of Economic Studies*, Vol. 57, pp. 99–125.

Ricardo, David, 1817, *The Principles of Political Economy and Taxation* (reprinted, J. M. Dent & Sons Ltd., London).

Ruffin, Roy J., 1984, "International Factor Movements," in *Handbook of International Economics*, Vol. I, ed. by R. W. Jones and P. B. Kenen (Amsterdam: North-Holland).

Trefler, Daniel, 1993, "International Factor Price Differences: Leontief Was Right!," *Journal of Political Economy*, Vol. 101, No. 6, pp. 961–87.

———, 1995, "The Case of the Missing Trade and Other Mysteries," *American Economic Review*, Vol. 85, pp. 1029–46.