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Cross-Country Comparisons of Industry Total Factor Productivity: Theory and Evidence

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Abstract

International trade economists typically assume that TFP for each industry is the same in every country. This paper casts doubt on this hypothesis, finding large and persistent TFP differences across countries. The paper considers measurement issues in depth, and a methodology for international TFP comparisons is described. This methodology is applied to a dataset on prices, inputs, and outputs for a group of industrialized countries in the 1980s. The paper finds that the United States was the TFP leader in machinery and equipment during the 1980s, with Japan slightly behind. These results are compared to the previous literature on disaggregated TFP comparisons.

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1. Introduction

Two standard assumptions in neoclassical trade theory are that technological knowledge is the same in all countries, and that production processes exhibit constant returns to scale. An implication of these assumptions is that total factor productivity (TFP) for each industry is the same in every country: given quantities of inputs will produce equal amounts of output. A growing body of work casts doubt on this hypothesis. Dollar and Wolff (1993), van Ark and Pilat (1993), Jorgenson and Kuroda (1990), and Trefler (1993, 1995) demonstrate that there are important differences in TFP across countries, while Dollar and Wolff (1993) argue that these TFP differences are related to export performance. If technology is not the same across countries, then much of the theoretical work in neoclassical trade theory is irrelevant to applied research on cross-country comparisons, and much of the applied research that assumes identical technology (for example, many applied general equilibrium models and factor endowment regressions) is misspecified. Consequently, the existence of large TFP differences is an important topic for international trade economists for both theoretical and policy purposes.

This paper uses new data on value added, inputs, and prices to construct TFP indices for machinery for a set of developed countries during the 1980s. The paper has several goals. The first goal is to document the point, well known to researchers in international productivity comparisons but less well known to international trade economists, that it is very difficult to convincingly measure international differences in TFP, even for the relatively simple case of industrial output across developed countries. To this end, I review some of the previous attempts along these lines and consider measurement issues in some detail. I also propose and implement measures which take account of some of the major difficulties in making international TFP comparisons. The second purpose of the paper is to present some new estimates of TFP which document very large and persistent differences across countries and industries during the 1980s. These new estimates are important because they cover a wide range of countries, they use recent data, and they ameliorate if not overcome some of the data and index number problems of previous work. These estimates are compared to other estimates of disaggregated TFP differences, and some implications for international trade theory are explored briefly in the conclusion.

The data source for nominal inputs and outputs used in this paper is a new database developed by the OECD called STAN (STAN stands for STructural ANalysis; see OECD 1992a). STAN is a disaggregated dataset on nominal industry level inputs, outputs, and trade flows for most of the OECD countries, developed from a number of OECD and UN sources. I use price data from a variety of sources including the OECD and the US Bureau of Economic Analysis (BEA) to convert the STAN data into real internationally comparable units.

2. The Theory of Total Factor Productivity Comparisons

TFP is intended to be a measure of the level of technology or technical efficiency. The comparison of TFP between two countries b and c asks the question: how much output could country b produce using country c's inputs, or vice versa? For now, assume that value added can be modelled as a function of the capital stock and employment, and that these inputs are measured perfectly and in the same units for each observation. For a particular industry in country c , write real value added y_c as a constant returns to scale function of the real capital stock k_c and the level of employment l_c:

$$y_c = f_c(k_c,l_c) = f_c(x_c) \tag{1}$$

Now define the distance function $D_b(y_c, x_c)$ as follows:

$$D_b(y_c, x_c) = \mathrm{Min}_\delta \{ \delta \in \mathbb{R}^1_+ : f_b(\delta x_c) \geq y_c \}$$

With this definition, $D_b x_c$ is the smallest input bundle capable of producing y_c using the technology in country b. $D_c(y_b, x_b)$ is defined analogously. Note that in general it need not be the case that $D_c = 1/D_b$, so that the calculated distance between the technologies of two countries b and c depends on the value added function used for the comparison. Further complications arise in making multilateral comparisons within a panel of countries since the choice of base country and year will affect the conclusions. As a solution to this index number problem, suppose that each country's value added function is translog with identical second-order terms, so that the value added function of country c can be written as

$$\ln y_c = \alpha_{0c} + \alpha_{1c} \ln l_c + \alpha_{2c} \ln k_c + \alpha_3 (\ln l_c)^2 + \alpha_4 (\ln k_c)^2 + \alpha_5 (\ln l_c \cdot \ln k_c)$$

where constant returns to scale requires $\alpha_{1c} + \alpha_{2c} = 1$ and $2\alpha_3 + \alpha_5 = 2\alpha_4 + \alpha_5 = 0$. Under the additional assumptions that producers are cost-minimizers and price takers in input markets, Caves, Christensen and Diewert (1982) show that the geometric mean of the two distance functions for any two countries b and c gives the TFP index

$$TFP_{bc} = \frac{y_b}{y_c} \left(\frac{\bar{l}}{l_b} \right)^{\sigma_b} \left(\frac{\bar{k}}{k_b} \right)^{1-\sigma_b} \left(\frac{l_c}{\bar{l}} \right)^{\sigma_c} \left(\frac{k_c}{\bar{k}} \right)^{1-\sigma_c} \tag{2}$$

where $\bar{k}$ and $\bar{l}$ 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 and $\bar{s}$ is the arithmetic average of the labor shares. To interpret (2), notice that if the value added function is Cobb-Douglas, then the labor shares are constant and (2) reduces to the Cobb-Douglas index:

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

The index (2) is superlative, meaning that it is exact for the flexible translog functional form. Furthermore, (2) is transitive:

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

which makes the choice of base country and year inconsequential.

3. Value Added

The output concept used most often in international productivity comparisons is value added. The existence of a real value added function depends on one of two alternative conditions (Diewert, 1978):

1. Gross output G is a weakly separable function of an index of capital and labor and an index of purchased inputs or materials M:

$$G = F(k,l,M) \equiv h[y(k,l),M]$$

where y(k,l) is real value added; or

2. The price of gross output and the price of purchased inputs vary strictly in proportion.

Weak separability in this context means that changes in materials prices have no effect on the optimal capital-labor ratio. It is not likely that either of these conditions is satisfied in the data. For an analysis of industry-level gross output that deflates materials inputs appropriately, see Jorgenson, Kuroda and Nishimizu (1987), Jorgenson and Kuroda (1990), and Oulton and O'Mahony (1994). These authors argue persuasively that gross output TFP, rather than value added TFP, is what is relevant for most contexts and in particular is most relevant for analysis of the "competitiveness" of national industries. Unfortunately, deflating gross output requires consistent data on prices of materials inputs which is not available for the broad sample of countries used in this study[1]. These caveats should be kept in mind when reviewing the results of this paper.

The STAN data contains information on nominal value added Y, so a conversion procedure is necessary to make output internationally comparable. Since goods arbitrage is less than perfect and there are differences in the type of good produced in a category across countries, it is necessary to have a cross-country price level index to deflate by. Define

P_{cjt} = price level of industry j standardized output in country c in year t

The price level P_{cjt} is a unit-less number which expresses the $US cost of output in country c relative to the $US cost of output in the US. If $P_{cjt} > 1$, then it is the case that a standardized unit of output is more expensive in country c than in the US; it does <u>not</u> mean that output in country c is of higher quality, since the price index ostensibly compares like goods in the countries being compared. The standardized unit of output being compared is meant to be representative of the OECD as a whole, so the choice of the dollar as a standard for purposes of cross country comparisons is inconsequential. Defining the purchasing power parity (PPP) exchange rate as $e_{cjt} = E_{ct} \cdot P_{cjt}$, where E_{ct} is the nominal exchange rate (foreign currency cost of $1), then e_{cjt} is the cost in US dollars of purchasing a unit of standardized output which would cost $\$E_{ct}$ in the US.

Once value added is converted into year t $US, a US price index is required to make different years comparable. Denote this US value added deflator as π_{jt}, where for t = 1987 $\pi_{jt} \equiv 1$ for all j. As a result, I measure real value added y in units of 1987 dollars of standardized goods as

$$y_{cjt} = Y_{cjt}/e_{cjt}\pi_{jt}$$

The hard part of this procedure is finding an appropriate set of deflators, P_{cjt} and π_{jt}.

Most previous researchers (e.g. Dollar, Baumol, and Wolff, (1988), Maskus (1991), and Dollar and Wolff (1993)) have used PPP exchange rates for GDP compiled by the OECD or by Summers and Heston (1991). It is widely recognized that this procedure is inappropriate for a number of reasons (see, e.g., van Ark, (1993a)). GDP PPP's are biased for manufacturing output comparisons because they

1. include import prices and exclude export prices,
2. include transport and distribution margins,
3. include indirect taxes and exclude subsidies, and
4. refer to final output and not intermediate goods.

In addition, using GDP PPP's is inappropriate to the extent that relative prices of manufactured goods are not the same across countries. Unfortunately, there is no alternative to using GDP PPPs because manufacturing output deflators for cross country comparisons are not available[2].

Some of the problems of using GDP PPPs can be mitigated by using the component deflators reported in the OECD documentation of the construction of the overall GDP PPPs (Ward 1985, OECD 1987, and OECD 1992b). Use of this data instead of the overall GDP PPPs avoids assuming that industry price levels are the same as overall GDP price levels. This paper constructs price levels for machinery and equipment using this disaggregated data. These sectoral price levels refer to final output, not value added. The price levels are calculated at the 3-digit level of the ISIC for ISIC codes 382, 383, and 384.

To construct data for each year of the 1980s, I first express each industry price level as a proportion of the overall GDP price level for 1980, 1985, and 1990 using information from Ward

1985, OECD 1987, and OECD 1992b. For intervening years, I interpolate these price level percentages linearly. Finally, these numbers are multiplied by the overall GDP price level in each year to generate industry specific price levels by year[3].

Table 1 lists the industry price levels as percentages of the overall GDP price level, and therefore gives an indication of the distortion created by deflating by the overall GDP price level. The dominant impression from Table 1 is that the numbers are not close to unity, which means that the distortion from using GDP PPP's is large.

The procedure above converts each country's nominal value added into common units for each year. To make each series comparable over time requires another price index. I use the implicit value added deflator from the BEA reported in the May 1993 Survey of Current Business. The index uses fixed 1987 weights, and is equal to 1 in 1987 for each industry. An advantage of using the US index is that it refers to value added instead of final output, and it has been recently revised to take account of quality change over time.

4. Capital

The STAN data contain information on nominal gross fixed capital formation (GFCF) by industry, I_{cjt}. There are two steps required to construct internationally comparable capital stocks. The first step is to convert nominal GFCF into real GFCF, and the second step uses real GFCF to construct real capital stocks.

The GFCF price levels P_{ct} and nominal exchange rates E_{ct} are taken from Summers and Heston (1991). It should be noted that these investment price levels include the prices of residential construction and civil engineering projects, which is theoretically inappropriate. Of course, the fact that I use the same price level for each industry's capital formation is a potentially more serious problem. Once GFCF is converted into year t $US, a price index is required to make different years comparable. I use the implicit deflator for US fixed non-residential investment from the National Income and Product Accounts, various years. Denote this deflator as π_t, with a base year of 1987. As a result, I measure real investment in units of 1987 dollars of standardized goods as

$$i_{cjt} = I_{cjt}/e_{ct}\pi_t$$

Given the series on real investment, the capital stock is a function of past investment flows. The choice of function is both important and somewhat arbitrary, since it is not feasible to gather information on useful asset lives and depreciation patterns across industries and countries. I (rather uncomfortably) follow many previous researchers and construct the capital stock as a distributed lag of past investment flows:

$$k_{cjt} = \sum_{n=1}^{T} (1 - \delta)^{n-1} i_{cj,t-n}$$

Note that the capital stock in year t does not include year t investment, but only up through year t-1. In this paper, because I only have investment going back to 1970, I use $\delta = 0.15$ and $T = 10$. If the actual useful life of the capital stock is 20 years, this amounts to dropping about 10% of the total weight used in constructing the "true" capital stock.

5. Labor

Internationally comparable data on employment by industry (including STAN) generally fails to provide information on hours worked and on the occupation/skill breakdown of the labor force. This section describes a method for constructing an index of labor input from the STAN data and other sources.

If different types of labor are separable from capital, then we can write the value added function as in equation (1), where labor input l is an aggregate of different kinds of labor input. A particularly simple aggregator is the Cobb-Douglas form:

$$\log l = \sum_{k=1}^{L} \alpha_k \log l_k \tag{3}$$

Constant returns to scale in this index requires $\sum \alpha_k = 1$. If firms are cost-minimizers and price takers in labor markets, then α_k will be labor type k's share in total labor cost.

To make (3) operational requires a method of dividing l into it's components and a method of estimating the cost shares α_k. The International Labor Organization's (ILO) Year Book of Labor Statistics provides a breakdown by occupational classification of total employment in manufacturing. The occupational breakdown used here is

ILO Category 0/1	Professional, Technical and Related Workers
ILO Category 2	Administrative and Managerial Workers
ILO Category 3-9	Other

In this paper I use the percentages of total manufacturing employment within each category to divide industry level employment into these three categories.

Construction of the cost shares α_k requires data on wages. Unfortunately, it is not possible to find internationally comparable wage data that is disaggregated by occupation. The approach used here is to assume that the occupational wage differentials in the United States are the same as in other countries. These wage differentials can be constructed from data in the Bureau of Labor Statistics (BLS) Handbook of Labor Statistics for the years 1983 to 1988 (BLS 1989, page 163-168)[4]. Denote the wage of labor type k as w_k and the occupational wage differentials as β_k, with the normalization that the lowest paid occupation is occupation L and $\beta_L = 1$. Substituting $w_k = \beta_k w_L$ into the definition of total labor cost = $\sum_k w_k \cdot l_k$, and solving for w_L it is the case that

$$w_L = \sum_k w_k \cdot l_k / \sum_k \beta_k \cdot l_k$$

Given this constructed numeraire wage, the wage shares follow immediately as

$$\alpha_k = w_k l_k / \sum_j w_j \cdot l_j = \beta_k l_k / \sum_j \beta_j \cdot l_j \qquad k = 1,...,L.$$

For a particular industry, these shares vary substantially across countries and over time, which makes comparisons of aggregate labor inputs problematical since it implies that the α_k are not constant. This creates an index number problem which I solve in a manner suggested by the Caves, et. al. (1982) procedure. In analogy to the total cost shares used in the TFP index above, I use the following weights in constructing the index of labor for country c in year t:

$$\hat{\alpha}_{kct} = (\alpha_{kct} + \bar{\alpha}_k)/2$$

where $\bar{\alpha}_k$ is the arithmetic mean of α_{kct} across countries and years.

There are substantial differences across countries in hours worked. I normalize the STAN employment data to a 40 hour week, using average hours worked in manufacturing from the ILO Year Book of Labor Statistics, various years.

6. TFP Results

In this section I report results of TFP comparisons using the multilateral index of equation (2) and the data on real inputs and outputs described above.

Under the assumptions about technology and input market behavior used to derive (2), labor's share in total cost is equal to the elasticity of output with respect to labor, so that

$$s_c = \alpha_{1c} + \alpha_5 \ln (k_c/l_c) \tag{4}$$

The cost shares in the raw data are very volatile, and in many cases exceed one. In the results reported below, I use a smoothing procedure based on equation (4) to generate the cost shares used in constructing the TFP index. For each industry, I estimate the following regression by OLS over all time periods t and countries c:

$$s_{ct} = \beta_{0c} + \beta_1 \ln (k_{ct}/l_{ct}) + \epsilon_{ct}$$

I use the fitted values from this regression as the labor cost shares in constructing the reported TFP indexes. In cases where the fitted values exceed one I use the sample mean for the industry. For shipbuilding and repairing, the sample mean for labor's share exceeds one, so I use the sample mean for labor's share in all machinery. Of course, this suggests that the TFP index for shipbuilding should be regarded with great skepticism.

For reasons of space, I do not report the complete TFP results. The complete results are reported in an appendix, which is available from the author on request. Tables 2 and 3 summarize the TFP results in different ways. Table 2 uses a regression procedure to summarize the individual industry TFP differences over time, while Table 3 uses an index number approach to summarize yearly TFP differences across countries.

In constructing Table 2, for each industry, the log of TFP is regressed on country fixed effects and a time trend. The US is the excluded fixed effect, so the exponential of the country fixed effects are average TFP relative to the US during the sample period, after detrending. The elements of Table 2 are these exponentiated estimated fixed effects. For each industry, proportionate differences outside the approximate interval (0.95,1.05) are statistically significantly different from 1.0 at the 5% confidence level; the only exception is the "other transport equipment" industry, where because of the small sample size none of the proportions is significantly different from 1.0

Table 2 makes it clear that the US was either the leader or co-leader in TFP during the 1980's in six of the eight industries. The US trailed badly only in electrical machinery, and was tied for second with Japan in shipbuilding. In motor vehicles, the US and Japan had a TFP lead of 20-25% on a group of countries including Canada, Germany, and Italy. The US was the clear leader in office and computing equipment and (surprisingly?) in radio, TV, and communications equipment. The fact that the three largest economies (US, Japan, and Germany) generally have the best TFP performance is consistent with industry-level economies of scale being an important determinant on TFP; for more on this hypothesis, see Harrigan (1997b).

Table 3 summarizes cross-industry TFP using a version of the multilateral TFP index of equation (2). The index number formula used in Table 3 weights sectoral outputs relative to the mean using revenue shares, and expresses this quantity relative to an index of total capital and labor used in all sectors, where inputs are weighted using cost shares. The formula for comparing country-year b relative to country-year c is

$$TFP_{bc} = \left[\prod_{j=1}^{N} \left(\frac{y_{bj}}{\bar{y}_j} \right)^{\rho_{bj}} \left(\frac{\bar{y}_j}{y_{cj}} \right)^{\rho_{cj}} \right] \left(\frac{\bar{l}}{l_b} \right)^{\sigma_b} \left(\frac{\bar{k}}{k_b} \right)^{1-\sigma_b} \left(\frac{l_c}{\bar{l}} \right) \tag{5}$$

where

y_{cj} = real value added in country c by sector j

$\rho_{cj} = (r_{cj} + \bar{r}_j)/2$, where r_{cj} is the share of total value added in country c accounted for by sector j.

l_c = total labor employed in country c (that is, summed over all N sectors)

k_c = total capital stock in country c (that is, summed over all N sectors)

$\sigma_c = (s_c + \bar{s})/2$, where s_c is labor's share in total cost in country c.

Overbars indicate averages over all the observations in the sample: $\bar{k}$ and $\bar{l}$ are geometric averages while $\bar{r}_j$ and $\bar{s}$ are arithmetic averages. The subscripts b and c can refer to any two distinct observations, such as two different countries during the same year, two different countries in different years, or the same country in different years. As with equation (2), equation (5) is easiest to understand in the Cobb-Douglas case, when the revenue and cost shares are the same across observations, in which case (5) reduces to

$$TFP_{bc} = \left[\prod_{j=1}^{N} \left(\frac{y_{bj}}{y_{cj}} \right)^{r_j} \right] \left(\frac{l_c}{l_b} \right)^{s} \left(\frac{k_c}{k_b} \right)^{1-s}$$

The index (5) used in Table 3 has all the same desirable properties as the industry-by-industry index (2) used in Table A1: it is superlative and transitive.

One practical problem with applying (5) is that it is undefined if there are missing observations for a particular industry. Since there are many holes in the data, this makes it impossible to compare many observations. In constructing Table 3, I apply (5) using data on all industries except Aircraft and Other Transport Equipment.

The information in Table 3 is presented in two ways. In Panel A, each observation is expressed relative to the US in 1987; Panel B presents year by year comparisons relative to the US. In the late 1980s, the United States was the clear leader in TFP among the large countries, with Japan roughly even or slightly behind. A group of five countries (Germany, Italy, the Netherlands, Canada and Norway) were 10-20% points behind the US and Japan. Britain, at 60-70% of US TFP, is the clear laggard among the eight countries in the table. A surprising and possibly anomalous result is that Finland is roughly equal to the US and Japan in TFP. Panel A of Table 3 shows that of the seven countries with at least nine years of data, only Canada and Japan did not see substantial TFP growth from the early to the late 1980s; United States TFP grew by around 35%.

7. Comparison with Other Studies

In this section I compare the results summarized in Tables 2 and 3 to some results of previous researchers. There are two general types of studies that have calculated international TFP differentials: studies of value added (such as this paper) and studies of gross output. Within this breakdown, there are studies which vary in their level of disaggregation and their country coverage. There are many other studies of <u>growth</u> in TFP which are not reviewed here, since they are not directly relevant to the question of the <u>level</u> of TFP across countries.

Among the studies which calculate TFP using a value added output measure are Dollar and Wolff (1993), Dollar, Wolff and Baumol (1988), Maskus (1991), van Ark (1993b), and van Ark and Pilat (1993). The first three of these use overall GDP price levels to deflate sectoral outputs, while the last two use industry-specific deflators calculated from primary sources.

In Dollar and Wolff (1993), the authors use the following TFP index (pg. 67):

$$TFP_{cd} = \frac{y_c}{y_d} \frac{s\,l_d + (1-s)k_d}{s\,l_c + (1-s)k_c}$$

This index can not be derived from index number theory, and seems to be an error. In addition, Dollar and Wolff report some results based on using country specific wage shares, which is not appropriate when making an index number comparison[5]. Despite these methodological problems, it may be worthwhile to compare their results with the results in Tables A1, 2, and 3 above. In their Table 4.1, part II, Dollar and Wolff report TFP for total manufacturing in 1985 using constant wage shares and the inappropriate index above. They find that the US is the TFP leader, with Japan at 93% of the US level and Italy and Germany 7 and 9 percentage points behind Japan respectively. In a disaggregated comparison of the US and Japan, using inappropriate country-specific wage shares, they find that Japan has TFP at 96% of the US level in machinery and at 77% in transport equipment; these are rather different from the numbers reported in Table 2 above, but the general message that Japan trails the US but maybe not by much is preserved.

Two closely related studies are van Ark (1993b) and van Ark and Pilat (1993). These papers deflate value added by a price index which is constructed by direct comparisons of output prices at the wholesale level rather than using GDP PPPs or their components. Unfortunately, this theoretically superior procedure is compromised by the very small number of matches across countries for particular products (see the discussion by Jorgenson following van Ark and Pilat 1993). Both studies use a TFP index based on a Cobb-Douglas production function. In van Ark 1990, the author finds that in 1975 TFP in total manufacturing in the UK was 50-55% of the US level; this large gap is consistent with my Table A1 and Table 2. In van Ark and Pilat 1993, the authors report TFP for machinery and equipment in 1990 (Table 7, pg. 26). They find that Japanese TFP is 27% higher, and German TFP 10 % lower, than the US level. The finding for

Germany is quite close to my Table 2, but their finding that Japan has a large lead over the US is strongly at variance with my results.

Dollar, Baumol, and Wolff (1988) and Maskus (1991) both use a regression based methodology for calculating TFP. Both papers use overall GDP PPPs to deflate value added, and estimate a variant of the following regression for a single year across countries c and industries j:

$$\ln(y_{cj}/l_{cj}) = \beta_c + \alpha_{cj} \ln(k_{cj}/l_{cj}) + \epsilon_{cj}$$

With the US the excluded fixed effect, the exponential of β_c is country c's cross-industry average TFP relative to the US. Comparing only those countries in each study which overlap with the countries in this paper, Table 4 reports each paper's results. Table 4 also reports similar regression-based results from Harrigan (1997b), which uses the same data as this paper.

Maskus finds that the US in 1984 had a very substantial TFP lead over all the other countries, and that Japan trailed the US, Germany, Britain, and Canada. This contrasts with Dollar, et. al. (1988) for 1980 and Dollar and Woolf (1993) for 1982 and 1985, who generally find a modest TFP lead for the US relative to Japan and Germany. An exception is Dollar, et. al.'s result that Germany and the US had the same TFP in total manufacturing in 1980.

The second class of studies of TFP uses data on gross output, and deflates all inputs (capital, labor, materials, energy, etc) in a symmetric way. This procedure was pioneered by Jorgenson and various coauthors. Because of the very stringent data requirements needed for the Jorgenson procedure, however, there have been only a few studies employing this method and they have compared very small numbers of countries. In Jorgenson, Kuroda and Nishimizu (1987), the authors do not report the levels of relative TFP, but they do report that Japan trailed the US in machinery and equipment in 1979, although they expected Japan to close the gap with the US in the near future (pg. 26). Jorgenson and Kuroda (1990) updates the earlier study, and reports that by the mid-1980's Japan had industry TFP that was equal to or greater than US TFP in many machinery sectors. Their results are generally consistent with my Tables 2 and 3, which provides some grounds for hoping that the results of value added and gross output TFP comparisons might generally be comparable.

8. Conclusion

Previous research has suggested that there are substantial technology differences in manufacturing among the developed countries. This paper has confirmed this view by applying index number theory in a consistent way to recent data covering a broad sample of developed countries. The results of this paper suggest that the US and Japan were the co-leaders in overall TFP in manufacturing during the 1980s, with the US perhaps slightly in the lead. This overall conclusion, however, masks substantial differences in sectoral productivity within machinery and equipment, as suggested by Dollar and Wolff (1993).

Overall TFP has well understood implications for relative material living standards. In addition, sectoral TFP differences have implications for our understanding of what determines the pattern of trade among the advanced countries. In Harrigan (1997b), different hypotheses about the causes of TFP differences are compared. Using the same data as this paper, a simplified model where there are constant returns to scale and country technology differences statistically dominates a model with increasing returns and identical technology. In the neoclassical model of Harrigan (1997a), TFP and factor supply differences jointly determine specialization along the lines of comparative advantage. Using a somewhat different dataset from this paper, Harrigan (1997a) finds that TFP is an important determinant of comparative advantage. It appears from this line of research, along with Dollar and Wolff (1993) and Trefler (1993, 1995), that TFP differences should receive greater attention from international trade economists using the neoclassical general equilibrium framework.

End Notes

1. In section 7 below, I show that my results on US-Japanese relative TFP using value added are very similar to the results of Jorgenson, Kuroda, and Nishimizu (1987) and Jorgenson and Kuroda (1990) who use correctly deflated gross output.

2. An exception to this is the work of a group of researchers at the University of Groningen who construct industry level value added deflators by compiling unit value indexes from primary statistical sources (see van Ark, 1993a and 1993b, and van Ark and Pilat, 1993). The Groningen group's efforts cover only a small group of countries, however, and their price levels have been criticized because of the small number of product matches that they are based on (see the comments following van Ark and Pilat, 1993).

3. All countries have data available for 1985 and 1990, while all but Australia and Sweden have data available for 1980. I set price level percentages for 1980-84 in Australia and Sweden equal to their 1985 values.

4. I use the 1983 differentials for 1980-82 and the 1988 differentials for 1989-90. This is a small distortion since these differentials change slowly over time.

5. An index number by definition compares two vector observations using some common weights for the corresponding elements of the two vectors. In some of their results Dollar and Wolff use two different wage shares in the construction of bilateral TFP comparisons (Panel I of Table 4.1 and all of Table 4.2), although in other results they use a single international average wage share (Panel II of Table 4.1).

Table 1 - Industry Price Levels as a Percentage of GDP Price Levels

industry	year	Country										
		Aus	Can	Fin	Fra	Ger	Ita	Jpn	Nth	Nor	Swe	Gbr
ISIC 382	1980		88	141	128	119	156	109	122	131		146
Non-Elec.	1985	91	126	109	120	107	132	122	116	111	91	129
Equipment	1990	130	117	109	147	131	159	129	136	114	97	152
ISIC 383	1980		108	128	148	130	156	106	126	122		144
Electrical	1985	87	109	71	83	81	87	96	81	75	107	75
Equipment	1990	96	86	64	118	108	115	69	99	76	70	105
ISIC 384	1980		95	191	121	111	179	70	124	154		153
Transport	1985	112	117	138	91	85	115	96	99	128	106	118
Equipment	1990	117	119	147	141	124	150	73	141	170	126	161

Table 2 - Summary of TFP Results, Average TFP relative to US Average TFP, detrended

	Non-Electrical Machinery	Office & Computer Equipmnt	Electrical Machine-ry	Radio, TV, & Comm.	Motor Vehicles	Ship-building	Aircraft	Other Trans. Equip.
Australia			262	86	61	67		
Britain	52	58	166	52	37	38	42	
Canada	99	51	241	76	78	81	66	96
Finland	76	93	256	66	44	51	46	
Germany	69	64	158	82	79	78	69	
Italy	73	48	245	60	73	52	67	83
Japan	79	63	229	63	94	100		
Netherlnd	67	54			75	119		84
Norway	65	36	209	50	36	45	35	
Sweden						50		

Notes to Table 2: The numbers in this table are regression-based summaries of the TFP data in Table 2. Each entry is 100 times the exponential of the country fixed effect D_c in the following regression for sector j:

$$\ln TFP_{cjt} = D_{cj} + \delta_j \cdot t + \epsilon_{cjt}$$

where $\ln TFP_{cjt}$ is the log of industry j TFP in country c in year t relative to the sample mean TFP of industry j. The United States is the excluded fixed effect, so the entries in the table are percentage differences from the United States.

Table 3 - Overall TFP in Machinery & Equipment

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Panel A: TFP is expressed relative to a base of United States in 1987 = 100										
Britain	35	36	41	44	53	64	63	64	68	
Canada	94	86	76	79	86	88	86	83	93	
Finland	48	52	60	61	69	89	82	105	110	117
Germany	63	65	69	73	80	94	89	90	90	86
Italy						79	76	82		
Japan	91	92	90	84	87	91	87	95	112	121
Norway	51	52	52	53	56	66	73	79	81	83
United States	89	88	81	82	87	91	93	100	111	114
Panel B: TFP is expressed relative to a base of United States in each year = 100										
Britain	39	41	51	54	61	70	68	64	61	
Canada	106	98	93	96	99	97	93	83	84	
Finland	54	59	74	75	80	97	88	105	99	103
Germany	71	74	85	89	92	104	95	90	81	76
Italy						86	82	82		
Japan	102	105	111	103	100	100	94	95	100	106
Norway	58	59	64	64	64	73	78	79	72	72
United States	100	100	100	100	100	100	100	100	100	100

Notes to Table 3: The TFP comparisons in this table are index numbers using the industry level data presented in Appendix Table 1. Data for two of the eight industries, Aircraft and Other Transport Equipment, are excluded. For the index number formula used in this table, see equation (5) in the text.

Table 4 - Comparison of TFP Results with other Studies

Study	Harrigan 1997b	Dollar & Wolff 1993	Maskus 1991	Dollar, et. al. 1988
Coverage	Machinery & Equipment	Total Manufacturing	Machinery & Equipment	Total Manufacturing
year	1980-1989	1982, 1985	1984	1980
TFP Relative to US = 100				
Australia	115	n.a., 78	45	73
Britain	62	70, 64	66	78
Canada	91	n.a, 71	70	82
Finland	75	n.a., 63	n.a.	77
Germany	90	87, 84	68	101
Italy	74	68, 86	52	84
Japan	93	92, 93	61	91
Netherlands	82	67, 67	n.a.	n.a.
Norway	55	n.a., 62	44	66
Sweden	58	n.a., 62	59	89

Note to Table 4: These estimates are all regression based. For a discussion of the methodology of these studies and their comparability, see the text.

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Appendix Table 1 - Total Factor Productivity, relative to US Level in 1987

Country	Year	MANEC	OC	EM	EE	MV	SH	AE	OTR
Australia	80			223	108	88	128		
	81			235	118	87	130		
	82			245	136	94	130		
	83			135	84	52	68		
	84			134	97	58	63		
	85			134	97	58	65		
Britain	80	40	44	52	33	25	29		
	81	38	43	56	38	25	37		
	82	41	49	70	46	28	37		
	83	43	51	77	52	31	33		
	84	49	55	95	65	36	40		
	85	58	62	116	76	43	50	39	
	86	61	59	113	72	44	33	46	
	87	65	63	108	68	41	39	42	
	88	65	69	113	72	44	42	45	
Canada	80	122	60	117	89	67	114	87	109
	81	107	54	122	85	61	110	95	93
	82	84	51	110	82	57	92	77	90
	83	75	42	105	71	79	73	41	76
	84	85	45	113	77	88	77	64	81
	85	89	43	125	74	87	79	65	79
	86	99	39	130	75	75	57	56	79
	87	100	43	137	88	64	55	65	83
	88	108	53	161	94	73	75	60	98
Finland	80	49	90	81	31	32	40		
	81	53	99	89	38	31	40		
	82	56	93	99	56	31	51		
	83	56	79	108	67	34	47		
	84	67	89	121	69	38	48		
	85	85	75	152	91	45	65		
	86	83	84	164	96	47	37		
	87	109	109	178	121	50	66		
	88	114	104	218	105	54	47		
	89	119	57	254	132	58	62	46	

MANEC Non-Electrical Machinery, **OC** Office and Computing, **EM** Electrical Machinery except EE, **EE** Radio, TV, & Communications, **MV** Motor Vehicles, **SH** Shipbuilding, **AE** Aircraft, **OTR** Other Transport Equip.

Appendix Table 1, Continued

Country	Year	MANEC	OC	EM	EE	MV	SH	AE	OTR
Germany	80	62	51	63	61	63	61	62	
	81	60	51	62	69	66	68	68	
	82	57	56	67	79	71	78	67	
	83	58	59	75	88	75	71	64	
	84	64	62	89	97	78	88	70	
	85	78	67	105	112	91	85	74	
	86	74	64	103	102	78	80	69	
	87	78	61	101	102	75	92	70	
	88	78	66	104	110	73	76	72	
	89	80	60	95	110	72	68	84	
Italy	85	76	48	152	77	53	54	72	
	86	76	44	148	71	49	49	63	78
	87	84	43	149	73	54			
	88					199			
Japan	80	77	61	103	63	105	111		
	81	77	56	103	67	94	119		
	82	73	57	109	65	83	110		
	83	67	58	107	64	79	92		
	84	64	78	112	70	76	90		
	85	80	57	118	66	80	83		
	86	79	54	120	63	74	80		
	87	84	53	131	69	83	87		
	88	94	59	159	86	101	96		
	89	98	62	180	96	115	116		
Nether-lands	80	51	50			138	93		
	81	53	42			92	90		
	82	55	44			51	118		
	83	53	54			53	126		
	84	59	72			58	121		
	85	76	44			59	135		
	86	78	59			61	125		65
	87	89	45			56	146		120
	88	84	49			82	104		68

MANEC Non-Electrical Machinery, **OC** Office and Computing, **EM** Electrical Machinery except EE, **EE** Radio, TV, & Communications, **MV** Motor Vehicles, **SH** Shipbuilding, **AE** Aircraft, **OTR** Other Transport Equip.

Appendix Table 1, Continued

Country	Year	MANEC	OC	EM	EE	MV	SH	AE	OTR
Norway	80	50	27	69	33	32	39	38	
	81	51	32	86	37	31	38	41	
	82	51	37	85	41	31	39	36	
	83	51	37	92	49	31	40	32	
	84	56	40	98	56	33	37	32	
	85	70	40	117	61	36	42	36	
	86	77	44	140	69	36	47	24	
	87	87	32	155	78	36	53	41	
	88	85	30	159	81	37	54	39	
	89	89	26	165	77	38	54	39	
Sweden	80						48		
	81						59		
	82						67		
	83						56		
	84						42		
	85						54		
	86						56		
	87						42		
	88						37		
	89						37		
USA	80	103	99	54	119	73	91		
	81	101	97	59	111	71	93		
	82	91	91	32	111	68	93	92	79
	83	88	81	29	108	91	94	95	81
	84	91	88	26	115	102	99	104	89
	85	97	79	43	108	105	99	105	84
	86	102	81	43	106	100	99	99	90
	87	100	100	100	100	100	100	100	100
	88	108	110	114	116	117	104	103	103
	89	112	114	115	122	125	107	107	131

Notes to Appendix Table 1: For the index number formula used in this table, see equation (2) in the text.

MANEC Non-Electrical Machinery, **OC** Office and Computing, **EM** Electrical Machinery except EE, **EE** Radio, TV, & Communications, **MV** Motor Vehicles, **SH** Shipbuilding, **AE** Aircraft, **OTR** Other Transport Equip.

Discussion of Appendix Table 1

Table A1 reports TFP for each observation with complete data. For each industry, the country and year of comparison is the US level in 1987; this year was chosen because it is a year with complete US observations across industries, and because it represents a year of approximately full employment in the US. Because the TFP index is multilateral, choosing this normalization makes no difference to any other bilateral comparisons within an industry. The first observation is that few of the entries are close to 100, meaning that for most countries and years the level of TFP is different from the US level in 1987. This general point accords with previous research, and casts doubt on the notion that technology is the same across the sampled countries. Second, there is a great degree of volatility over time within countries, some of which seems to be attributable to business cycle effects; for example, US TFP declines during the 82-83 recession, and increases thereafter. These cyclical effects are why the numbers are presented relative to the US level in 1987; year by year comparisons to the US are uninformative because they are dominated by differences across countries in the stage of the business cycle.

Careful scrutiny of Table A1 induces a deep suspicion about data problems. For example,

1. Australian TFP in each industry plummets between 1982 and 1983, a result due to a big jump in measured employment.

2. Italian TFP in motor vehicles nearly quadruples from 1987 to 1988.

3. US TFP in electrical machinery more than doubles from 1986 to 1987.

These are the largest apparent anomalies in Table A1, and they seem easily attributable to gross measurement error. It is certain that there are other measurement errors in both the nominal quantities from the STAN data as well as the price and occupational data. A second type of error that infects Table A1 comes from the inevitable distortions imposed by the deflation of nominal quantities with prices derived for different uses. A third type of error comes from the crude procedure used to construct capital stocks. Nevertheless, Table A1 represents a careful application of index number theory to some of the best data that is available, and it seems very difficult to maintain that the large and persistent TFP differences identified across countries can be attributed solely to measurement difficulties.