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TECHNOLOGY TRANSFER THROUGH IMPORTS

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ABSTRACT

While there is general agreement that technology differences must figure prominently in any successful account of the cross-country income variation, not much is known on the source of these technology differences. This paper examines cross-country income differences in terms of factor accumulation, domestic R&D, and foreign technological spillovers. The empirical analysis encompasses seventeen industrialized countries in four continents over three decades, at a level disaggregated enough to identify innovations in a number of key high-tech sectors. International technology transfer is found to play a crucial part in accounting for income differences. We also relate technology transfer to imports, showing that imports are often a major channel. At the same time, our analysis highlights that international technology transfer varies importantly across industries and countries.

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I. Introduction

There is broad consensus among economists that productivity differences must figure prominently in any successful account of the cross-country income variation—differences in labor and capital are just not big enough (Hall and Jones 1999). At the same time, we do not have a good understanding yet of where productivity differences come from and how they evolve over time. In this paper, total factor productivity differences across countries are explained in terms of domestic technical change and international technology transfer. Research and development (R&D) spending is the major input in technical change, generating knowledge which has both private and social returns. Past innovative efforts benefit today's inventors, and today's inventions generate externalities, or spillovers, for producers in the future.

Since today's level of economic integration is unprecedented in the economic history of the world, our model of income differences must also incorporate the enormous interdependence of countries for technology transfer across countries. In this framework, international technology transfer occurs whenever technology investments by entrepreneurs in one country generate technology spillovers to producers in other countries. International market transactions are a likely conduit for such technology spillovers. In this paper we will specifically assess the contribution of imports in this process.

Many theories of income differences are based on hard-to-observe factors. This makes rigorous testing of those theories difficult if not impossible. In comparison, our account of cross-country income differences through technical change and international technology transfer is empirically straightforward. Our results are based on a comprehensive new data set on R&D, factor inputs, imports, and productivity for a broad sample of twenty-two manufacturing industries in seventeen industrialized countries and the years 1973 to 2002.

The analysis shows, first of all, that R&D has an important effect on productivity. A 10% increase in domestic R&D translates on average into about 1.5% higher productivity in our sample. At the same time, the contribution of international technology transfer often exceeds the effect of domestic R&D on productivity. On average, the combined impact of R&D investments in six countries close to the world's technology frontier, the US, Japan, Germany, France, the UK, and Canada, is about three times as large as that of domestic R&D.

Moreover, we show that the global patterns of technology transfer are highly asymmetric. For example, the impact of US R&D on UK productivity is twice as large as the US effect in Germany or Spain. We also find that some countries benefit more from foreign technology than other countries across the board. Canada, for example, benefits about 50% more from Japanese R&D and 33% more from French R&D than the average country. This suggests that Canada has a relatively high absorptive capacity for benefiting from international technology spillovers.

In addition, Canada benefits very strongly from US R&D, which is surely in part because of its geographic proximity (Keller 2002). However, geography cannot be the whole story, since productivity in Ireland is far more strongly affected by US R&D than productivity in similarly located England. A more complete picture emerges when we link technology transfer to international trade between countries. It is shown that the majority of all technology transfer from the US and the UK occurs through imports, whereas Germany and Japan transfer technology abroad primarily through non-trade channels. We also find that across the board, technology transfer has become much more important during the 1990s relative to the period before.

This paper makes a number of contributions. First of all, it is the most comprehensive study of its kind. It encompasses more countries and a longer sample period, and perhaps most importantly, it allows isolating major high-technology sectors that were the drivers of economy-wide productivity trends during the late 1980s and 1990s. On the econometric side, we employ instrumental-variable and control-function approaches, which enable us to estimate causal effects as opposed to correlations. Our analysis is rich enough to reveal a substantial amount of technology-sender and –recipient heterogeneity, thereby setting the stage for future studies towards a better understanding of the global web of technology transfer.

We also present new results on the role of imports in international technology transfer, where the early evidence has been mixed.[4] In contrast to much of the literature that seeks to address this issue (including Xu and Wang 1999, Caselli and Coleman 2001, and Eaton and Kortum 2001), we specify an explicit alternative to trade-related technology transfer. This not only provides a more powerful test of the hypothesis, but also allows us to assess the relative magnitude of imports-related technology transfer relative to all international technology transfer.

The remainder of the paper is as follows. In section II we describe the new dataset that is underlying our empirical analysis, before turning to estimation issues in section III. The empirical results are found in section IV, and section V provides a concluding discussion.

II. Data

The sample period for this analysis covers the years 1973 to 2002. With three decades of data, the period is long enough to include both the productivity slowdown in the 1970s as well as the surge of innovations in the 1990s. We study technical change at the industry-level. This is important because technical trends tend to break in an uneven way across sectors; in the 1990s, it was primarily information and technology sectors. Thus, rather than analyzing manufacturing or the entire economy, where such changes tend to be muted, we examine disaggregated data for

[4] See Coe and Helpman (1995) and Keller (1998); additional discussion is provided in Keller (2007, 2004).

twenty-two manufacturing industries. This allows special emphasis on particularly technology-intensive sectors, which is important since recent evidence suggests that international technology transfer varies substantially across industries (Keller and Yeaple 2007). Moreover, our analysis is global in the sense that the 17 advanced countries in our sample are located in four different continents and account for most of the world's R&D expenditures.[5]

Internationally comparable figures on employment, output, and sectoral prices come from Groningen Growth and Development Centre (GGDC) database (van Ark et al. 2005) for the years 1979-2002. We have combined this with data on employment, output and sectoral prices for 1973-78, from the OECD's STAN database (OECD 2005a). This is also the basis for the GGDC figures. Also from the OECD's STAN database comes data on investment. Data on sample countries' business R&D (ANBERD database, OECD 2005b), as well as on the bilateral trade among them (BTD database, OECD 2005c) are also from OECD.

The measure of output in this analysis is value added, since internationally comparable data on intermediate inputs is not available.[6] Labor inputs are measured by the number of workers. We have constructed capital stocks and R&D stocks for each industry in each country and year from the investment data using the perpetual inventory method as given in Appendix C. For each country, there are 660 possible observations (with 22 industries and 30 years); however, actual data availability varies. As Table 1 indicates, the dataset is complete for many series. The major exceptions are (i) Belgium, for which R&D data become available only in 1987; (ii) Ireland, for which investment data started only in 1992, and (iii) South Korea, where R&D data are only recorded from 1995 onwards. In addition, there are some missing values during the 1970s. By industry, there is a maximum of 510 observations for each industry. As the lower part

[5] The countries in sample are: Australia, Belgium, Canada, Denmark, Finland, France, United Kingdom, Germany, Ireland, Italy, Japan, South Korea, the Netherlands, Norway, Spain, Sweden and USA.
[6] Details on data sources, construction and estimation are provided in the Appendices A through C.

of Table 1 shows, data availability by industry varies little. This means that such data availability differences will not have an important influence on the results.

Table 2 provides information on R&D intensities (average of the sample period), defined as R&D expenditures over value added, in both the country and the industry dimension. Across countries, the R&D intensity varies by a factor of three to four, with values from 3.1% for the low R&D-intensity countries Ireland and Spain to values of 10.0% and 10.6% for the high R&D-intensity countries US and Netherlands, respectively.[7] The R&D intensity varies a great deal more across industries, from 0.6% on average in the wood products industry to 26.1% in the radio, television, and communications equipment industry. Also high are the R&D intensities of the aircraft (23.8%), computer (21.3%), and pharmaceuticals (18.0%) industries. Moreover, as the table indicates, there is a substantial amount of variation in R&D intensities for a given country or industry. For instance, Ireland's computer industry (industry #14) has an R&D intensity of only one tenth of the average across countries, while in another high-R&D intensity industry, communications equipment (industry #16), Ireland's R&D intensity is quite close to the average across countries. There is also substantial variation in R&D intensities across industries in a country. For example, Canada's R&D intensity ranges from as low as 0.5% in food products to as high as 37% in radio, television and communication industry.

Tables 3 to 5 provide summary statistics on employment, capital stocks, and R&D stocks by industry and by country. In particular, Table 5 indicates that the size of the US industry's R&D is by far the largest of all 17 countries: the median US industry's size in terms of R&D is 39.6% of the sample. Next in size is Japan (median of 27.4%), followed by Germany (7.5%),

[7] South Korea's average R&D intensity is, with 6.1%, considerably higher than Ireland's or Spain's, but this is in part due to the fact that for South Korea the average is computed with data from 1995 onwards, a time by which South Korea's R&D spending had substantially grown.

France (6.5%), and the UK (4.9%). Also the remaining G-7 countries, Canada and Italy, are among the more important producers of technology (R&D shares 2.5% and 2.3%, respectively).

It is well-known that international trade varies substantially across countries and industries. Table 6 gives a glimpse of that by showing the share of the US in total imports by partner country and industry. In Canada almost three quarters of all imports come from the US. In contrast, most European countries import only around 10-15% of their goods from the US (except the UK where the US share is 21.6%). By industry, the US share of total imports has been highest for aircraft, followed by computers. For imports, we study their importance for technology transfer from Canada, France, Germany, the UK, Japan, and the US (referred to as the G6 countries)

We now turn to the major estimation issues.

III. Estimation

Technology in this paper is the residual contribution to output that is not due to measured inputs (Solow 1957). Consider the Cobb-Douglas production function for industry i at time t in country c:

(1) $$Y_{cit} = A_{cit} K_{cit}^{b_k} L_{cit}^{b_l},$$

where $i = 1,\ldots, 22$; $c = 1,\ldots, 17$; and $t = 1973,\ldots, 2002$. Here, Y is output, K is capital, L is labor, and $ß_k$ and $ß_l$ are the elasticities of capital and labor, respectively.[8] The term A in equation (1) is an index of technology, or productivity. It follows that

(1') $$\ln A_{cit} = \ln Y_{cit} - b_k \ln K_{cit} - b_l \ln L_{cit}$$

[8] These may vary by industry or country, which we will discuss below.

If one fixes the values of ß$_k$ and ß$_l$ —a choice roughly in line with national income statistics is ß$_k$ =1/3 and ß$_l$ =2/3 —, the technology term A can be computed from (1') with data on inputs and outputs. In this paper, regression analysis is used to estimate ß$_k$ and ß$_l$ while at the same time the implied technology term is related to R&D spending. From equation (1),

(1") $$y_{cit} = b_k k_{cit} + b_l l_{cit} + u_{cit},$$

where for any variable Z, $z = lnZ$, and u_{cit} is equal to $\ln A_{cit} = a_{cit}$. Following Griliches (1979) and others, a is determined by domestic R&D expenditures, R, and other factors, X

(2) $$a_{cit} = b_0 + g\, r_{cit} + Xb + e_{cit},$$

where e is a stochastic error term. One major element of X is foreign R&D, which may have an effect on domestic technology through international technology transfer. In addition, we will examine imports as a mechanism of international technology transfer. Substituting (2) in (1") yields our main estimation equation

(3) $$y_{cit} = b_0 + b_k k_{cit} + b_l l_{cit} + g\, r_{cit} + Xb + e_{cit}.$$

Equation (3) is an augmented production function. A number of generic issues exist in the estimation of the capital and labor coefficients, and in the multivariate regression context any bias in ß$_k$ and ß$_l$ generally leads to biases in the other regression coefficients as well. A major econometric issue confronting production function estimation is the possibility that some of these inputs are unobserved. In that case, if the observed inputs are chosen as a function of the unobserved inputs, there is an endogeneity problem, and OLS estimates of the coefficients of the observed inputs will be biased. Specifically, even in the case where capital and labor are the only inputs, if the error term is composed of two parts

(4) $$e_{cit} = w_{cit} + u_{cit},$$

where u_{cit} is noise (or measurement error in y_{cit}), while w_{cit} (which could be a determinant of productivity or demand) is observed by agents who choose the inputs. This implies that OLS will generally not yield unbiased parameter estimates because $E[l_{cit}\, e_{cit}] \neq 0$ or $E[k_{cit}\, e_{cit}] \neq 0$, or both. The unobservable factor w_{cit} does not have to be varying over time or across groups in order to have this effect.[9] Along these lines, $w_{cit} = w_{ci}$ may capture time-invariant productivity differences across industries, or $w_{cit} = w_t$ may be shocks that affect all industries in the sample.

We will employ several estimators in order to address this issue. First, we assume that the unobserved term w_{cit} is given by country-, industry-, and time-effects that are fixed and can be estimated as parameters:

(4') $\quad e_{cit} = h_c + m_i + t_t + u_{cit}$,

If (4') holds, OLS will yield consistent and unbiased estimates; in fact, OLS will then be the best linear unbiased estimator. Second, we will employ the General Method of Moments (GMM) techniques developed by Arellano, Blundell, Bond, and others (Arellano and Bond 1991, Blundell and Bond 2000). Assume that

(4'') $\quad e_{cit} = V_{ci} + t_t + u_{cit}$,

where year fixed effects (t_t) control for common macro effects; V_{ci} is the unobservable industry component, and u_{cit} is a productivity shock following an AR(1) process, $u_{cit} = r u_{cit-1} + y_{cit}$. The industry component V_{ci} may be correlated with the factor inputs (l_{it}, k_{it}, and r_{it}) and elements of X, and V_{ci} may also be correlated with the residual productivity shock u_{cit}. Assumptions over the initial conditions and over the serial correlation of u_{cit} yield moment conditions for combining equations in levels (of variables) with equations in differences (of variables) for a System GMM

[9] A group here is a country-by-industry combination, denoted by the subscript *ci*.

approach. In both equations, one essentially uses lagged values to construct instrumental variables for current variables.

Third, we adopt the approach developed by Olley and Pakes (1996). This involves assumptions on the structure of the model (on timing, invertability, dimensionality, etc.) such that w_{cit} can be expressed as a function of investment i_{cit} and capital k_{cit}.

(4''') $\quad e_{cit} = w_{cit} + u_{cit} = g(i_{it}, k_{it}) + u_{cit}$,

where the function g(.) is unknown.[10] The idea is that conditional on capital, we can learn about w_{cit} by observing i_{cit}, that is, $i_{cit} = f(w_{cit}, k_{cit}) = g^{-1}(w_{cit}, k_{cit})$. In essence, investment serves as a proxy for the unobserved w_{cit}. Once a consistent estimate of w_{cit} is obtained, the source of the potential endogeneity problem in equations (3, 4) is eliminated, and the production function parameters can be estimated. We will employ both a variant of Olley and Pakes' two-step procedure as well as the more recent one-step GMM procedure proposed by Wooldridge (2005).

We also compare these regression-based estimates of b_l and b_k with direct estimates from on the OECD STAN's data on labor's share in total compensation, as cost minimization together with CRS implies that b_l is equal to labor's share, and b_k is equal to one minus labor's share in total costs. This yields an alternative estimate of the technology term a.

IV. Empirical Results

1. The Contributions of Labor and Capital

Initially we focus our attention on the input parameters for capital and labor. Table 7 reports OLS estimates for b_k and b_l from

[10] See also Griliches and Mairesse (1998) and Ackerberg, Caves, and Frazer (2005) for a discussion of these assumptions.

(5) $y_{cit} = b_0 + b_k k_{cit} + b_l l_{cit} + e_{cit}$,

which is a restricted version of equation (3).[11] The columns in Table 7 correspond to results for different assumptions on the regression error e_{cit}. When the equation only includes a constant, b_k is estimated around 0.43 and b_l at about 0.57, and the null hypothesis of constant returns to scale cannot be rejected (*p*-value of 0.27).[12] Including time- (7.2), country- (7.3), and industry fixed effects (7.4) improves the fit in terms of $\overline{R}^2$ of the equation, and it leads to relatively modest changes in the estimates (b_k falls to 0.375, while b_l rises to 0.626). Also with fixed effects, the model seems well-characterized with constant returns to scale (*p*-value of 0.98 in 7.4). When we allow for deterministic fixed effects for each country-by-industry combination (also called within-estimation), however, we estimate b_k to be much higher and b_l to be much lower (see 7.5).[13] It is likely that this reflects well-known problems of the within-estimator in the presence of measurement error (Griliches and Hausman 1986).

Since OLS may suffer from endogeneity problems, in Table 8, we compare the least squares estimates with alternative estimators. First, consider the case where there is no unobserved heterogeneity (no fixed effects). Column one of Table 8 repeats the least squares estimates of column one in Table 7 for convenience. Specification (8.2) employs the System GMM IV estimator (Blundell and Bond 2000). Labor and capital are treated as endogenous and may be correlated with the error through a random group fixed effect V_{ci}. Labor and capital are instrumented with their own appropriately lagged values, which accounts for the lower number of observations in the System GMM compared to the OLS estimation. We include three

[11] We have computed physical capital stocks using the perpetual inventory method and depreciation rate of 5%. The R&D stocks are computed using a rate of depreciation of 15%. The labor measure is the total number of employees.
[12] Heteroskedasticity-consistent (Huber-White) standard errors are reported in all OLS regressions.
[13] This within-estimator involves estimating C x I = 17 x 22 = 374 group fixed effects. In contrast, (7.4) involves C + I = 17 + 22 = 39 fixed effects for the country and industry dimensions.

instruments, l_{t-2}, l_{t-3}, and k_{t-2}, and given two endogenous variables (l_t, k_t) there is one overidentifying restriction. At the bottom of (8.2), the *p*-value of 0.968 for the Sargan test of overidentification statistic says that one cannot reject the null hypothesis that the instruments, as a set, are exogenous.[14]

The last two rows in Table 8 test for serial correlation in the equation's first differences using LM tests. Generally, as the lag length increases, the quality of the instrument declines. In order to avoid a weak-instruments problem, the lag order should be low while at the same time the lagged value should not be itself endogenous. The AR(2) test in the last row of Table 9 indicates that because the evidence for second-order autocorrelation in the first-differenced residual is limited, variables at date (*t-2*) and earlier are marginally valid instruments.

The next two columns present two different versions of the Olley-Pakes (1996) estimator. Specification (8.3) follows closely the Olley-Pakes (OP) original two-step procedure. In step one the unobservable w_{cit} (see equation (4''')) is approximated by a third-order polynomial in investment and capital, which allows the identification of b_l. In the second step, the assumption that capital is uncorrelated with the innovation w_{cit}, which follows a first-order Markov process, ensures the identification of b_k. In column (8.4), we show the results of implementing the Olley-Pakes estimator in the one-step GMM procedure recently proposed by Wooldridge (2005), which is denoted as OP/W.[15] The OP results yield a labor coefficient of 0.53 (see 8.3), similar to that for the one-step variant (8.4), where we estimate b_l to be 0.51. However, the capital coefficient

[14] It is possible to reject the null that the instruments as a set are exogenous if we include further lagged values as additional instruments. At the same time, it is well-known that this test has low power when the number of overidentifying restrictions is high, since then there is an overfitting problem.

[15] This assumes that w_{cit} is a random walk (not only first-order Markov), and the identification for both b_l and b_k comes solely from moment conditions that correspond to Olley and Pakes' second stage.

using the OP method is estimated to be 0.63, considerably higher than 0.45, obtained with the OP/W estimator, and our OLS estimates of b_k.

For all three estimators, System GMM, OP, and OP/W, the introduction of fixed effects leads to a slightly higher labor coefficient, as it does for OLS (see Table 8). However, the capital coefficient using the OP method is now estimated to be not significantly different from zero anymore (p-value of about 0.14), and the point estimate is also quite different from the earlier one without fixed effects (0.23, before 0.63). In contrast, the OP/W one-step estimator is producing results that are more stable.[16]

It is instructive to compare the estimates of b_l and b_k with the average labor and capital shares in the data. This labor share is 0.647, which with constant returns to scale yields 0.353 for b_k.[17] These values are quite close to System GMM estimates with fixed effects in specification (8.6). To summarize, we estimate the labor elasticity in the range of 0.56 (in 8.8) to 0.68 (in 8.6), with a midpoint estimate of 0.62. Given that the assumption of CRS is not rejected, this puts the capital share at around 0.38.

We are now turning to the impact of R&D.

2. The effects of domestic and foreign R&D

After having examined the quantitative contributions of capital and labor to value added, we now turn our attention to R&D spending. In Table 9, the OLS specification in column 2 introduces the industry's domestic R&D stock in addition to its capital and labor (shown again in column 1 for convenience). For this, we have estimated equation (3) by excluding the X control

[16] This may suggest that step-one identification in OP is weak in this context; Ackerberg, Caves, and Frazer (2005) discuss some of the issues involved.

[17] The average labor share in the data is computed as the average of labor compensation over value added (the median is, with 0.662, similar).

variables. Both capital and labor coefficients fall with the inclusion of R&D (b_l now estimated 0.437, and b_k 0.299). The coefficient on R&D is 0.271, which is at the higher end in the range presented in the literature.[18] The R&D elasticity of 27% implies a rate of return of about 80%.[19] In the System GMM specification shown in column 3, R&D is treated as endogenous; its coefficient estimate is not very different than if it is treated as exogenous (0.246 in (9.3) versus 0.271 in (9.2)).[20] Using the one-step Olley-Pakes estimator leads to a somewhat lower R&D coefficient, at 0.179, and to a higher capital coefficient, as before (see Table 8). Overall, these results are consistent with earlier studies showing that domestic R&D is an important determinant of productivity.

The analysis of international technology transfers begins with spillovers from the US, which conducts most of the R&D in the world. The OLS results in the first column of Table 10 estimate positive and significant R&D elasticities for both domestic and US R&D.[21] The major concern with using OLS is endogeneity, so we employ the System GMM and Olley-Pakes techniques in columns (2) and (3). US R&D is estimated with a foreign elasticity of between 23% and 35%, higher than the domestic R&D elasticity, which comes in between 15% and 18%. Does this mean that for the average country, US R&D has a stronger effect on its productivity than domestic R&D? Not necessarily, since this specification may be omitting important

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[18] This may be due to at least two factors: first, relative to other R&D studies we use broader industry aggregates. With manufacturing divided into 22 industries, our estimate may pick up some industry-level externalities. Second, we do not control yet for foreign technology spillovers; as will become clear from Table 10, they are important. See Griliches (1995) for more discussion.

[19] The average of value added here is 10251, the average R&D is 3402.7, and 0.271*10251/3402 = 0.817. Additional rates of return for foreign R&D will be reported below.

[20] We include l_{t-2}, l_{t-3}, k_{t-2}, and r_{t-2} as instruments, where r_{t-2} is the R&D stock lagged by two years.

[21] In these regressions, we avoid double-counting of the foreign R&D variables. Under domestic R&D variable, the data of each country enters for its domestic industries, whereas under foreign R&D the data for domestic industries are zero. In the first specification of Table 10, for example, under variable "domestic R&D", US R&D data enter for US industries, while under variable "US R&D" US R&D data enter for industries in all other countries except for the US. In general, foreign R&D variables are introduced as $I_c \cdot r_c$, where I_c is an indicator variable that is 0 if this observation is for country c, and 1 otherwise.

international R&D spillovers. In some countries, especially in Europe, the R&D from other major technology producers may well be more important than US R&D.

Some evidence for that can be seen by the drop for the US R&D effect, from 35% to 17%, when Japanese and German R&D are included in column 4. Adding also the next three largest countries in terms of R&D, France, the UK, and Canada, one sees that the international R&D spillovers are in fact relatively diffuse: for all six countries, we estimate significant spillover effects in the average sample country (columns 5 and 6). We will refer to these six countries, US, Japan, Germany, France, UK, and Canada, as the G6 countries. At the same time, international spillovers from these countries vary substantially: the preferred System GMM estimates (column 5) range from 4.2% for the UK to 15.2% for Japan.[22] This suggests that the effects are highly heterogeneous depending on the source country. Moreover, in contrast to column 2 where only the US is considered a source of foreign technology, when R&D for all G6 countries is included, the elasticity of domestic R&D is estimated to be higher than that from any foreign source. This highlights the importance of domestic technology creation.

A crucial question is whether international R&D spillovers have changed over time—specifically, is there evidence for more technology transfer in recent years? The results presented in columns 7 and 8 of Table 10 shed new light on this by dividing the sample into two subperiods. We present results for, roughly, the 1980s and 1990s. For all G6 countries with the exception of the UK, the foreign R&D elasticity has increased over time. The effect is substantial

[22] In the IV GMM specification, we include l_{t-2}, l_{t-3}, k_{t-2}, and r_{t-2} as instruments, as before, while the foreign R&D variables is treated as exogenous. The Sargan overidentification test provides evidence that the instruments, as a set, are exogenous (*p*-value of 0.313). Moreover, there is some evidence for first-order serial correlation in the differenced residuals (p-value of LM test of 0.210), whereas there is none for second-order serial correlation (*p*-value of 0.989). The IV GMM technique thus seems to work well.

in some cases: in the case of the US, for example, the R&D elasticity almost tripled.[23] This suggests that even though the effect of R&D in the domestic economy has remained the same, the international transfer of technology has become significantly stronger over the last three decades.[24]

3. Total factor productivity and labor productivity as dependent variables

By estimating a single elasticity each for capital and labor, our analysis so far has implicitly assumed that factor elasticities are identical across countries, years, and industries. We now relax that assumption by presenting results based on total factor productivity (TFP), computed using information on the cost share for labor together with imposing constant returns to scale (using equation 3). We will also present results for labor productivity in this section.[25]

These results are in Table 11. When the dependent variable is TFP, the domestic R&D elasticity is estimated to be lower than with value added as dependent variable. This may in part be due to the fact that industries with large capital stocks tend to have high capital shares as well.[26] By assuming that the capital elasticity is constant, the value added regression does not account for that, and the high value added is attributed in part to R&D (which is positively correlated with capital). Furthermore, in the value added regressions, we did not impose CRS assumption, in which case R&D might be capturing any non-CRS effects.

The size of the international R&D spillover coefficients for Germany and the UK is lower than in the value added regressions (the UK's is not significant anymore), but the coefficients for

[23] Similar results are obtained when the entire sample period of 1973 to 2002 is divided into two subperiods with 15 years each. However, given the unbalanced panel, we prefer to focus on the 1980s and 1990s for this part of the analysis.

[24] Our findings extend the results of Keller (2002) in this respect.

[25] For the impact of private and public R&D on labor productivity in OECD countries at the aggregate level, see Acharya and Coulombe (2006).

[26] The correlation of the physical capital stock with it its share in total cost is 11%.

the US, Japan, France, and Canada are comparable (see Table 11, columns 3-4). The highest foreign spillover elasticities are estimated for R&D from Japan, the US, and Canada.[27] This is exactly what we found when factor elasticities were restricted across sectors, countries, and time; see the right-most column in Table 11 which reports the baseline IV System GMM estimates (Table 10, (5)) for reference. One difference is that for the TFP specification we are unable to find suitable instruments, as the LM test for second-order serial correlation indicates (*p*-value of 3.7%).[28] In the value-added specification, this is not the case; it is one reason of why we prefer it to the TFP specification in this context.

Finally, we also report results with labor productivity as dependent variable, shown in column 5 of Table 11. Relative to the value-added results (column 6), the domestic R&D is estimated to be somewhat lower (12.0% versus 15.7%), but otherwise the estimates are quite similar. Overall, these results are broadly consistent with those based on value added as dependent variable, and they suggest that the restrictions imposed by common factor shares are not what are driving our results.

4. Source and Destination Heterogeneity

The average R&D spillovers from the major technology producing countries is only part of the full picture of international technology diffusion, since there is evidence that international R&D spillovers vary substantially across bilateral relations (Keller 2002). There are two dimensions that are of particular interest to us here. First, we consider the US as the technology

[27] The strong result on Canada may be in part explained by the fact that the US contributes to Canadian R&D through R&D conducted in US-owned multinationals located in Canada. More generally, it is important to keep in mind that the OECD's R&D statistics are compiled on the basis of geography, not on the basis of ownership.
[28] We estimate the model with two period lagged R&D, $r_{t-2,}$ as instrument for the endogenous r_t, so the equation is just identified. If we include further lags of R&D as additional instruments, the Sargan test rejects the overidentification restrictions.

source and ask how the strength of US technology spillovers varies across recipient countries. Second, we examine the degree to which Canada, as the technology recipient country, benefits from foreign technology spillovers originating in different countries.

The average US spillover is around 23%, as we have shown in Table 10 (specification 3, using the Olley-Pakes/Wooldridge one-step GMM method). Allowing for heterogeneity across countries, using the following equation,

$$y_{cit} = b_0 + b_k k_{cit} + b_l l_{cit} + g\, r_{cit} + \sum_{c' \in 16, c' \neq US} b_{c'}\, r_{USit} + \sum_{c'' \in G5, c' \neq US} b_{c''}\, r_{c''it} + e_{cit}$$

one finds that US R&D has effects ranging from a low of 18.6% in France to a high of more than twice that, 46.5%, in Ireland (Table 12a, column 2). Controlling for R&D spillovers from other G6 countries, the spillover effects from US R&D vary widely. They range from essentially zero to the maximum of 27.7% in Ireland (column 3). The strong effect in Ireland may in part reflect technology transfer related to US foreign direct investment (for example, Dell Computers).[29] In Canada, we estimate an elasticity of 16.5% (second only to Ireland). In contrast, the average for the other nine countries in which US R&D has a positive effect is only 5.7%. Moreover, in five countries—Australia, France, Italy, Korea, and the Netherlands—, US R&D has no significant positive effect at all once we control for R&D spillovers from other G6 countries. Overall, the benefits for Canada from US technology creation are considerably above those that other countries are experiencing.

If US R&D generates heterogeneous spillover effects, this may well be the case for other G6 country R&D as well. While generally estimating more spillover parameters makes both the model less parsimonious and yields less precise estimates, we can focus on a given country and

[29] At the same time, Ireland is a somewhat special case in this analysis, because Irish data becomes only available in the mid-1990s, at the height of the recent technology boom (see Table 1 on data availability).

ask whether it benefits from G6 R&D more or less than other countries in the sample. In the case of Canada, Table 12b summarizes the results of estimation of the following equation:

$$(6) \qquad y_{cit} = b_0 + b_k k_{cit} + b_l l_{cit} + g\, r_{cit} + g_{CAN} I(CAN)\, r_{cit} + \sum_{c' \in G6} \left(b_{c'} + b_{c',CAN} I(CAN) \right) r_{c'it} + e_{cit}\,,$$

where *I(CAN)* is an indicator function that equals one if c = Canada, and zero otherwise. The set G6 includes the countries Canada, France, Germany, Japan, the UK, and the US. In equation (6), ($g + g_{CAN}$) measures the domestic R&D elasticity in Canada, while g estimates the domestic R&D elasticity in the average sample country. Similarly, the spillover effect from US R&D in Canada is given by ($b_{US} + b_{US,CAN}$), whereas the average spillover effect from US R&D is just ß_{US}, and analogously for the spillovers from the other G6 countries.

Abstracting from international technology transfer, the domestic R&D elasticity in Canada is about 0.47 while in other countries it is only about 0.25. Once we control for G6 R&D spillovers, in the average sample country the domestic R&D elasticity is about 14%, in Canada it is about 50% (Table 12b, column 2). Hence Canada's domestic technology creation appears to be highly productive.[30]

Turning to the foreign spillover effects, we see that Canada tends to benefit more from foreign technology than the average sample country. Specifically, Canada gains two to three times as much from US and German R&D than countries do on average. In contrast, Canada does not appear to benefit more from Japanese and French R&D than other countries. These results are obtained using either the System GMM or the one-step Olley-Pakes methods (columns 2 and 3, respectively). The results suggest that producers in Canada have a relatively high capacity to absorb foreign technology.

[30] Note that a substantial part of the R&D conducted in Canada occurs in affiliates of foreign-owned companies. It is not obvious that foreign R&D conducted in Canada has the same implications for economic welfare as Canadian-owned R&D.

Overall, there is tremendous heterogeneity in international technology transfer by source- and destination countries.

5. Technology transfer through imports

International trade has long been considered as a channel of technology transfer. The most influential test of this hypothesis is based on open economy versions of endogenous growth models of the early 1990s (Grossman and Helpman 1991). It asks whether a country's productivity is higher, all else equal, if it imports predominantly from high-R&D countries.[31] This would be consistent with technology being embodied in the imported goods, and there could also be imports-related learning effects. Empirically authors tend to find that the composition of imports of countries has *not* a major effect on productivity along these lines.[32] In general, this could mean that imports are indeed not a major conduit for technology transfer. Alternatively, the result could merely imply that an ancillary assumption of the approach is rejected. Specifically, a maintained assumption in the typical approach is that foreign R&D elasticities are the same in all countries. This hypothesis is easily rejected in our sample; recall that the size of average R&D spillovers varies by a factor of three or more among countries such as Japan and the UK (Table 10). Moreover, spillover patterns may not be captured well by linear import shares. As we have seen above, US R&D has no significant effect in about one third of the sample countries, although they import on average roughly the same from the US as the other countries in the sample.[33]

[31] Coe and Helpman (1995) were the first to test this prediction.
[32] See Keller (2004) for additional discussion.
[33] Australia, France, Italy, Korea, and the Netherlands do not significantly benefit from US R&D once other G5 technology sources are controlled for (Table 12a, (3)). These five countries import on average 20% from the US, while the other eleven countries import on average 21% from the US (Table 6).

Therefore we opt for a more flexible approach, the results of which are presented in Table 13. For a given industry and year, we compute US share of country c's imports ($m_{cUSit} = M_{cUSit} / \sum_{c'} M_{cc'it}$), and interact that variable with US R&D to estimate

$$(7) \qquad y_{cit} = b_0 + b_k k_{cit} + b_l l_{cit} + g\, r_{cit} + \sum_{c' \in G6} b_{c'} r_{c'it} + c_{US}\, m_{cUSit}\, r_{USit} + e_{cit},$$

where c_{US} is the new parameter of interest. If $c_{US} > 0$, industries that import relatively much from the US benefit from imports-related R&D spillovers, in addition to any other US R&D effect picked up by $ß_{US}$. Because the degree to which any industry imports from the US is endogenous and likely affected by how high US R&D spending in this industry is, we use the System GMM estimation technique.[34] In specification (1) of Table 13, c_{US} is not significantly different from zero at standard levels. Since we have primarily considered R&D spillovers from the G6 countries, we focus the analysis to imports from these six countries as well. Hence we define import shares as a fraction of total imports from these six countries, $m^{G6}_{c,c'it} = M_{c,c'it} / \sum_{c' \in G6} M_{c,c'it}$, and include both its interaction with US R&D as well as the import share itself:

$$(7') \qquad y_{cit} = b_0 + b_k k_{cit} + b_l l_{cit} + g\, r_{cit} + \sum_{c' \in G6} b_{c'} r_{c'it} + c^{G6}_{US}\, m^{G6}_{cUSit}\, r_{USit} + \sum_{c',c'' \in G5; c' \neq c'' \neq US} n^{G6}_{c''} m^{G6}_{c',c''}\, r_{c''it} + e_{cit}.$$

Specification (2) in Table 13 indicates that c^{G6}_{US} is estimated at 0.221, while the direct US spillover effect falls essentially to zero ($ß_{US}$ = 0.004). This suggests that spillovers from the US are strongly related to imports. The value of 0.221 implies a US spillover elasticity of 5.7%, evaluated at the mean import share (of 25.6%). This is lower than the value of 8.7% (Table 10, Column 5), the value we found for the direct US R&D without allowing for imports-related spillovers. The difference is, however, that now the US spillovers that an industry receives are a

[34] The US imports-R&D interaction is instrumented by its value two years lagged. Diagnostic tests at the bottom of column 1 provide evidence that this IV strategy is valid. The foreign R&D variables are treated as exogenous.

function of its import share. That ranges from 0 to 98.97 percent in our sample, which means that the US R&D spillover elasticity ranges from 0 to 21.9%, a range that includes the earlier spillover estimate of 8.7%.[35]

The result that US R&D spillovers are strongly related to imports from the US does not change as we extend equation (7') to include imports effects for Japan and Germany, as well as import effects for France, the UK, and Canada (specifications (3) and (4) in Table 13, respectively). As is the case for the US, spillovers from UK R&D appear to be also primarily related to imports from the UK; both the System GMM and the Olley-Pakes/Wooldridge GMM results, columns 4 and 5, find insignificant R&D but significant imports-R&D interactions effects for the UK. The opposite is true for Germany and Japan, where the direct R&D effect is positive, while there is no evidence for imports-related R&D spillovers. For the remaining two countries, Canada and France, we find both imports-related and other R&D spillover effects, with the evidence for spillovers associated with imports from Canada being stronger.

It is interesting to see what the relative economic importance of spillovers related to imports, versus not related to imports is. Canada's direct R&D elasticity estimate is 0.129 in the System GMM specification, and the imports-R&D interaction effect is 0.193. In this sample, on average about 4.9% of the G6 imports come from Canada, so that the average imports-related R&D elasticity is slightly less than 1 percent (0.193 times 0.049). At the 95th percentile, Canada's share in G6 imports is 27%, leading to an imports-related R&D elasticity of around 5 percent. What does this mean for the relative importance of imports-related R&D spillovers from Canada vis-à-vis its total spillover? Evaluated at the average import-share of 4.9%, the

[35] There is a negative correlation between imports from the US and value added (n_{US}^{G6} is equal to -2.102). This does not necessarily mean that a higher import share from the US is associated with lower productivity—it depends on the size of US R&D in this particular industry. The elasticity of productivity with respect to the import share at the average US R&D level is -0.21, while at the 75th percentile it is 0.12.

fraction of spillovers from Canada related to imports is about 7%.[36] For countries with higher import shares from Canada, such as the US, the value at the 95th percentile of imports may be more relevant, and it is about 29%.

The case of France, for example, differs mainly because the countries in the sample import more from France than from Canada; on average, France accounts for 13.9% of all imports from G6 countries in this sample. On average, imports-related R&D spillovers account for a fraction of 0.16 in the total spillovers from France, and this value goes to 0.33 and higher for countries that import substantially from France.[37] Overall, for bilateral relations where international technology transfer is related to imports, the latter account for between 10 and 20 percent of the total effect.

V. Summary and Discussion

The previous analysis has yielded a number of key results. First of all, R&D has an important effect on productivity. A 10% increase in domestic R&D translates on average into about 1.5% higher productivity in our sample. At the same time, the contribution of international technology transfer often far exceeds the effect of domestic R&D on productivity. On average, the combined impact of R&D investments in six countries close to the world's technology frontier, the US, Japan, Germany, France, the UK, and Canada, is about three times as large as that of domestic R&D according to our estimates.

Moreover, we show that the global patterns of technology transfer are highly asymmetric. For example, the impact of US R&D on UK productivity is twice as large as the US effect in Germany or Spain. We also find that some countries benefit more from foreign technology than

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[36] This is calculated as (0.193*0.049)/(0.129+0.193*0.049), where 0.129 = β_{CAN} in Table 13, column 4.

[37] At the 95th percentile of m^{G6}_{cFRAit}, about 37% of French spillovers are associated with imports from France.

other countries across the board, a finding which suggests that there are important differences in absorptive capacity. These could be related to domestic R&D investments or high levels of education, for example. International technology transfer has also become much more important during the 1990s relative to previous decades.

In addition, we confirm earlier results that geography has a strong influence on the extent to which countries benefit from foreign technology. Canada, for example, benefits very strongly from US R&D. However, the results indicate that geography is not the whole story. A more complete picture emerges when we link technology transfer to international trade between countries. Technology transfer between some countries is primarily occurring through technology embodied in imports, while in other cases non-trade channels are much more important than technology embodied in imports.

While a complete account of the source- and destination heterogeneity in international technology transfer is outside the scope of this paper, we believe that further research on these factors is crucial for better understanding the sources of cross-country productivity differences.

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Table 1: Data availability

Country	Name	Value added	Labor	Capital	R&D
		Number of Observation			
1	Australia (AUS)	636	660	600	660
2	Belgium (BEL)	636	660	660	352
3	Canada (CAN)	660	660	660	660
4	Denmark (DNK)	660	640	630	660
5	Finland (FIN)	656	660	660	660
6	France (FRA)	630	651	660	660
7	Great Britain (UK)	654	636	660	660
8	Germany (GER)	660	658	660	652
9	Ireland (IRL)	504	540	165	528
10	Italy (ITA)	654	660	660	654
11	Japan (JPN)	654	660	660	660
12	S. Korea (KOR)	660	660	660	176
13	Netherlands (NLD)	636	654	660	660
14	Norway (NOR)	654	660	660	641
15	Spain (SPN)	654	550	594	660
16	Sweden (SWE)	648	660	660	648
17	USA	630	660	660	636

Industry (International Standard Industrial Classification-ISIC 3)						Industry Description
1	15-16	504	505	491	468	1. FOOD PRODUCTS, BEVERAGES AND TOBACCO
2	17-19	504	505	491	468	2. TEXTILE, TEXT. PRODUCTS, LEATHER AND FOOTWEAR
3	20	498	499	491	468	3. WOOD AND PRODUCTS OF WOOD AND CORK
4	21-22	504	505	491	468	4. PULP, PAPER, PAP. PRODUCTS, PRINTING & PUBLISHING
5	23	504	499	480	468	5. COKE, REFINED PETROLEUM PRODUCTS & NUCLEAR FUEL
6	24ex2423	504	499	491	468	6. CHEMICALS EXCLUDING PHARMACEUTICALS
7	2423	480	494	491	468	7. PHARMACEUTICALS
8	25	498	499	491	468	8. RUBBER AND PLASTICS PRODUCTS
9	26	504	505	491	468	9. OTHER NON-METALLIC MINERAL PRODUCTS
10	271+2731	498	493	474	462	10. IRON AND STEEL
11	272+2732	492	492	474	468	11. NON-FERROUS METALS
12	28	504	499	485	468	12. FABRICATED METAL PRODUCTS
13	29	492	499	491	462	13. MACHINERY AND EQUIPMENT
14	30	492	499	485	468	14. OFFICE, ACCOUNTING AND COMPUTING MACHINERY
15	31	470	499	485	456	15. ELECTRICAL MACHINERY AND APPARATUS
16	32	486	499	485	462	16. RADIO, TV AND COMMUNICATION EQUIPMENT
17	33	498	493	485	468	17. MEDICAL, PRECISION AND OPTICAL INSTRUMENTS
18	34	498	499	474	462	18. MOTOR VEHICLES, TRAILERS AND SEMI-TRAILERS
19	351	492	499	474	462	19. BUILDING AND REPAIRING OF SHIPS AND BOATS
20	353	480	469	414	455	20. AIRCRAFT AND SPACECRAFT
21	352+359	504	486	444	468	21. RAILROAD EQUIPMENT
22	36-37	480	493	491	454	22. OTHER MANUFACTURING AND RECYCLING

Table 2: R&D Intensities by Country & Industry (R&D expenditures over value added; in %), 1973-2002

Country / Industry	AUS	BEL	CAN	DNK	FIN	FRA	UK	GER	IRL	ITA	JPN	KOR	NLD	NOR	SPN	SWE	USA	Average
1	1.0	1.2	0.5	1.4	1.7	0.8	1.2	0.6	0.9	0.2	2.2	1.2	1.9	1.3	0.3	1.8	1.3	1.1
2	0.4	1.9	0.8	0.4	1.0	0.7	0.5	1.0	1.7	0.0	1.5	1.0	0.7	1.2	0.2	1.1	0.5	0.9
3	0.4	0.8	0.4	0.4	0.9	0.3	0.1	0.9	1.2	0.1	1.8	0.3	0.3	0.9	0.1	0.4	0.6	0.6
4	0.6	1.2	0.8	0.2	1.3	0.3	0.5	0.3	0.2	0.1	0.8	0.7	0.2	1.1	0.2	1.8	1.1	0.7
5	1.2	3.2	10.9	1.6	4.4	4.1	9.4	2.2	0.5	1.6	3.1	1.8	6.0	3.8	1.0	2.4	8.2	3.8
6	4.5	10.4	2.2	5.6	6.4	7.6	6.3	11.3	0.9	3.3	13.1	5.3	9.3	9.6	1.8	5.6	8.1	6.5
7	4.2	25.5	13.4	26.4	25.0	22.6	36.2	20.1	5.9	10.2	17.0	3.8	24.1	7.6	6.3	36.3	21.5	18.0
8	1.0	3.5	0.8	1.6	3.4	3.9	0.9	2.3	2.2	1.4	5.3	2.7	1.7	2.4	1.2	3.0	3.4	2.4
9	1.1	2.3	0.5	1.4	2.1	2.0	1.3	1.5	1.6	0.2	4.3	1.6	0.6	1.5	0.4	1.8	2.4	1.6
10	3.3	2.4	0.7	2.7	2.0	2.9	1.6	1.8	2.2	1.0	3.6	1.2	13.7	4.7	0.8	4.0	1.4	2.9
11	1.8	4.2	3.8	0.1	11.1	4.9	2.0	2.1	1.2	0.9	5.5	1.7	7.6	4.7	0.7	3.5	2.2	3.4
12	0.7	2.1	0.8	0.9	2.0	0.7	0.8	1.4	2.0	0.3	1.8	1.1	0.8	1.7	0.4	2.4	1.4	1.3
13	3.2	5.7	1.8	4.7	5.4	3.4	3.9	4.8	2.2	1.1	6.6	5.7	3.8	6.7	1.5	8.6	4.1	4.3
14	13.7	9.7	34.2	18.6	17.9	14.4	16.4	13.4	2.1	21.0	24.8	11.5	72.3	30.5	5.7	15.6	40.0	21.3
15	3.6	6.1	3.6	4.5	9.5	5.4	8.9	6.5	3.8	2.3	15.5	9.2	47.2	6.6	1.9	11.1	7.2	9.0
16	19.7	38.7	37.4	16.2	23.0	34.9	23.7	38.9	24.6	17.2	14.9	21.6	11.3	39.3	9.5	42.0	31.2	26.1
17	11.6	13.5	3.1	12.9	14.3	17.4	6.0	5.6	2.3	1.9	15.6	6.8	5.6	13.0	2.8	13.3	13.6	9.4
18	5.3	2.3	1.0	4.9	2.7	11.0	7.6	10.8	5.1	8.8	33.1	15.1	7.9	6.0	2.6	16.2	14.7	9.1
19	3.8	1.7	0.0	4.4	2.2	1.1	2.6	2.3	2.9	2.1	2.0	2.4	1.0	2.1	3.0	3.2	2.3	2.3
20	1.4	12.8	20.3	0.1	2.5	64.0	30.7	55.6		22.0	22.5	32.3	15.4	4.2	23.6	31.3	42.6	23.8
21	4.2	15.5	1.8	8.5	9.2	4.7	5.9	7.2	0.9	3.1	7.1	4.6	1.8	2.1	3.0	6.9	11.3	5.8
22	0.7	1.9	0.8	4.5	1.0	0.8	1.3	0.2	0.5	0.2	1.6	2.2	0.5	0.9	0.4	0.8	1.5	1.2
Average	**4.0**	**7.6**	**6.3**	**5.5**	**6.8**	**9.5**	**7.6**	**8.7**	**3.1**	**4.5**	**9.3**	**6.1**	**10.6**	**6.9**	**3.1**	**9.7**	**10.0**	

Industry:
1 FOOD PRODUCTS, BEVERAGES AND TOBACCO
2 TEXTILES, TEXTILE PRODUCTS, LEATHER AND FOOTWEAR
3 WOOD AND PRODUCTS OF WOOD AND CORK
4 PULP, PAPER, PAPER PRODUCTS, PRINTING AND PUBLISHING
5 COKE, REFINED PETROLEUM PRODUCTS AND NUCLEAR FUEL
6 CHEMICALS EXCLUDING PHARMACEUTICALS
7 PHARMACEUTICALS
8 RUBBER AND PLASTICS PRODUCTS
9 OTHER NON-METALLIC MINERAL PRODUCTS
10 IRON AND STEEL
11 NON-FERROUS METALS
12 FABRICATED METAL PRODUCTS
13 MACHINERY AND EQUIPMENT
14 OFFICE, ACCOUNTING AND COMPUTING MACHINERY
15 ELECTRICAL MACHINERY AND APPARATUS
16 RADIO, TELEVISION AND COMMUNICATION EQUIPMENT
17 MEDICAL, PRECISION AND OPTICAL INSTRUMENTS
18 MOTOR VEHICLES, TRAILERS AND SEMI-TRAILERS
19 BUILDING AND REPAIRING OF SHIPS AND BOATS
20 AIRCRAFT AND SPACECRAFT
21 RAILROAD EQUIPMEN
22 OTHER MANUFACTURING AND RECYCLING

Table 3: Employment by Country & Industry (Total number of workers engaged; in 1000), 1973-2002

Country	AUS	BEL	CAN	DNK	FIN	FRA	UK	GER	IRL	ITA	JPN	KOR	NLD	NOR	SPN	SWE	USA	Average
Industry																		
1	180	106	259	92	56	617	610	1008	57	474	1512	290	171	55	412	75	1769	456
2	114	105	178	34	50	511	608	629	30	1196	1872	1034	58	15	422	29	1975	521
3	48	15	114	14	40	116	93	210	5	229	433	64	27	23	106	48	776	139
4	127	60	253	57	86	346	505	650	21	293	1046	188	149	51	172	118	2209	372
5	6	8	17	1	4	41	34	44	1	29	47	31	8	2	11	3	165	27
6	31	57	77	14	17	186	258	526	14	186	343	112	76	9	101	25	795	166
7	24	15	17	10	3	72	82	115	4	87	152	49	12	7	42	14	262	57
8	46	24	80	20	16	205	243	367	9	174	408	168	30	8	98	26	839	162
9	54	45	56	25	20	195	214	369	13	316	607	160	37	12	184	26	605	173
10	45	52	57	3	15	113	196	377	1	152	443	115	10	6	71	40	544	132
11	35	13	50	6	3	48	71	125	1	39	154	21	3	13	23	11	331	56
12	113	69	137	47	33	464	514	863	13	625	1138	199	107	20	246	87	1496	363
13	62	51	117	73	62	416	564	1361	14	560	1410	288	85	28	166	109	1936	429
14	9	1	15	2	3	65	54	91	12	25	249	34	8	2	12	7	304	52
15	39	38	56	19	18	305	234	614	11	246	771	139	15	12	87	34	905	209
16	26	26	40	12	18	219	207	235	8	119	998	318	84	7	36	37	686	181
17	15	7	46	14	6	129	163	371	12	108	301	57	16	5	33	21	945	132
18	75	60	132	8	8	341	326	789	5	260	300	200	27	5	176	69	891	216
19	14	2	19	14	16	41	93	59	1	41	155	85	29	35	42	14	197	50
20	14	6	36	1	3	86	168	69		35	29	5	11	3	11	13	696	74
21	18	4	11	1	4	27	23	51	5	37	48	15	5	3	19	6	100	22
22	74	41	109	34	22	233	214	350	11	310	1025	174	140	14	185	61	1054	238
Average	**53**	**37**	**85**	**23**	**23**	**217**	**249**	**422**	**12**	**252**	**611**	**170**	**50**	**15**	**121**	**40**	**886**	

Industry:
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5 COKE, REFINED PETROLEUM PRODUCTS AND NUCLEAR FUEL
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Table 4: Capital Stock by Country & Industry (in millions US $ PPP 1995; depreciation rate 5%), 1973-2002

Country / Industry	AUS	BEL	CAN	DNK	FIN	FRA	UK	GER	IRL	ITA	JPN	KOR	NLD	NOR	SPN	SWE	USA	Average
1	16594	12985	25896	7187	6021	86839	71686	90587	1866	51045	185117	17602	20110	8994	281099	13162	208600	65023
2	2968	7472	8518	1905	3742	49331	149243	55343	191	81862	296768	30862	4453	2521	48541	11032	67496	48367
3	4320	1493	15695	6026	3407	32114	5833	29192	127	24598	36093	3999	2218	1915	60364	8156	197478	25472
4	5446	4655	56782	6748	19295	42461	47327	64735	671	22516	181316	7971	10049	6136	12015	31031	301844	48294
5	2088	4321	9109	393	2027	119765	16579	157046		154219	76206	7119	11264	1335	467503	1294	82224	69531
6	4523	11830	30143	2140	2954	21799	28479	56146	1687	27394	132325	15961	16743	2736	9157	3800	182623	32379
7	27520	908	1724	1341	495	4139	6722	12792	888	67543	20557	1823	1400	276	4128	2129	29922	10842
8	4354	3916	5817	1717	885	15423	20566	23375	296	26622	101676	9879	4722	1038	69146	1988	43792	19718
9	4846	5293	11828	5057	3230	35631	97304	50441	283	38025	123337	9318	5976	2367	290051	4808	73137	44761
10	13097	15110	59115	337	1938	55118	299485	27978		35365	152557	21770	5080	1710	4707	5254	106343	50310
11	12189	1692	16181	10161	485	16744	3908	14811		6139	41326	2959	5924	2054	1091	871	42579	11195
12	4404	3041	10619	2861	1355	119318	31115	45543	185	64298	67331	8919	7958	1804	4329	3856	82341	27016
13	14653	2657	3795	4082	3139	21204	100915	100058	258	59904	88925	7744	5447	1345	7657	6071	84170	30119
14	347	26	379	46	33	1719	1700	3007	2629	1335	19015	2971	336	26	130	230	15988	2936
15	3151	5326	4742	719	1496	17969	13936	27430	385	14357	36627	7669	675	1626	2575	1234	24039	9645
16	410	3572	3522	467	891	5568	10144	22359	4018	7495	76619	38584	6057	272	1153	2350	110343	17284
17	548	388	1091	537	257	13657	5342	21036	470	4379	14495	871	1481	460	214	547	46015	6576
18	4584	52465	14760	201	478	50853	28172	86869		35869	128157	13409	3384	437	12202	8768	150550	36947
19	709	71	477	1612	3167	368	7046	2235		6513	37655	6441	1389	3243	597	5318	18415	5954
20		21865	2160		9134	12517	10799	3322		2433	30404	453	435	131	271	973	45681	10041
21		74	1983	13	782	1473	842	3833		3273	10154	121172	232	127	379	317	3415	9871
22	286	21026	3271	677	1331	18245	36243	65811	253	24192	12880	1843	3677	1062	5542	685	46877	14347
Average	**6352**	**8190**	**13073**	**2582**	**3025**	**33739**	**45154**	**43816**	**947**	**34517**	**84979**	**15425**	**5410**	**1892**	**58311**	**5176**	**89267**	

Industry:
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Table 5: R&D Capital Stock by Country & Industry, 1973-2002

Country Industry	AUS	BEL	CAN	DNK	FIN	FRA	UK	GER	IRL	ITA	JPN	KOR	NLD	NOR	SPN	SWE	USA	Average
1	409	240	476	198	167	1096	2087	954	158	226	5614	396	922	145	565	356	7444	1262
2	48	186	172	16	35	603	784	580	36	47	2166	231	61	16	90	47	1349	380
3	42	20	113	12	44	102	117	335	5	15	654	9	21	33	12	31	2191	221
4	158	158	765	20	350	285	570	359	15	35	2290	159	62	123	69	692	7285	788
5	29	125	657	3	46	2393	2930	707	1	2873	2456	339	1957	27	956	25	12509	1649
6	421	2404	1028	180	304	5138	4667	16772	77	1650	19293	2070	3169	279	484	473	37713	5654
7	395	1642	958	807	224	4933	7867	6262	182	2754	11124	570	1204	174	727	2056	34051	4466
8	134	193	140	59	86	1756	501	1659	32	662	5632	425	126	35	649	136	5297	1031
9	136	194	102	90	74	973	948	1148	28	104	4652	337	60	38	326	131	4111	791
10	347	281	185	11	78	851	763	1101	4	421	5941	528	202	95	128	295	2864	829
11	203	142	783	2	67	565	285	521	2	97	2769	123	85	232	37	80	3146	538
12	149	232	253	59	92	862	774	2122	33	442	2639	235	154	88	138	351	5695	842
13	447	636	474	536	532	2629	4528	14884	49	1324	15476	1282	618	285	406	1814	19443	3845
14	109	55	1092	47	51	1338	773	2393	154	475	21709	7246	2943	40	204	174	37251	4474
15	359	476	493	106	320	2170	4457	10418	61	1011	13536	660	3032	196	338	577	16067	3193
16	888	2984	6365	290	1201	10005	7222	17525	1150	4377	37832	58261	2144	497	992	4149	95387	14781
17	229	213	253	313	165	5004	1681	2743	68	305	5872	259	237	124	141	459	39287	3374
18	719	327	454	166	34	9379	4930	20788	23	4824	20511	6722	384	41	1002	2175	67340	8225
19	80	5	1	104	56	68	295	203	2	176	473	448	31	180	135	163	3237	333
20	40	164	3155	0	12	17188	13097	9333	4	2476	1454	413	230	10	540	903	148638	11627
21	53	77	107	20	37	254	127	364	4	245	514	54	9	12	84	94	2223	252
22	42	101	136	303	20	260	903	124	9	118	1741	135	131	17	54	31	2448	387
Average	**247**	**493**	**826**	**152**	**182**	**3084**	**2741**	**5059**	**95**	**1121**	**8379**	**3677**	**808**	**122**	**367**	**692**	**25226**	
% sample	0.5	0.9	1.5	0.3	0.3	5.8	5.1	9.5	0.2	2.1	15.7	6.9	1.5	0.2	0.7	1.3	47.4	
Median	**153**	**194**	**464**	**75**	**76**	**1217**	**925**	**1403**	**30**	**431**	**5133**	**405**	**216**	**91**	**265**	**323**	**7365**	
% sample	0.8	1.0	2.5	0.4	0.4	6.5	4.9	7.5	0.2	2.3	27.4	2.2	1.2	0.5	1.4	1.7	39.2	

Note: The industry names are as given in the above tables.

Table 6: US Share in Total Imports (average over the sample period; in %), 1973-2002

Country / Industry	AUS	BEL	CAN	DNK	FIN	FRA	UK	GER	IRL	ITA	JPN	KOR	NLD	NOR	SPN	SWE	Average
1	25.5	3.5	65.5	7.5	6.5	5.8	8.2	6.2	9.7	3.6	45.4	53.0	10.8	7.9	18.1	7.9	17.8
2	16.3	3.0	55.3	2.0	2.5	3.4	11.4	2.6	4.4	7.1	15.0	16.2	2.1	2.2	10.6	3.4	9.8
3	36.1	7.3	89.8	5.1	8.0	4.7	13.3	9.5	7.5	24.1	40.4	47.7	4.3	2.2	21.1	6.4	20.5
4	32.5	4.3	88.4	4.1	6.4	7.2	15.6	9.6	6.6	13.5	50.8	47.1	8.4	3.9	11.7	6.6	19.8
5	66.2	2.3	81.0	1.2	3.9	6.8	7.7	3.1	1.2	16.7	45.7	36.3	5.8	7.2	19.6	2.6	19.2
6	39.2	11.2	81.1	4.7	7.5	11.5	19.1	11.3	15.5	6.9	49.8	29.8	13.7	7.1	11.8	8.9	20.6
7	22.9	14.6	60.4	4.8	5.8	19.9	19.9	15.9	12.2	16.1	34.3	21.0	11.4	5.7	18.4	8.1	18.2
8	25.2	5.2	78.7	2.9	4.3	5.2	19.4	6.0	8.0	4.9	42.3	29.0	5.2	3.6	5.4	4.1	15.6
9	15.5	3.6	72.3	1.6	4.2	3.6	17.7	5.6	6.7	4.2	31.5	22.3	2.8	2.7	4.2	4.4	12.7
10	8.5	1.4	59.6	0.4	0.5	0.8	8.7	1.0	1.8	2.1	11.8	4.9	0.9	1.6	2.3	1.0	6.7
11	23.7	11.9	75.6	1.8	3.8	9.3	21.0	7.5	8.5	8.5	30.3	14.7	4.7	2.7	7.1	5.3	14.8
12	28.6	4.5	81.7	2.4	4.4	5.4	24.0	7.4	9.1	8.0	54.8	32.1	4.6	4.2	16.2	6.4	18.4
13	34.9	8.9	77.8	6.9	7.1	11.1	27.8	14.4	15.2	10.3	48.2	26.8	11.0	10.9	10.2	9.7	20.7
14	51.5	17.3	80.7	19.8	30.3	34.6	33.3	30.4	49.5	16.8	73.2	48.5	25.2	30.1	23.2	28.9	37.1
15	27.9	5.9	82.1	5.3	6.0	12.3	27.9	15.6	18.5	9.1	60.4	24.6	12.0	8.2	9.1	8.1	20.8
16	21.3	7.5	67.9	8.9	14.8	19.3	27.2	16.4	25.6	11.3	63.7	45.4	13.4	13.4	12.7	14.8	24.0
17	41.9	15.4	76.1	16.0	18.1	28.7	38.0	28.5	38.3	20.1	63.9	31.6	27.1	20.7	19.0	21.8	31.6
18	14.3	2.8	87.7	1.0	3.1	2.3	19.2	3.9	0.7	1.0	27.4	19.5	1.6	4.3	3.4	3.7	12.3
19	23.0	10.6	72.7	3.0	6.5	9.5	24.8	13.7	4.9	12.7	38.5	4.6	14.8	2.7	19.5	5.0	16.7
20	75.7	51.3	79.8	72.1	60.3	61.7	54.5	31.7	74.0	52.5	88.7	83.5	58.3	73.6	62.8	64.3	65.3
21	16.8	2.3	61.8	1.9	2.9	2.4	13.1	5.7	7.4	3.6	42.5	13.1	8.0	6.4	7.5	5.7	12.6
22	25.9	15.3	70.7	4.9	6.7	10.2	22.8	11.1	15.4	9.9	38.0	29.2	7.1	4.9	8.2	9.1	18.1
Average	**30.6**	**9.6**	**74.8**	**8.1**	**9.7**	**12.5**	**21.6**	**11.7**	**15.5**	**12.0**	**45.3**	**30.9**	**11.5**	**10.3**	**14.6**	**10.7**	

Industry:
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Table 7 : OLS Results

	(1)	(2)	(3)	(4)	(5)
Labor	0.567	0.611	0.583	0.626	0.308
	(0.010)	(0.010)	(0.011)	(0.018)	(0.028)
Capital	0.427	0.391	0.396	0.375	0.75
	(0.010)	(0.009)	(0.010)	(0.013)	(0.014)
Time FE	no	yes	yes	yes	yes
Country FE	no	no	yes	yes	no
Industry FE	no	no	no	yes	no
Country x industry FE	no	no	no	no	yes
N	10,289	10,289	10,289	10,289	10,289
$\bar{R}^2$	0.875	0.891	0.902	0.917	0.965

Standard errors are in parentheses

Table 8: Instrumental Variables and Olley-Pakes Results

	(1) OLS	(2) IV System GMM	(3) OP	(4) OP/W GMM	(5) OLS	(6) IV System GMM	(7) OP	(8) OP/W GMM
Labor	0.567	0.6	0.528	0.511	0.626	0.676	0.548	0.557
	(0.010)	(0.006)	(0.046)	(0.010)	(0.018)	(0.012)	(0.054)	(0.018)
Capital	0.427	0.394	0.628	0.447	0.375	0.342	0.234	0.513
	(0.010)	(0.004)	(0.087)	(0.110)	(0.013)	(0.005)	(0.164)	(0.105)
Time FE	no	no	no	no	yes	yes	yes	yes
Country FE	no	no	no	no	yes	yes	yes	yes
Industry FE	no	no	no	no	yes	yes	yes	yes
N	10289	9309	9925	9954	10289	9309	9925	9954
$\bar{R}^2$	0.875				0.917			
Sargan Overid Prob>chi2		0.968				0.425		
AR(1) test Prob>z		0.282				0.371		
AR(2) test Prob>z		0.088				0.081		

Standard errors in parentheses

Table 9. Domestic R&D and Productivity

	(1) OLS	(2) OLS	(3) IV System GMM	(4) OP/W GMM
Labor	0.626	0.437	0.469	0.431
	(0.018)	(0.017)	(0.012)	(0.009)
Capital	0.375	0.299	0.291	0.446
	(0.013)	(0.009)	(0.006)	(0.048)
Domestic R&D		0.271	0.246	0.179
		(0.009)	(0.006)	(0.005)
Fixed effects #	yes	yes	yes	yes
N	10,289	9,444	8,487	9,099
AR(1) test Prob>z			0.948	
AR(2) test Prob> z			0.297	

Standard errors in parentheses
Country-, industry-, and fixed effects are included

Table 10: International R&D Spillovers

	(1) OLS	(2) IV System GMM	(3) OP/W GMM	(4) IV System GMM	(5) IV System GMM	(6) OP/W GMM	(7) IV System GMM	(8) IV System GMM
							1980-1991	1992-2002
Labor	0.562	0.59	0.497	0.683	0.693	0.582	0.737	0.798
	(0.014)	(0.011)	(0.009)	(0.011)	(0.010)	(0.009)	(0.012)	(0.014)
Capital	0.232	0.224	0.404	0.161	0.147	0.244	0.114	0.128
	(0.008)	(0.005)	(0.045)	(0.005)	(0.005)	(0.041)	(0.005)	(0.008)
Domestic R&D	0.202	0.184	0.154	0.159	0.157	0.139	0.142	0.141
	(0.007)	(0.005)	(0.004)	(0.005)	(0.005)	(0.004)	(0.006)	(0.007)
US R&D	0.351	0.348	0.228	0.165	0.087	0.071	0.034	0.098
	(0.013)	(0.007)	(0.007)	(0.008)	(0.008)	(0.007)	(0.011)	(0.012)
JPN R&D				0.24	0.152	0.151	0.024	0.153
				(0.007)	(0.008)	(0.007)	(0.011)	(0.013)
GER R&D				0.131	0.095	0.078	0.079	0.086
				(0.007)	(0.007)	(0.006)	(0.010)	(0.012)
FRA R&D					0.108	0.074	0.115	0.171
					(0.008)	(0.006)	(0.010)	(0.012)
UK R&D					0.042	0.047	0.075	0.072
					(0.007)	(0.006)	(0.010)	(0.012)
CAN R&D					0.137	0.091	0.095	0.127
					(0.007)	(0.006)	(0.009)	(0.011)
N	9195	8364	8893	8239	8239	8767	3648	3709
Sargan Overid Prob>chi2		0.248		0.459	0.313		0.553	0.415
AR(1) test Prob>z		0.347		0.249	0.21		0.078	0.937
AR(2) test Prob>z		0.778		0.984	0.989		0.727	0.522

Standard errors in parentheses; all regressions include country-, industry- and time fixed effects

Table 11: Total Factor Productivity and Labor Productivity as Dependent Variable

	(1) OLS	(2) IV System GMM	(3) IV System GMM	(4) OP/W GMM	(5) IV System GMM	(6) IV System GMM
Labor						0.693
						(0.010)
Capital						0.147
						(0.005)
Capital/Labor					0.160	
					(0.005)	
Domestic R&D	0.187	0.160	0.050	0.122	0.120	0.157
	(0.010)	(0.006)	(0.006)	(0.006)	(0.004)	(0.005)
US R&D			0.126	0.104	0.096	0.087
			(0.013)	(0.011)	(0.008)	(0.008)
JPN R&D			0.151	0.198	0.151	0.152
			(0.012)	(0.010)	(0.008)	(0.008)
GER R&D			0.032	0.039	0.104	0.095
			(0.010)	(0.009)	(0.007)	(0.007)
FRA R&D			0.084	0.062	0.112	0.108
			(0.012)	(0.010)	(0.007)	(0.008)
UK R&D			-0.004	0.019	0.045	0.042
			(0.012)	(0.010)	(0.007)	(0.007)
CAN R&D			0.119	0.099	0.134	0.137
			(0.011)	(0.009)	(0.007)	(0.007)
N	9444	8844	8554	8785	8464	8239
Sargan Overid Prob>Chi2		n/a*	n/a*		n/a*	0.313
AR(1) test Prob>z		0.000	0.000		0.293	0.210
AR(2) test Prob>z		0.113	0.037		0.989	0.989

Standard errors in parentheses; all regressions include country- , industry- and time fixed effects
* equation is exactly identified

Table 12a: US R&D Spillovers

		(1) OP/W	(2) OP/W	(3) OP/W
Domestic R&D		0.154	0.165	0.148
		(0.004)	(0.005)	(0.004)
US R&D		0.228		
		(0.007)		
	in AUS		0.195	-0.016
			(0.013)	(0.013)
	in BEL		0.260	0.033
			(0.015)	(0.014)
	in CAN		0.255	0.165
			(0.011)	(0.012)
	in DNK		0.260	0.044
			(0.013)	(0.012)
	in FIN		0.235	0.045
			(0.012)	(0.011)
	in FRA		0.186	0.018
			(0.011)	(0.014)
	in UK		0.245	0.097
			(0.011)	(0.013)
	in GER		0.188	0.047
			(0.011)	(0.013)
	in IRL		0.465	0.277
			(0.022)	(0.021)
	in ITA		0.192	-0.016
			(0.011)	(0.011)
	in JPN		0.195	0.117
			(0.011)	(0.012)
	in KOR		0.232	0.006
			(0.021)	(0.019)
	in NLD		0.228	0.009
			(0.011)	(0.011)
	in NOR		0.266	0.054
			(0.012)	(0.012)
	in SPN		0.248	0.043
			(0.013)	(0.012)
	in SWE		0.244	0.032
			(0.011)	(0.011)
JPN R&D				0.163
				(0.008)
GER R&D				0.069
				(0.007)
FRA R&D				0.043
				(0.010)
UK R&D				0.068
				(0.009)
CAN R&D				0.133
				(0.007)
N		8893	8893	8767

Standard errors in parentheses; all regressions include fixed effects, as well as labor and capital (coefficients suppressed)

Table 12b: Spillovers in Canada

		(1) IV GMM	(2) IV GMM	(3) OP/W GMM
Domestic R&D		0.249	0.141	0.134
		(0.006)	(0.006)	(0.004)
	in CAN	0.222	0.359	0.244
Foreign R&D				
US			0.049	0.050
			(0.008)	(0.007)
	in CAN		0.150	0.104
JPN			0.100	0.120
			(0.008)	(0.007)
	in CAN		0.039	0.059
GER			0.062	0.060
			(0.007)	(0.006)
	in CAN		0.197	0.196
FRA			0.088	0.067
			(0.007)	(0.006)
	in CAN		0.034#	0.023
UK			0.038	0.046
			(0.007)	(0.006)
	in CAN		-0.039#	-0.001#
CAN			0.285	0.177
			(0.010)	(0.009)
N		8487	8239	8767
Overid [p-val]		0.123	0.318	
AR(1) [p-val]		0.946	0.246	
AR(2) [p-val]		0.297	0.954	

#: Not significantly different from zero at 5% level
Standard errors in parentheses; all specifications include fixed effects (country, industry, year), as well as labor and capital

Table 13: International Technology Transfer through Imports

	(1) IV GMM	(2) IV GMM	(3) IV GMM	(4) IV GMM	(5) OP/W GMM
Domestic R&D	0.158	0.156	0.159	0.159	0.141
	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)
Foreign R&D					
US	0.090	0.004	0.029	0.029	0.015
	(0.009)	(0.010)	(0.013)	(0.016)	(0.011)
JPN	0.153	0.166	0.169	0.150	0.158
	(0.008)	(0.008)	(0.009)	(0.010)	(0.008)
GER	0.093	0.080	0.104	0.100	0.086
	(0.007)	(0.007)	(0.011)	(0.012)	(0.008)
FRA	0.107	0.089	0.084	0.071	0.058
	(0.007)	(0.007)	(0.008)	(0.011)	(0.008)
UK	0.043	0.042	0.042	0.005	0.018
	(0.007)	(0.008)	(0.007)	(0.010)	(0.008)
CAN	0.136	0.156	0.153	0.129	0.095
	(0.007)	(0.007)	(0.007)	(0.008)	(0.006)
US share in total imports*US R&D	0.010				
	(0.007)				
US share in G6 imports*US R&D		0.221	0.170	0.249	0.156
		(0.016)	(0.023)	(0.027)	(0.019)
JPN's share in G6 imports*JPN R&D			-0.025	0.044	-0.020
			(0.029)	(0.031)	(0.022)
GER's share in G6 imports*GER R&D			-0.085	-0.037	-0.025
			(0.027)	(0.027)	(0.017)
FRA's share in G6 imports*FRA R&D				0.100	0.049
				(0.056)	(0.029)
UK's share in G6 imports*UK R&D				0.255	0.221
				(0.049)	(0.029)
CAN's share in G6 imports*CAN R&D				0.193	0.057
				(0.033)	(0.020)
US share in G6 imports		-2.102	-1.547	-1.553	-1.131
		(0.170)	(0.224)	(0.425)	(0.212)
JPN's share in G6 imports			0.249	0.341	0.608
			(0.263)	(0.489)	(0.247)
GER's share in G6 imports			0.837	1.145	0.557
			(0.222)	(0.510)	(0.236)
UK's share in G6 imports				-1.172	-1.169
				(0.500)	(0.265)
CND's share in G6 imports				-0.541	0.106
				(0.475)	(0.240)
N	8145	8145	8145	8145	8719
Overid [p-val]	0.354	0.384	0.377	0.286	
AR(1) [p-val]	0.197	0.139	0.13	0.054	
AR(2) [p-val]	0.99	0.981	0.861	0.707	

Standard errors in parentheses; the import share from FRA is excluded from (5) and (6) to avoid collinearity
All regressions include labor and capital, as well as country-, year-, and industry fixed effects (not reported)

Appendix A: Data Note

The paper uses several databases of OECD which have been supplemented from other different sources as required. The main data we have used from OECD are: Analytical Business Expenditure in Research and Development (ANBERD) database, Structural Analysis (STAN) database, Commodity, Trade and Production (COMTAP) database, and Bilateral Trade (BTD) database. We have also used data from Groningen Growth and Development Centre (GGDC). Data on employment of US foreign affiliates in foreign countries are taken from US Bureau of Economic Analysis. Besides, we have used data directly from the website of national statistical agencies in Canada, Japan, the UK and the US to complement some of the missing cells. The industries for the study are based on International Standard Industrial Classification (ISIC) Rev. 3 code. We have used data from both old system Revision 2 (ISIC Rev. 2), and ISIC Rev. 3. Since ISIC Rev. 2 has data on only 22 manufacturing industries and ISIC Rev. 3 has data on 31 industries, including 22 that are in ISIC 2, the study takes the 22 industries which are common to both systems as sample (the ISIC rev. 3 code and industry names are provided in Table 1). The data for the study covers 30 years, from 1973 to 2002. In what follows, we will provide a detail data description and related concordance that we have used.

ANBERD: These data are available in two series: ANBERD 2 and ANBERD 3, the former based on ISIC Rev. 2, and the latter based on ISIC Rev. 3 industry code. Although these two data series covers different number of countries and industries, they are complement to each other. ANBERD 2 data start from 1973 and covers till about 1995-97, and ANBERD 3 data start from 1987 and go at least till 2002 for most of the countries (except for Ireland in which case they stop at 2001). Regarding country coverage, ANBERD 2 has data only for 15 countries in the sample (missing are Belgium and Korea) whereas the ANBERD 3 covers all 17 countries.

We have combined both data series; if there were overlap between two datasets, we have taken them from ANBERD 3. For 13 countries (Australia, Canada, Denmark, Finland, France, Great Britain, Ireland, Japan, Netherlands, Norway, Spain, Sweden and USA) we have taken data from ANBERD 2 from 1973 to 1986 and from ANBERD 3 from 1987 onward. For the remaining four countries, we have proceeded as follows. For Italy, the data from 1973 to 1990 are from ANBERD 2, and for the rest of the years, they are from ANBERD 3. For Belgium, the R&D data start in 1987, and that for Korea, it starts in 1995. Regarding Germany, the ANBERD 2 data covers West Germany from 1973 to 1995 and united Germany from 1991 to 1995, and ANBERD 3 covers united Germany from 1995 and onward. So to create a complete series for Germany, we took data for West Germany from 1973 to 1990 and for united Germany from 1991 to 1994 (both from ANBERD 2) and from united Germany from 1995 to 2002 (from ANBERD 3).

For all countries the ANBERD 2 database and for most countries the ANBERD 3 database are in national currency. The only difference is that for Belgium, Finland, France, Germany, Ireland, Italy, Netherlands and Spain the ANBERD 3 data are in Euro, whereas the ANBERD 2 data for these countries are in national currency. Hence, to bring data in common currency, we converted the ANBERD 2 data for these countries into Euro using irrevocable exchange rate.[38]

When combined, the data are available from 1973 to 2002 for all countries and industries with the following missing values. The data for 6 countries (Australia, France, Germany, Japan, Spain and Sweden) are available for all industries throughout the sample period. For Canada, Italy and US, the data are missing only for one industry each. For another three countries (Finland, UK and Netherlands), data for two industries are missing for some years. For remaining five countries, data were missing for more than three industries, in most cases though not throughout the sample period but for some years.

Since the ANBERD (both series) data are in current price, we use the industry value added deflator based on GGDC and STAN databases (more on these two databases later) to convert them into 1995 prices. Finally, using we converted them into 1995 purchasing power parity (PPP) US dollar.

COMTAP and BTD: Trade data come from three OECD databases: (1) COMTAP for years 1970-1979, (2) BTD 2 for years 1980-1989 and (3) BTD 3 for years 1990-2003. Trade data are complete for all 17 countries except for Korea, which starts only from 1994. Both COMTAP and BTD 2 are based on ISIC Rev. 2, whereas BTD 3 is based on ISIC Rev. 3. For Germany, the import data are taken for West Germany from 1970 to 1989 and for united Germany from 1991 and onward. We converted all three COMTAP, BTD 2 and BTD 3 databases into 22 sample industries.

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[38] The national currency per EURO rate is as below: Belgium = 40.3399; Finland = 5.94573; France = 6.55957; Germany = 1.95583; Ireland = 0.787564; Italy = 1936.27; Netherlands = 2.20371, and Spain = 166.386.

The trade data, which are in US dollar, are converted into 1995 purchasing power parity (PPP) dollar. Since the PPP to US $ exchange rate is not readily available, we used two other available series from STAN database to obtain it as follows:

$$\frac{\text{PPP in U.S. dollar}}{\text{U.S. dollar}} = \frac{\text{National currency}/\text{U.S. dollar}}{\text{National currency}/\text{PPP in U.S. dollar}}$$

Multiplying the U.S. dollar trade data by the rate on the left hand side in year 1995, we obtained trade data in PPP at 1995 rate.

STAN: We have used value added, gross fixed capital formation (investment), employment (persons engaged and hours worked) and labor compensation data from STAN database. We have used mainly STAN 3 database which are based on ISIC Rev. 3 industry code and start coverage from 1970 till more recent years. However, it appears that for early years for some countries, data that are available on STAN 2 database are not available in STAN 3. In such cases, we used the STAN 2 database to cover the missing values in STAN 3. Furthermore, we realize that some of the entries which are empty in both STAN 2 and STAN 3 databases were available in old STAN data CD. In such cases, we have used data from old CD to refill the empty cells. Thus our data construction was based on the premise that use as much as they are available in STAN 3, if possible recover the missing cells from STAN 2, and if still missing recover them from old CD.

In STAN 3, value added and investment data are available in nominal terms, and in real terms, i.e. as volumes. The former are in national currencies. The volumes are expressed as index numbers with national reference year equal to 100. Since, for the study, we need both value added and investment in value not as index, we performed the following two steps. First, we converted the index into value. Second, since different countries index values were based on different reference year, we re-based the reference year for all countries in 1995. The first step was performed the follows:

(A1) $$\mathrm{p_r y_t} = \frac{\mathrm{I_t} \times \mathrm{p_r q_r}}{100}, \qquad t = 1973 \text{ to } 2002,$$

where $\mathrm{p_r q_t}$ is the constant price value added in reference year price, *r*; $\mathrm{p_t y_t}$ is the value added in current price, and $\mathrm{p_r q_r}$ is the current price value added in the reference year, and *I* stands for index data in the database (in case of investment, the similar equation was used with value added data replaced by investment data). Since both $\mathrm{I_t}$ and $\mathrm{p_r y_r}$ are available in the data, we were able to compute the expression on the left-hand side. The calculation in (A1) is based on the fact that $I_t = (\mathrm{p_r q_t}/\mathrm{p_r q_r}) \times 100$.[39]

In the data, the reference years are not the same for all sample countries. For both value added and investment indices, the reference year is 2000 (2000 = 100) for six countries, 1995 for nine countries and 1997 for Canada.[40] In the second step, for those countries whose reference years are different from 1995, we converted their value at constant price given by equation (A1) into 1995 by using the following mechanism:

(A2) $$\mathrm{p_{1995} q_t} = \frac{p_{1995} q_{1995}}{\mathrm{p_r} q_{1995}} \times \mathrm{p_r} q_t, \qquad t = 1973 \text{ to } 2002,$$

[39] However, the volume indices were not available for some industries in some countries and year. So in an attempt to use the same indices across all countries, we have moved up to more aggregate indices to compute constant price investment. This amounts to assuming that the price change for more disaggregate level of industries was the same as the price change in more aggregate industry level. In sum, we used the index of ISIC 24 for ISIC 24x2423 and ISIC 2423 for all countries and of ISIC 2423 for Norway; the index of ISIC 27-28 for industries ISIC 271 and ISIC 273. Furthermore, we used the index of ISIC 30-33 for industries ISIC 30, ISIC 31, ISIC 32, and ISIC 33. And finally, we used the index of ISIC 34-35 for industry ISIC 34 and for industries ISIC 351, ISIC 353 and ISIC 352+359.

[40] A note on West Germany (GEW) and United Germany (GER)) is needed here. For GEW, data run from 1970 to 1991, whereas for GER they run from 1991 to 2002. We have taken data for a period of 1970-1990 from GEW and for a period of 1991-2002 from GER to make a complete (1970-2002) series for Germany. However, in volume index, it needed some work to make them based on the same reference year, as the index for GEW is based on 1991 = 100 and the volume index for GER is based on 1995 = 100. We choose to base them both in year 1995 = 100. For this purpose, we took the benefit of the fact that for both GEW and GER, there are indices for year 1991. So based on the index of GER in 1991 basing it on 1995 = 100 and combine them with GER series.

where $p_{1995}q_t$ is value added in 1995 price; $p_{1995}q_{1995}$ is current price value added in 1995; $p_r q_{1995}$ is value added in 1995 in reference year price, and $p_r q_t$ is the value from equation (A1). Note that for countries whose reference year was 1995 Equation (A2) holds as an identity. We repeated (A2) for investment series as well.

STAN 2 current price value added and investment data were in the same currency as in STAN 3 except for Belgium, Finland, France, Germany, Ireland, Italy, Netherlands and Spain, which in national currency, not in Euro. We converted STAN 2 data for these countries into EURO first. Regarding constant price data, unlike STAN 3, the STAN 2 database does not have investment data in constant price and those in value added are also in actual value, not in index. But they are based on 1990 prices. We converted the constant price value added from 1990 price to 1995 prices using the following formula:

$$\text{(A3)} \qquad p_{1995}q_t = \frac{p_{1995}q_{1995}}{p_{1990}q_{1995}} \times p_{1990}q_t$$

Similarly, the constant value added data from old CD, which are basically STAN 2 data, are also in value but in 1985 prices. To convert these data into 1995 price, we need to do the following:

$$\text{(A3')} \qquad p_{1995}q_t = \frac{p_{1995}q_{1995}}{p_{1985}q_{1995}} \times p_{1985}q_t \,.$$

However, since we have neither current value added, $p_{1995}q_{1995}$, nor constant value added, $p_{1985}q_{1995}$, data for 1995 in this source, we converted the data in old CD into 1995 prices using the following procedure:

$$\text{(A4)} \qquad p_{1995}q_t = \left(\frac{p_{1995}q_{1990}}{p_{1985}q_{1990}}\right)_M \times p_{1985}q_t \,,$$

where the expression inside the parenthesis is for total manufacturing, denoted by subscript *M*. The expression inside the bracket has no industry dimension but has only country dimension as we have estimated it for each country. The numerator in this expression is taken from STAN 3 and the denominator from data in CD. We used this ratio of constant value added in year 1990, one based on price in 1995 and the other in year 1990, for all industries.

By doing so, we have data on value added and investment (both at constant and current prices) employment, and compensation.

GGDC: We have taken data for value added (both in current price and in constant price) and employment (both persons engaged in employment and hours worked) from GGDC. This dataset is comparable with the OECD STAN database but provides a dataset without gaps by complementing STAN with information from industry and services statistics and additional (historical) national accounts data for individual countries. The GGDC database have total of 57 industries, with 27 in manufacturing. We concorded these 27 industries into the 22 industries of our sample. The industries in GGDC could be easily concorded, except for two industries in which case we have to decompose these two GGDC industries into two each. In GGDC, the ISIC 24 is not split into ISIC 24x2423 and 2423. Similarly, industry ISIC 27 is not disaggregated into ISIC 271 and ISIC 272.

To split GGDC 24 and 27 into two industries each, we used the value added at current price data from STAN database where data on ISIC 24x2423, ISIC 2423, ISIC 271 and ISIC 272 are reported separately. We computed the annual share of value added of 24x2423 and 2423 in ISIC 24 and used that share to decompose GGDC ISIC 24 into two categories. We did the same for ISIC 271 and 272, using the value added shares of these two industries in ISIC 27. This refilling mechanism was possible only for 13 countries. Among the remaining four countries, for the Netherlands the STAN database has data on 24x2423 and 2423, whereas those for ISIC 271 and ISIC 272 are available only from 1995 to 1999. Hence, to split data throughout the sample period for ISIC 27, we used the average share of these two industries in that period. For Ireland, we had no information to split ISIC 27. For Norway it was just the opposite, we could split ISIC 27 but not ISIC 24. For Australia, STAN did not have information on either of two industries. Hence, to split ISIC 27 for Ireland, ISIC 24 for Norway, and both ISIC 24 and ISIC 27 for Australia, we used the 50/50 rule. Even though this type of breakdown is not very realistic, we don’t expect these cells to bias our results as they represent only 0.1 percent of the data cells for the study.

We combined the data on value added (both at current and constant price) and employment from STAN and GGDC, taking data from STAN for years 1973 to 1978 and from GGDC for years 1979 and onward. The reason for taking data from GGDC whenever they were available rather than from STAN was that the data on the former were complete, whereas on the latter there were several missing cells. Then using the combined value added data in current price and constant price, we calculated value added deflator, d_t, which was used to deflate the investment and R&D data.

(A5) $$d_t = p_t q_t / p_{1995} q_t ,$$ *t = 1973 to 2002,*

where $p_t q_t$ is the current price value added given in the data. Then, we converted these national currency value added and investment data into 1995 PPP. Furthermore, the PPP converted series of constant price value added was used to compute labor employment per person engaged.

Employment of US Foreign Affiliates in Foreign Countries: These data are taken from US Bureau of economic analysis. They are available for all sample industries except for the ISIC 35 which was not decomposed into three industries that we are interested in. Hence, we divided the entry in ISIC 35 into three industries by one-third. The drawback, however, of these series is that they are available only for seven countries: from 1983 for Canada and Japan and from 1989 for Australia, France, Germany, Italy, Netherlands and UK. We have used this data as a separate variable in our estimation, with other countries as missing values.

Appendix B: Supplementing and Estimating Missing Data

The variables that are used for the study are trade, US employment in foreign affiliates, value added, employment, R&D, labor compensation, and physical investment. The data on trade are almost complete except for few years for Korea, so we have not estimated the missing values for this variable either. Even though the data on employment in US affiliates are missing, we did not estimate them, as there is no reasonable way to do so. The value added and employment data after 1979, when we had them from GGDC, are complete. However, there are some missing values prior to 1979 for these variables. Among the three remaining variables, even though there are some data missing for R&D and labor compensation, the frequency of missing cells is more frequent in investment data. Below, we describe how we estimated some of the missing cells in investment data. We have also estimated few missing cells in value added, employment, R&D expenditure and labor compensation using similar techniques.

As mentioned above, the investment data are available in both current and constant prices. For the study, the preference would be to use constant price investment data, as they are based on more appropriate deflators. However, if we rely in constant price investment there will be a lot of missing cells. In terms of availability, the constant price investment data are a subset of current price investment in a sense that almost all data that are available in former series are also available in the latter but not vice versa. For example, even though the investment data in current price are available, they are completely missing in constant price for three countries (Australia, UK, and Korea). Similarly, even though the data in current price for Finland, France, Japan, Denmark and Sweden are available from 1973, the constant indices for these countries start only in 1975, 1978, 1980, 1993 (for the last two countries) respectively. Finally, there is a gap of four years in data availability for Ireland, as the current price data start in 1991 and those in constant price in 1995. Besides, even for other countries and years, when we compare data availability by industry, the data gap in current price and constant price are substantial. Hence, in this study, we have used the current price investment data by deflating them by value added deflators.

For the missing value, when possible, first we used national statistical agencies' to refill the data if possible. This was done only for UK, Canada, the US and Japan. For UK, all of 2001 and 2002 data were obtained from Table 6 "gross fixed capital formation" of Input-output Supply and Use Tables from National Statistics UK. Data for Canada for most of 2001 and 2002 were taken from Statistics Canada. Similarly most of the data for 2001 and 2002 for the US were supplemented using Bureau of Economic Analysis "historical-cost investment in private fixed assets by industry" from the website. For Japan, the STAN database has investment data only in current price that too only in STAN 2 which extends only till 1993; STAN 3 does not have data on Japan. We supplemented these data by acquiring a file from Department of National Accounts, Economic and Social Research Institute in Japan, which has data from 1980 onward in constant price. Hence our investment series for Japan will be a mixed of two series: till 1979 we use the investment in current price by deflating with value added deflator, and from 1980 to 2002 we use data series which were already in constant price (using investment deflator).

Before describing estimation methods of the missing values, a closer look at the industry level current price investment data shows that even though the data for industries ISIC 15-16, 17-18, 21-22, 25, 26 and 36 were more or less complete, there were missing values for other industries. With sample period of 30 years (1973-2002), 22 industries and 17 countries (30 x 22 x 17), we have total of 11,220 cells of information. Out of them, 1,930 (about 17 percent) cells of data were missing. To estimate part of missing cells we used three different approaches. The first approach is based on the assumption that the investment share of 3- or 4-digit level industry in 2-digit level industry remained the same as it was in the preceding three years. This method is used to estimate data mostly for industries at 3- and 4-digit level and for more recent years. Since there are two 4-digit industries (ISIC 24x2423 and ISIC

2423) and three 3-digit industries (ISIC 351, ISIC 353, ISIC 352+359), we have used this method mostly for these five industries. The method, called Method 1, is given by the following equation:

(B1) $\mathrm{i}_t(3/4) \equiv w\mathrm{i}_t(2)$,

where $\mathrm{i}_t(2)$ is the investment at 2-digit industry; $\mathrm{i}_t(3/4)$ is the investment at 3 or 4 digit industries within that 2-digit industry in time period *t;* $w = \left(\sum_k \frac{i_{t-k}(3/4)}{i_{t-k}(2)} \right) \Big/ 3$, (k = *1, 2, 3),* is the average share of investment at 3- or 4-digit industry within its 2-digit industry investment in the preceding three years. Since the data at 3- and 4-digit industries were missing only for the most recent years, this method is mostly used to fill data for years 1999 through 2000. But in few cases, we have used this method to regain data even earlier period. For a couple of countries we used this method to decompose data for individual industries ISIC 30, 31, 32 and 33, when data on ISIC 30-33 was given, and for ISIC 271, 272 when data for ISIC 27 was given and for ISIC 351 and 352+359 when data for ISIC 35 was given.

The second estimation method —Method 2— is used for those industries which have data available for at least three-fifths and less than four-fifths of sample period (between 18 and 23 years). We used the change in current price value added to estimate investment as given below:

(B2) $i_{t+1} = i_t \exp\left[\ln\left(y_{t+1}/y_t\right)\right]$,

where i_t is investment in current price, and *y* is value added in current price. In most cases the data were available for early periods and we used (B2) to estimate data for later period. In few cases, the data were available for later periods and were missing for earlier period. In this case, we used $i_{t-1} = i_t \exp\left[\ln\left(y_{t-1}/y_t\right)\right]$ to estimate the missing values. In very few cases, the data were missing in both ends with data available only for the middle period. In that case, we used (B2) to estimate data only for the later period and left the earlier period empty.

For those industries which have data for at least 24 years, we used the growth rate of investment—Method 3—to estimate investment in the current year as follows:

(B3) $i_{t+1} = i_t\left[1 + \ln\left(i_t/i_{t-1}\right)\right]$

Equation (B3) is good to estimate data for later period given that the earlier period data were available. To refill data for earlier period, we used $i_{t-1} = i_t\left[1 + \ln\left(i_t/i_{t+1}\right)\right]$.

For investment, 140 cells were filled up using method 1; about 466 cells were filled up using Method 2, and about 126 cells were filled up using Method 3. Hence, altogether 732 of the 1,930 missing cells were filled up. The remaining 1,198 were left empty either because the data for industries were empty throughout or were available for less than 18 years, the cut off number of years for data refinement. Among them, nine industries (distributed in different countries) had no entry at all (contributing 270 empty cells). The other empty cells were distributed in different industries and countries, more in Belgium, Ireland, Denmark and few in France, Spain and Sweden.

Then we used value added deflators to convert adjusted current price investment into constant price, and further converted them into 1995 PPP dollar.

In very few cases, we have augmented the value added and deflator prior to 1979 using Method (3). In case of current value added, we filled 143 cells and in case of deflator, we filled 274 cells. In case of R&D, we filled 270 cells using this method.

We have also augmented data for labor compensation using the following mechanism:

(B4) $w_{t+1} = w_t \exp\left[\ln\left(e_{t+1}/e_t\right)\right]$

where *w* is the labor compensation, and *e* is the labor employment. For most of the empty cells we have used equation (B4). However, for a few cells, especially if they occur at the beginning of the period (year 1973) where we don't have the employment growth rate for this year, we used the following process

(B4') $w_{t-1} = w_t\left[1 + \ln\left(w_t/w_{t+1}\right)\right]$

The labor compensation data for Canada for year 2002 were missing from the database and were supplemented using data from Statistics Canada.

For those industries whose labor compensation to value added shares were greater than 0.85 and less 0.2 have been replaced by median value of compensation to value added, median across all countries and all years for the given industry.

Appendix C: Method to Construct Capital Stock

Using two sets of constant price physical investment and the combination of two as another set, we computed three sets physical capital stock. We also computed capital stock of R&D expenditure. For that purpose, we used the following perpetual inventory method to construct the stock of R&D and of physical capital for country c, industry I year t:

(C1) $k_{cit} = i_{cit-1} + (1-d)k_{cit-1}$,

where k represents both physical and R&D capital and i represents both physical and R&D investment, and δ is the depreciation rate. Based on the common practice, we use 5% depreciation rate for physical capital and 15% for R&D. The beginning of period capital stock (both physical and R&D) was given as follows:

(C2) $k_1 = i_0 + (1-d)i_{t-1} + (1-d)^2 i_{t-2} + \ldots$

$$= \sum_{s=0}^{\infty} i_{-s}(1-d).^{s} = i_0 \sum_{s=0}^{\infty}\left[\frac{1-d}{1+g}\right]^{s} = \frac{i_1}{g+d}$$

where g is the average annual growth rate of constant price investment and R&D expenditure throughout the study period.