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ECONOMIC GROWTH, TFP CONVERGENCE AND WORLD EXPORTS OF IDEAS: A CENTURY OF EVIDENCE*

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ABSTRACT

This paper examines the effect of international patent stock on total factor productivity for 16 OECD countries over the past 120 years. The results show that the international patent stock is highly influential for economic growth and, together with knowledge spillovers through the channel of imports, has contributed significantly to TFP growth and σ-convergence among the OECD countries over the past 120 years.

JEL classification: E13, E22, E23, O11, O3, O47.

Key words: TFP growth, international diffusion of ideas, international patents, convergence.

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ECONOMIC GROWTH, TFP CONVERGENCE AND WORLD EXPORTS OF IDEAS: A CENTURY OF EVIDENCE

1 INTRODUCTION

Since the seminal paper of Solow (1957), it has been known that technological change has been an important factor behind the increasing labour productivity that has been experienced over the past century (see also Hall and Jones, 1999, and Prescott, 1998). However, very little is known about the importance of ideas for growth in total factor productivity (TFP), the international diffusion of ideas, the origin and the direction of the flow of ideas since the second industrial revolution, and whether the spillover of ideas has deterred or contributed to TFP convergence among the industrialised countries. In the Solow (1956) model technological progress is exogenous and, as such, technological knowledge is a free good which is accessible for everybody free of charge. Solow did not discuss the implications of this for international knowledge spillovers; however, subsequent research in the neoclassical tradition suggested that technological knowledge is freely available internationally (see, for a discussion of these issues, Fagerberg, 1994).

The endogenous growth literature has identified various channels of international knowledge spillovers. Based on the models of Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991), recent studies have documented R&D cross-country knowledge spillovers through the channel of trade as an important engine of TFP growth in the industrialised countries.[1] Keller (2002) found significant international R&D spillover effects that are declining with distance and Jaffe (1986) and Park (1995) find that R&D are transmitted internationally by technological proximity. Common for most of these empirical studies is that the stock of ideas is measured by R&D expenditures. Although R&D data give valuable information about the generation of knowledge, they cannot be used to trace bilateral flows of ideas across countries, and, with the exception of a few countries, they are available first from the mid 1960s to the mid 1980s for the OECD countries. This renders it impossible to assess the importance of technological spillovers as engines of growth since the second industrial revolution or to assess whether the international flow of ideas has contributed to the TFP convergence, as documented by Dowrick and Nguyen (1989) and Wolff (1991).

A novel data set on TFP and patents applied for by non-residents, or international patents, is used in this paper as an alternative way of tracing the international transmission of ideas over the past 120 years, and to test the effects on TFP of the international patent stock, domestic patent stock, imports of knowledge through the channel of trade, and the world stock of knowledge. International patents are likely to contain vital information about the international diffusion of technology because they travel easily across borders and because each patent is likely to contain a significant component of technology that has commercial promise. The significant direct and indirect costs that are associated with the filing of international patent applications render only the commercially most promising ideas patentable abroad (Eaton and Kortum, 1996, Dernis *et al*., 2001).[2] The importance of international patents as international flows of knowledge has been highlighted in the models of Eaton and Kortum (1996, 1999).

Eaton and Kortum (1999) argue that international patenting is a more direct indicator than R&D of where ideas are going and, therefore, the way in which technologies are internationally transmitted. More importantly, international data on bilateral patent flows between countries are available since the second industrial revolution in the latter part of the 19th century for many of the countries that are today members of the OECD. However, the enormous difficulties that are associated with finding these data have probably prevented researchers from exploiting this rich source of data.[3] The international dissemination of patents filed by US residents in other countries, for instance, are not available from US statistical sources but only from national data sources of countries in which the patents of the US residents are filed.

Closely related to the issue on international dissemination of technology is income and TFP convergence among the industrialised countries. Following the seminal work of Gerschenkron (1962) empirical work has been undertaken to examine catch-up of countries to the technological frontier in the *post* WWII period and whether income and TFP have converged among the industrialised countries. However, very little work has been done on the role played by international technology spillovers in the TFP convergence. The historical TFP data in Maddison (1982) only cover a few countries in snapshot years, and, as such, are not suitable for elaborate time-series analysis.

The contribution of this paper is to estimate the influence of international patents on TFP growth in the destination country, trace the direction of flows of knowledge and examine whether the international flow of patents has been a contributing factor to TFP convergence among the OECD countries over the past 120 years. The next section estimates the influence on TFP of domestic patent stock, international patent stock, spillovers of foreign stock of knowledge through the channel of imports, world stock of knowledge, and the propensity to import. Section 3 simulates the contribution of international patent stock to TFP growth in the industrialised countries over the past 120 years and traces the bilateral effects; i.e. the contribution to TFP growth of spillovers of knowledge from country A to country B. Section 4 tests whether foreign knowledge spillovers have contributed to TFP convergence among the industrialised countries over the past 120 years.

2 Empirical evidence

To test the influence on TFP of international knowledge through the channel of international patenting while controlling for world knowledge, the propensity to import, and knowledge spillover through the channel of imports in the estimates, restricted versions of the following cointegration model are estimated for a panel of 16 countries:

$$\ln TFP_{it} = \alpha_0 + \alpha^D \ln S^D_{it} + \alpha^I \ln S^I_{it} + \alpha^T m_{it} \ln S^T_{it} + \alpha^W \ln S^W_{it} + \alpha^M m_{it} + TD + CD + \varepsilon_{it}, \qquad (1)$$

where TFP is total factor productivity, S^D is the domestic patent stock, S^I is the stock of international patents, S^T is the stock of patents spillovers through the channel of imports, S^W is the world stock of patents, m is the ratio of nominal imports of goods to nominal GDP, TD is time-dummies, CD is fixed-effect country dummies, ε is a disturbance term, and the subscripts t and i signify time and country. The time-dummies are included in the model to capture the effects of omitted variables on TFP that change at the same rate over time for each country. An international patent is defined as a patent that is owned by a person with residence in a country that is different from the country in which the patent is filed. The model is estimated over the period from 1887 to 2002, which is shorter than the data period because two-period lags and leads of first-differences of the right-hand-side variables are included in the estimates as discussed below.

Equation (1) incorporates various channels through which the stock of knowledge affects TFP. Common for almost all theories of endogenous growth is that TFP is driven by knowledge that increases the quality (vertical differentiation) and the variety (horizontal differentiation) of intermediate products that are used in the production process (see for instance Romer, 1990, and Grossman and Helpman, 1991). Expansion of horizontally differentiated intermediate inputs increases the economy-wide efficiency of production because firms have a larger variety of intermediate inputs to choose from to fit their production. For vertically differentiated products the final production is positively related to the number of times in which an input has been improved. Common for both cases is that the variety and the quality of intermediate inputs are predominantly explained by the stock of knowledge and, therefore, that TFP is a positive function of the stock of knowledge. This line of reasoning suggests that the TFP of a country depends on its own stock of knowledge, international patent knowledge stock and the stock of knowledge embodied in imported intermediate inputs.

Spillover of technology through the channel of imports follows the model of Rivera-Batiz and Romer (1991) and some of the models described in Grossman and Helpman (1991). This effect is captured by the S^T variable. This variable may also capture the effects on TFP of intra industry trade in which two countries exchange goods within the same SITC classification. Increasing intra industry trade increases the variety of intermediate inputs and, therefore, the efficiency of production. Spillover of foreign knowledge stock through the channel of international patenting follows from the models by Eaton and Kortum (1996, 1999) and is captured by the S^I variable. Finally, the models of Parente and Prescott (1994), one of the models considered by Rivera-Batiz and Romer (1991), and some of the models described in Grossman and Helpman (1991), show that ideas can travel internationally, independently of trade of goods and patent flows, and, therefore, are freely available to all countries. This effect is allowed for by the S^W term.

Equation (1) controls for the propensity to import to allow for potential effects of openness on TFP following the literature on openness and economic growth. There is a large literature that theoretically and empirically examines the nexus between income and trade barriers where openness is often used as a proxy for trade barriers (see, for a critical survey of the literature, Rodrìguez and Rodrik, 2000). Although most theories in this field predict that trade barriers impede growth, some models predict that, under certain circumstances, trade barriers may encourage growth (Rodrìguez and Rodrik, 2000). Thus, a priori, there is no clear-cut relationship between TFP and the propensity to import.

2.1 Data

The following 16 OECD countries (henceforth G16) are included in the data set during the period 1883 to 2004: Canada, the US, Japan, Australia, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the UK. The data are collected from various national and international sources over the period from 1883 to 2004. See the data appendix for the data used in this paper.

The stock of knowledge is based on patent counts and is estimated using the perpetual inventory method with depreciation rates of 8% and 20%. The 8% depreciation rate is close to the 7% depreciation rate estimated by Caballero and Jaffe (1993) over the period from 1900 to 1990 for the US and the 20% depreciation rate follows the estimates of Pakes and Schankerman (1984). The initial levels of capital and patent stocks are estimated as $I_0/(g+\delta)$, where I_0 is gross investment in the initial year, g is the average annual geometric growth rate during the entire sample period, and δ is the depreciation rate.

Patents applied for, as opposed to patents granted, are predominantly used in the estimates of the knowledge stock in this paper because the granting frequency varies across countries (see Griliches, 1990). Furthermore, the time between filing and granting or rejecting the patent varies across countries (Dernis *et al*., 2001). Following Eaton and Kortum (1999), the Japanese patent applications are scaled down by 4.9. Tong and Frame (1994) and Okada (1992) find that the number of inventive claims per patent is approximately the same across countries except for

Japan, where Okada (1992) finds that the patents granted to foreigners hold, on average, 4.9 times as many inventive claims as patents granted to Japanese inventors.

In the post 1975 period the estimates of the international patent stock are based on patents granted as opposed to patents applied for because international patents applied for have lost their value as reliable indicators of new knowledge since the introduction of the Patent Co-operation Treaty (PCT) in the beginning of the 1980s. The PCT gives an option that allows a patent application to remain open to exercise in the future (Dernis *et al.*, 2001). Since there are low costs in keeping the option embodied in international patents open, the ratio of foreign patents applied for and foreign patents granted has exploded over the past two decades. Consequently, patents applied for by foreigners cannot be used as a proxy for technology after around 1980.

World stock of knowledge is measured as the sum of the domestic patent stock of the G16 countries minus the own-country knowledge stock. International patents are not included in the world patent stock because most international patents are filed in multiple countries and because most of them have already been filed domestically (OECD, 1990).

Imports of knowledge through the channel of trade of country *i*, S^T are based on the following weighting schedule which is suggested by Lichtenberg and Van Pottelsberghe de la Potterie (1998):

$$S_{it}^{T} = \sum_{j=1}^{21} \frac{M_{ijt}}{Y_{jt}^{n}} S_{jt}^{d}, \qquad i \neq j. \qquad (2)$$

where M_{ij} is nominal imports of goods from country *j* to country *i*, Y_j^n is nominal income of country *j*, and S_j^d is the stock of country *j*'s domestic knowledge. According to (2) a country such as Japan has a relatively large knowledge stock, however, only a small fraction of its knowledge is transmitted internationally through the channel of trade since its propensity to export is relatively low, whereas the opposite holds true for small countries. This measure has been widely used in the literature since it was published by Lichtenberg and Van Pottelsberghe de la Potterie in 1998. Data for the G16 countries plus New Zealand, Austria, Greece, Ireland, and Portugal are used to construct S^T.

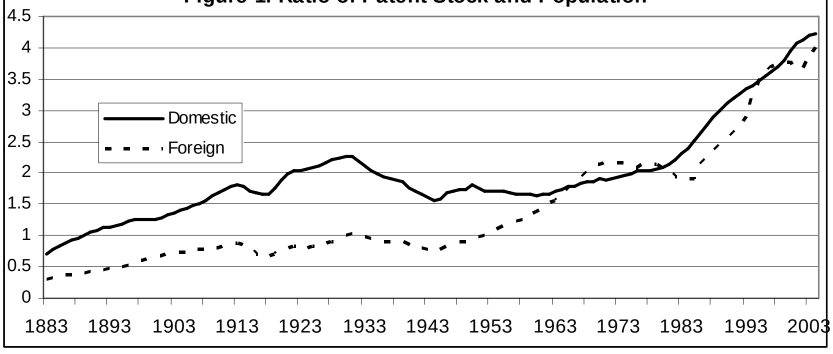
TFP data is estimated from homogenous Cobb-Douglas technology, where factor shares are allowed to vary over time and across countries based on the Divisia-Tornqvist index as follows:

$$TFP_{it} = \frac{Y_{it}}{L_{it}^{\alpha_{i,t-1}} K_t^{(1-\alpha_{i,t-1})}} , \qquad (3)$$

where *Y* is real GDP, *L* is labour inputs measured as annual hours worked per worker times economy-wide employment, *K* is non-residential capital stock, and $\alpha_{i,t-1}$ is labour's income share at time *t*-1 for country *i*. The capital stock is computed separately for machinery and equipment capital and non-residential buildings and structures. The perpetual inventory method is used with 17.6% and 3% depreciation rates for machinery and equipment and non-residential buildings and structures, respectively. Labour's income share is calculated as the economy-wide compensation to employees divided by nominal GDP, where compensation is corrected for imputed payments to the self-employed because earnings from self-employment in national accounts are counted as profits although they should be counted as labour income. To correct this bias the average earnings per employee, multiplied by the number of self-employed, is added to the compensation to employees. Since data on factor shares are not available over the entire period for all countries, the first observation is backward extrapolated as detailed in the data appendix. Capital stock and GDP are measured at USD purchasing power parities.

Figure 1 shows the weighted average of the ratio patent stock to population decomposed into international and domestic patent stock for the G16 countries, where the population sizes are used as weights. Per capita foreign patent stock increased over the periods 1883-1913, 1945-1970 and 1985-2000, while stagnating in the periods 1913-1945 and 1970-1985. This growth pattern roughly coincides with the TFP growth pattern in the G16 countries, as shown below. Per capita domestic knowledge stock increased gradually over the period from 1883 to the onset of the Great Depression, stagnated during the period 1930 to 1980 and increased markedly from 1980 to 2004.

Figure 1. Ratio of Patent Stock and Population



Notes:
Weighted average of the G16 countries in which population sizes are used as weights. The stock of knowledge is based on patent applications except for the international patent stock over the period from 1975 to 2004, which is based on patents granted. The patent stock is based on a 20% depreciation rate.

The international patent stock ratio has increased almost three times as much as the domestic patent stock ratio over the entire period. While the stock of domestic and international patents moved in tandem up to WWII the international patent stock has grown at impressive rates in the two decades following WWII and in the past two decades. Thus, international patents may potentially have been an important impetus for the strong growth among the G16 countries in the post WWII period.

2.2 Estimation method

Equation (1) is estimated using the dynamic ordinary least squares (DOLS) estimator of Stock and Watson (1993), where the first-differences of two-period lags and leads and concurrent values of the explanatory variables are included as additional regressors to allow for the dynamic path around the long-run equilibrium and to account for endogeneity. The number of leads and lags included in the estimates follows the recommendation of Stock and Watson (1993). Furthermore, the influence of serial correlation in the residuals on the estimated standard errors is corrected in the estimates of the standard errors. The DOLS estimator possesses an asymptotic normal distribution and, therefore, the associated standard errors allow for valid calculation of *t*-tests, provided that the variables in the estimation equation are cointegrated.

2.3 Estimation results

The results of estimating various restricted versions of (1) are presented in Table 1. The null hypothesis of no cointegration cannot be rejected at any conventional significance level in any of the estimates, which suggests that there is a genuine long-run relationship between the variables included in the models. The statistical implication of this result is that the *t*-statistics reported in Table 1 can be compared to tabulated *t*-values.

The estimated coefficients of international knowledge stock are statistically and economically highly significant in almost all the estimates. The average estimated elasticity is 0.26, which suggests very high social returns to international knowledge stock. The estimates show that the parameter estimates are robust to 1) whether 20% or 8% depreciation rates for the stock of knowledge are used; 2) whether the international knowledge stock is based on patents granted or patents applied for (except for the post-1975 period); 3) whether the world stock of knowledge is included in the estimates; and 4) whether the propensity to import is included in the estimates. The estimated elasticities of foreign patent stock are reduced to 0.11 when time-dummies are included in the estimates, which is not surprising given that the foreign patents initiate from the same sources across countries. It is, therefore, likely that the time-dummies have captured the effects from the international patent stock.

The estimates in rows 11 and 12 are based on TFP that is estimated under the assumption of increasing returns to scale (IRTS). A factor of 0.1 is added to capital's income share so that TFP is computed as $TFP_{it} = Y_{it} / (L_{it}^{\alpha_{i,t-1}} K_{it}^{(1-\alpha_{i,t-1})+0.1})$. Only a weak form of IRTS is assumed as slightly higher degrees of IRTS would result in a reduction in TFP over time for some countries, which is counterintuitive. The estimates in rows 11 and 12 show that the estimated coefficients of the international patent stock are still highly significant and that the estimated elasticities are close to the other estimates in the table, which suggests that the estimated elasticity of the foreign patent stock is insensitive to small variations in the assumptions of returns to scale.

Common for almost all the estimates in Table 1, is the insignificance of the estimated coefficients of domestic knowledge stock. This result implies that the hypothesis of equality between social and private returns to domestic knowledge can not be rejected in most of the estimates, noting that inputs of researchers and research capital have been accounted for in the TFP estimates under the assumption that researchers and research capital are paid their marginal products. This result could reflect that the law of large numbers fails to hold for domestic patents in the sense that the fraction of high quality patents may change over time. Thus, aggregated domestic patent stock may be a noisy measure of the domestic stock of knowledge and its estimated coefficient will, consequently, be biased toward zero. International patents, by contrast, consist of the patents that have shown the most commercial promise in the domestic market and are, therefore, likely to be more homogeneous over time than domestic patents. The finding that the international patent stock is substantially more influential for TFP growth than the domestic patent stock is consistent with the R&D based results of Guellec and Van Pottelsberghe de la Potterie (2004) and the models of Eaton and Kortum (1996, 1999) in which domestic research raises the world growth rate rather than the growth rate of the home country.

Turning to the estimated coefficients of knowledge spillover through the channel of trade, S^T, the estimated coefficients are economically and statistically significant in most of the cases. The estimated average elasticity is 0.17, which is close to the R&D based estimates obtained in the literature. Except for the estimates in row 10, the coefficient estimates are robust to whether 20% or 8% depreciation rates are used, whether patents applied for or patents granted are used, whether time-dummies are included in the estimates, whether TFP is based on constant or weakly increasing returns to scale, and whether world stock knowledge and the propensity to import are included in the estimates.

Table 1: Cointegration estimates with various measures of foreign knowledge.

Row	A/G	δ %	TD	$\hat{\alpha}^D$	$\hat{\alpha}^I$	$\hat{\alpha}^T$	α^W	α^M	DF_γ
1	A	20	N	-0.13(1.75)	0.39(5.14)	0.18(2.03)			-4.57
2	A	8	N	-0.13(2.05)	0.32(4.39)	0.20(2.64)			-5.96
3	A	20	Y	0.03(0.75)	0.11(2.66)	0.22(4.71)			-7.73
4	A	8	Y	0.04(1.01)	0.11(2.31)	0.23(5.05)			-7.84
5	A	20	N	-0.11(1.76)	0.27(3.91)	0.02(0.25)	0.38(3.16)		-4.69
6	A	8	N	-0.10(1.72)	0.28(3.57)	0.14(1.75)	0.14(1.25)		-5.99
7	A	20	N	-0.13(1.72)	0.39(5.22)	0.18(1.99)		0.07(0.28)	-4.73
8	A	8	N	-0.13(2.05)	0.33(4.49)	0.20(2.68)		0.11(0.46)	-6.09
9	G	20	N	-0.03(0.27)	0.31(2.68)	0.30(2.08)			-3.61
10	G	8	N	-0.02(0.22)	0.31(3.31)	0.05(1.89)			-6.17
11#	A	20	N	-0.12(1.52)	0.30(3.81)	0.14(1.53)			-4.81
12#	A	8	N	-0.12(1.67)	0.24(2.97)	0.17(2.03)			-5.97
13*	A	20	N	-0.02(0.25)	0.21(2.92)	0.22(1.29)			-7.69
				0.08(0.94)	0.14(1.70)	0.41(1.70)			
14*	A	8	N	0.03(0.40)	0.24(3.41)	0.09(2.45)			-8.38
				0.04(0.47)	0.25(3.23)	0.03(1.83)			

Notes:

The numbers in parentheses are absolute *t*-statistics. The A/G-column indicates whether the innovations variables are based on patents applied for (A) or patents granted (G) except for S^I over the period from 1975 to 2004, in which patents granted are used in all estimates as discussed in the text. The TD-column shows whether time-dummies are included in the estimates, where *Y* stands for yes and *N* for no. DF_γ is Kao's (1999) test for cointegration and is distributed as N(0,1) under the null hypothesis of no cointegration. δ is the rate of depreciation as a percentage for the stock of knowledge. Constant terms and fixed-effect dummies are included in the estimates but not shown. Two-period lags and leads and concurrent values of the explanatory variables in first-differences are included as additional regressors in the estimates. The t-statistics are corrected for autocorrelation following Stock and Watson (1993). Estimation period: 1887-2002.

TFP is estimated under the assumption of increasing returns to scale, in which the marginal productivity of capital is set equal to capital's income share plus 0.1.

* The coefficients are allowed to differ before and after 1936. The first columns show the coefficient estimates before 1936 and the second columns show the estimates after 1936. Wald tests for structural break in 1936: Row 13: $\chi^2(\hat{\alpha}^D_{t<1936} = \hat{\alpha}^D_{t\geq1936})$ = 16.1, $\chi^2(\hat{\alpha}^I_{t<1936} = \hat{\alpha}^I_{t\geq1936})$ = 9.5, and $\chi^2(\hat{\alpha}^T_{t<1936} = \hat{\alpha}^T_{t\geq1936})$ = 6.7. Row 14: $\chi^2(\hat{\alpha}^D_{t<1936} = \hat{\alpha}^D_{t\geq1936})$ = 0.2, $\chi^2(\hat{\alpha}^I_{t<1936} = \hat{\alpha}^I_{t\geq1936})$ = 0.2, and $\chi^2(\hat{\alpha}^T_{t<1936} = \hat{\alpha}^T_{t\geq1936})$ = 10.2. The tests are distributed as $\chi^2(1)$ under the null hypothesis of structural stability.

The estimates in rows 5 and 6 indicate that the world stock of knowledge positively influences TFP. However, the significance of its estimated coefficient is sensitive to whether 8% or 20% depreciation rates are used, which suggests that the importance of knowledge spillovers through channels that are independent of trade and international patenting cannot be determined from the estimates in this paper. Finally, the estimated coefficients of the propensity to import are economically and statistically insignificant suggesting that there are no direct effects of openness on TFP. This result is consistent with the estimates of Vamvakidis (2002) using long historical data for industrialised countries and consistent with studies using pre-WWII data, which fail to uncover any relationship between openness and growth (see for example Clements and Williamson, 2001).

As a final check of the model, structural stability tests with a breaking point in 1936 are presented for the models in rows 13 and 14, where 1936 is in the middle of the sample period. The null hypotheses of the same coefficients of S^I and S^D before and after 1936 are rejected at conventional significance levels when 20% depreciation rates for knowledge are used; however, when 8% depreciation rates are used the null hypotheses cannot be rejected at any conventional significance level. The null hypotheses of the same coefficients of S^T are rejected at conventional significance levels regardless of knowledge depreciation rates.

The estimated coefficients of S^I are surprisingly stable given that during the period examined the world has been exposed to two depressions and two world wars. The size of the destruction of the capital stock during the world wars is difficult to assess precisely and some of the data have been interpolated during the wars for some of the countries by statistical agencies. The large demand contractions during the depressions in the periods 1920-21 and 1929-33 is also likely to have lowered the capacity utilization of factors of production and reduced capital's income share below its full employment counterpart, which is the relevant measure in TFP estimates.[4] Despite these events the estimated coefficients of S^I, before and after 1936, are very close to each other, which indicates that the effects of international patent stock on TFP have not been changing over the past century despite changes in the economic environment. The stability results give further credibility to the model.

Overall, the estimates show a robust relationship between TFP, international patent stock and the foreign knowledge through the channel of imports. The estimates are robust to inclusion of control variables, measurement of patents, variations in depreciation rates and small variations in returns to scale. Furthermore, the null hypothesis of no cointegration could not be rejected at conventional significance levels in any of the estimates.

The results in Table 1 are consistent with other studies of international spillover effects. Van Pottelsberghe de la Potterie and Lichtenberg (2001) find that geographical proximity is a significant determinant of international patenting. Coupled with the finding of Keller (2002) that geographical proximity is important for technological spillover it follows that international patenting is important for cross-country spillovers, as found above. The estimates are also consistent with Park's (1995) finding that technological proximity is important for TFP growth when it is taken into account that technological proximity is also an important determinant of international patenting (Van Pottelsberghe de la Potterie and Lichtenberg, 2001).

3 MODEL SIMULATIONS

The estimates in the previous section are used in this section 1) to examine the contribution of the international patent stock and knowledge spillovers through the channel of imports to TFP growth over the past 120 years; and 2) to map the international patent-induced TFP growth on source and destination country.

Figure 2 displays the weighted average TFP growth and the contribution to TFP growth of the international patent stock and knowledge spillovers through the channel of imports in the G16 countries. The contribution to TFP growth of international knowledge and knowledge spillovers through the channel of imports is estimated by $0.26\Delta\ln S^I$ and $0.17\Delta(m\ln S^T)$, respectively, where the coefficients of 0.26 and 0.17 are the average estimated coefficients of $\ln S^I$ and $m\ln S^T$, respectively, in Table 1. The data are smoothed out using a 7-year centred moving average. TFP has, on average, increased by 1.4% annually over the whole period (thick line). Growth in the international patent stock has, on average, contributed to an annual 0.7 percentage point growth in TFP over the entire period (hatched line), while knowledge spillovers through the channel of imports have contributed another 0.2 percentage points to the TFP growth rate during the same period (the vertical distance between the hatched and the thin lines). Consequently, the cross-border knowledge spillovers account for more than half of the TFP growth in the overall period.

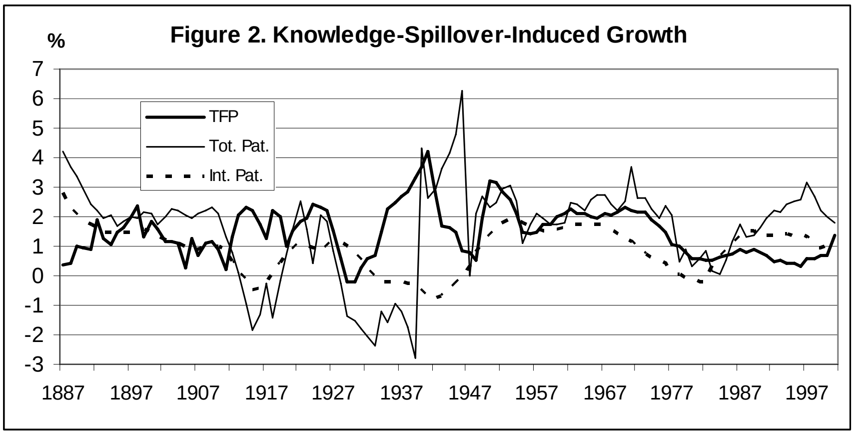


Figure 2. Knowledge-Spillover-Induced Growth

Notes:

The figures are weighted averages of the G16 countries where purchasing power parity GDP are used as weights. The data are smoothed out by seven-year centred moving averages. The patent stock is based on patents applied for, except for international patents in the period 1975-2004, during which international patents granted are used.

Total cross-border knowledge spillovers, as indicated by the thin line in Figure 2, explains most of the TFP growth before WWI and after WWII. Judging from the figure the correlation between TFP growth and knowledge-induced growth in the period 1913-1950 was low, which may reflect that the TFP growth cycle was heavily influenced by wars and depressions, as discussed in the last section.

Turning to the bilateral flow of ideas between countries Table 3 shows the contribution of the growth in the international patent stocks to the average annual TFP growth on source and destination country over the period from 1890 to 2001. The following equation is used to estimate the contribution of international patent stock knowledge spillovers from patents filed by residents in country *j* to TFP growth in the destination country *i*:

$$GTFP^{I}_{ij,1890-2001} = 100 \cdot 100 \cdot 0.26 \left[\frac{\ln(S^{I}_{ij,2001}) - \ln(S^{I}_{ij,1890})}{112} \right] \frac{S^{I}_{ij,1936}}{\sum_{j=1}^{21} S^{I}_{ij,1936}}, \; i \neq j \qquad (4)$$

where $S^{I}_{ij,1890}$ and $S^{I}_{ij,2001}$ are the stock of international patents filed in country *i* (destination country) by residents of country *j* (country of origin) in 1890 and 2001, respectively. The number of 0.26 in (4) is the average of the estimated coefficients of international knowledge in Table 1. The expression in the squared bracket is the average annual growth rate of the international knowledge stock transmitted from country *j* to country *i* in the period 1890-2001, where the log approximation follows the logarithmic transformation used in the estimates. The final right-hand-side term is the weight of the knowledge going from country *j* to country *i* in the international knowledge spillovers of all of the *j* countries that are transmitting knowledge to country *i*. The right-hand-side of (4) is scaled up to percentages by the factor of 100 and scaled up further by 100 to cater for the fact that the percentage growth in TFP attributed to bilateral international knowledge spillovers are small numbers. The weighting is based on 1936 as the base year because it represents the middle of the sample.

The interpretation of the cells in the table is as follows. The number of 8.9 in the second cell in the first row, for instance, represents the contribution of the international knowledge stock of US residents to Canada's annual TFP growth on average over the period from 1890 to 2001. Expressed in terms of percentages the patents of US residents filed in Canada have contributed to a 0.09% point growth in the Canadian TFP on an annual basis on average since 1890. The last column in the table entitled 'Sum' shows the contribution to country *i*'s average annual TFP growth of the total international knowledge stock from residents of all 22 countries in the table. For Canada, for example the sum of 15 shows that the growth in international patent stock in the period 1890-2001 has annually contributed to a 0.15% point growth in TFP for Canada. The second last row, as indicated by "Avr", shows the average of the rows for all countries. The number of 0.3 in this row for Canada, for example, shows that Canada in the period 1890-2001 contributed to a 0.003% increase in TFP on an annual basis for the average country in the table. The cells in final row are the "Avr" divided by the size of the population in billions in 1938. The number of 23 for Canada, for example, shows that Canada in the period 1890-2001 have contributed to a 0.23% increase in TFP per 1 billion Canadians for each country, on average, in the table. Greece and Spain are excluded from the rows in the table because data are not available before 1972 for these countries, however, they are listed in the rows because country of origin is reported by the destination country.

The main contributors to the growth in international knowledge have been Germany and the US followed by the UK, France and the Netherlands, as seen from the second last row in Table 3. The high contribution of these countries is, to some extent, due to the sheer size of their economies. When the contributions are scaled by the size of the population, as shown in the last row in Table 3, the picture looks quite different. On a per capita basis Switzerland is the main contributor followed by Luxembourg and the Scandinavian countries while Greece, Japan, Portugal and Spain stand out as the countries that have contributed the least to world TFP growth through the channel of international patenting. The low Japanese contribution is partly a result of the base year of 1936 of the weighting scheme. Because international patenting by Japanese residents first took off from a very low base in the 1960s, Japan's contribution to the international knowledge stock in the world knowledge stock in 1936 was low compared to the post 1970 period. However, weighting is not entirely responsible for the low performance of Japan. Since Japan's contribution to the growth in international patents has been predominantly concentrated in the post 1960 period, the contribution in the overall period 1890-2001 has been relatively low.

Table 3: Contribution of international patent stock to annual TFP growth over the period from 1890 to 2001.

From \ To	CAN	USA	Jap	AUD	NZ	AUT	BEL	DEN	FIN	FRA	GER	GRE	IRE	ITL	LUX	NET	NOR	POR	SPA	SWE	SWZ	UK	Sum
CAN	0.0	8.9	0.1	0.2	0.0	0.1	0.1	0.1	0.0	0.9	2.3	0.0	0.0	0.2	0.0	0.2	0.1	0.0	0.0	0.3	0.3	1.3	15.0
USA	1.8	0.0	1.5	0.6	0.0	0.5	0.5	0.3	0.1	2.9	11.6	0.1	0.0	1.5	0.0	1.5	0.3	0.0	0.1	1.3	1.3	3.7	29.5
JAP	0.2	15.4	0.0	0.1	0.1	0.6	0.5	0.4	0.1	3.0	24.0	0.0	0.0	1.1	0.0	1.1	0.2	0.0	0.3	0.7	3.5	4.8	56.2
AUD	0.4	10.5	0.1	0.0	0.7	0.2	0.2	0.1	0.0	1.1	1.2	0.0	0.0	0.3	0.0	3.0	0.2	0.0	0.1	1.5	1.2	4.8	25.8
NZ	0.3	5.1	0.4	3.6	0.0	0.1	0.2	0.3	0.0	0.6	4.5	0.0	0.0	0.2	0.0	1.4	0.0	0.0	0.0	0.3	0.3	6.8	24.3
AUT	0.3	6.6	1.4	0.1	0.0	0.0	0.3	0.1	0.1	2.4	10.4	0.0	0.0	0.9	0.0	0.8	0.4	0.0	0.1	0.7	5.2	2.3	32.5
BEL	-1.7	0.0	0.1	0.0	-0.2	0.2	0.0	0.2	0.0	2.3	4.0	0.0	0.0	0.6	0.0	1.1	0.1	0.0	0.1	0.4	0.9	1.2	9.6
DEN	0.2	6.1	0.0	0.1	0.0	0.5	0.6	0.0	0.5	2.5	15.9	0.0	0.1	1.5	0.2	2.4	1.3	0.0	0.3	4.0	3.6	4.8	44.8
FIN	0.3	2.4	1.5	0.1	0.0	0.1	0.5	1.0	0.0	1.2	9.5	0.0	0.0	0.0	0.1	2.2	1.0	0.0	0.2	6.9	1.5	2.3	30.8
FRA	0.1	5.5	0.3	0.1	0.0	0.3	0.6	0.2	0.1	0.0	11.2	0.0	0.0	1.6	0.1	2.2	0.2	0.0	0.2	1.0	3.0	0.9	27.5
GER	0.5	7.7	0.1	0.1	0.2	0.6	0.6	0.6	0.3	4.9	0.0	0.0	0.1	2.6	0.1	3.3	0.4	0.0	0.3	1.6	5.3	2.7	32.0
IRE	0.2	4.4	0.2	0.3	0.1	0.7	0.5	0.5	0.2	3.0	9.7	0.0	0.0	1.3	0.1	1.1	0.4	0.0	0.2	1.1	1.1	11.2	36.1
ITL	0.2	16.7	0.1	0.3	0.1	0.1	0.1	0.1	0.0	1.1	3.0	0.0	0.1	0.0	0.0	0.4	0.1	0.0	0.0	0.4	0.4	2.3	25.5
LUX	0.1	5.2	0.6	0.1	0.0	0.7	3.4	0.1	0.1	7.3	11.8	0.0	0.0	1.8	0.0	2.3	0.1	0.1	0.2	0.8	3.5	2.1	40.5
NET	0.2	5.8	2.1	0.3	0.0	0.5	1.4	1.2	0.0	3.3	21.3	0.0	0.0	1.2	0.1	0.0	0.7	0.0	0.2	2.9	3.8	5.1	50.4
NOR	0.3	4.3	0.2	0.2	0.0	0.1	0.3	0.7	0.5	1.6	4.5	0.0	0.0	0.8	0.1	2.6	0.0	0.0	0.2	3.3	2.0	1.8	23.4
POR	0.4	7.3	2.1	0.2	0.0	0.6	1.7	0.7	0.2	7.9	7.4	0.0	0.0	2.4	0.2	1.5	0.4	0.0	2.3	1.4	3.8	4.9	45.6
SWE	0.5	8.6	0.0	0.1	0.0	0.8	0.5	1.6	1.1	2.8	10.1	0.0	0.0	0.9	0.0	2.4	1.3	0.0	0.2	0.0	3.7	5.9	40.7
SWZ	0.1	5.9	0.0	0.1	0.0	0.8	0.4	0.3	0.1	2.8	11.0	0.0	0.0	1.7	0.1	1.9	0.3	0.0	0.2	1.8	0.0	3.1	30.8
UK	0.2	4.9	0.3	0.1	0.0	0.1	0.2	0.3	0.1	1.5	5.9	0.0	0.0	0.7	0.1	1.0	0.1	0.0	0.1	0.8	1.7	0.0	17.9
Avr	0.3	6.9	0.6	0.4	0.1	0.4	0.7	0.5	0.2	2.8	9.4	0.0	0.0	1.1	0.1	1.7	0.4	0.0	0.3	1.6	2.4	3.8	
%Pop	23	53	8	53	40	58	79	122	51	67	220	3	12	26	231	196	134	2	11	260	577	80	

Notes:
The figures are computed from Equation (4). International knowledge stock from Greece and Spain are excluded from the rows because data are not available before 1972. Avr is the average of all rows in the column and %Pop is the Avr divided by the population size of the country in the column in billions equivalents in 2004.

Considering the beneficiaries from the growth in international patents, Japan, the Netherlands and Portugal stand out as the countries that have benefited the most from the growth in the international patent stock. International patents have contributed to more than a 0.5 percentage point increase in the TFP growth over the period from 1890 to 2001 for these countries. At the other end of the spectrum, Canada, Belgium and the UK are the countries that have benefited the least from international patents, which, to some extent, explains why these countries have experienced low TFP growth rates over the past century relative to other OECD countries.

3.1 Which factors explain where patents are flowing?

The results in Table 3 show that ideas have been flowing unevenly across countries. These results beg the question of which country-*i*-specific variables explain the direction of flows of international patents. In other words, which factors of country *i* explain the flow of international patents to this country.

Economic theory suggests that the decision to patent in country *i* depends on the discounted expected returns from the patent (see Eaton and Kortum, 1996, 1999, for formal expositions). Eaton and Kortum (1996) argue that the following factors are among the most important in explaining where patents are going: 1) geographic proximity; 2) absorptive capacity of the recipient country; and 3) the size of the market of the recipient country. Studies have shown that geographic proximity facilitates technological diffusion (Keller, 2002). Referring to the economic geography literature on agglomeration, Keller (2002) shows that geographic distance works as an impediment to international technological spillovers. Through this channel technological knowledge can transmit by informal contacts, such as speeches, conferences and seminars.

Education has long been considered as important for imports of knowledge. In the account of the cross-country diffusion of technology Rosenberg (1982) writes that “transfer of technology has never been easy. Typically high levels of skill and competence are needed in the recipient country,” (p. 247). Furthermore, Nelson and Phelps (1966) argue that educational attainment contributes to productivity by facilitating the adoption of foreign technology rather than serving as a factor of production. Finally, the expected returns of patenting depend on the size of the market. If the size of the market is large it is easy to cover the costs that are associated with filing a patent (Eaton and Kortum, 1999).

To investigate the importance of each of these factors in explaining the growth in patent stock going from country *j* to country *i*, the following model is estimated:

$$\Delta \ln S_{t_0-t_1}^{I,ij} = \beta_0 + \beta_1 Dis_{ij} + \beta_2 Y_i^{ppp} + \beta_3 S_i^h + u_{ij} \qquad (5)$$

where $\Delta \ln S_{t_0-t_1}^{I,ij}$ is the growth in the stock of international patents going from country *j* to country *i* over the period from t_0 to t_1, Dis_{ij} is distance in miles between source and recipient country from Haveman (2000), Y^{ppp} is income in 1975 in USD purchasing power parity units, S^h is the stock of human capital in 1975 measured by average educational attainment of the population in the age between 15 and 65.

Table 4: Factors explaining the growth in the patent stock from country *j* to country *i*.

	$\Delta S^{I,ij}_{90/38-50/01}$	$\Delta S^{I,ij}_{60-01}$	$\Delta S^{I,ij}_{50/61-90/01}$	$\Delta S^{I,ij}_{1890-2001}$
$\ln Dis_{ij}$	0.06(0.33)	0.12(1.00)	0.14(0.95)	0.10(0.90)
$\ln Y_j^{PPP}$	-0.13(0.41)	-0.20(1.00)	-0.09(0.26)	-0.11(0.22)
$\ln S_j^h$	0.01(3.61)	0.02(4.94)	0.01(3.18)	0.02(3.77)

Notes:
The numbers in parentheses are absolute *t*-statistics. The *t*-statistics are based on White's heteroscedasticity consistent covariance matrix. The estimated coefficients of distance and income are divided by 1000. The number of observations is 484. $\Delta S^{I,ij}_{90/38-50/01}$ = growth in international patent stock over the period from 1890/1938 to 1950/2001 from country *j* to country *i*. $\Delta S^{I,ij}_{60-01}$ = growth in international patent stock over the period from 1960 to 2001 from country *j* to country *i*. $\Delta S^{I,ij}_{50/61-90/01}$ = growth in international patent stock over the period from 1950/1961 to 1990/2001from country *j* to country *i*. $\Delta S^{I,ij}_{1890-92001}$ = growth in international patent stock over the period from 1890 to 2001 from country *j* to country *i*.

The results of estimating (5) are presented in Table 4 for first differences of $\ln S^I$ spanning over the following periods: 1890/1938 to 1950/2001, 1960 to 2001, 1950/1961 to 1990/2001, and 1890 to 2001. The estimates show that not all the explanatory variables have been important in explaining where ideas are going. Neither distance nor the size of the market of the recipient country is important for the growth in the flow of ideas. Educational attainment is the only important explanatory variable of the variables considered here in explaining the direction of international patent flows. Hence, countries with a highly educated labour force are more likely to benefit from the spillover of international ideas than countries with an uneducated labour force. The estimation results are consistent with the literature on technological spillovers and absorptive capacity in which the absorptive capacity is measured by R&D expenditures as a percentage of income (see for instance Griffith *et al*., 2003). However, the results are only partly consistent with the findings of Eaton and Kortum (1996) who find that distance as well as educational attainment are important for the flow of ideas.

4 CONVERGENCE

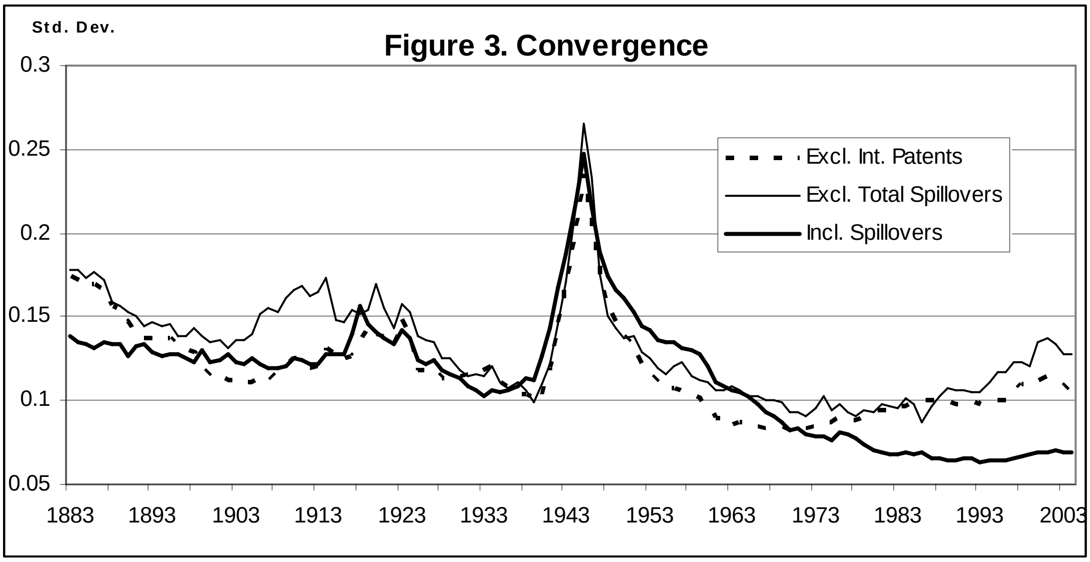
Based on Maddison's (1982) data in the snap-shot years 1870, 1880, 1890, 1900, 1913, 1929, 1938, 1950, 1960, 1970 and 1979 Wolff (1991) finds σ-convergence of TFP among the G7 countries. This begs the question of whether the convergence has also taken place among the G16 countries and whether cross-border knowledge spillovers have contributed to σ-convergence among the G16 countries over the past 120 years.

To test whether convergence has taken place over the period from 1883 to 2004 among the G16 countries the following test suggested by Carree and Klomp (1997) is carried out:

$$\Psi_{1883,2004} = \frac{\sqrt{N}\,(\hat{\sigma}^2_{1883}/\hat{\sigma}^2_{2004} - 1)}{2\sqrt{1-(1-\hat{\beta})^2}},$$

where N is the number of countries, $\hat{\sigma}^2_{1883}$ and $\hat{\sigma}^2_{2004}$ are the cross country variances of $\ln TFP_i$ in 1883 and 2004, and $\hat{\beta}$ is estimated from the regression $\ln(TFP)_{i,2004} = \alpha_i + (1-\beta)\ln(TFP)_{i,1883} + v_i$, where v is a disturbance term. Their statistic has a standard normal distribution under the null hypothesis of no σ-convergence. The tests are reported in the notes to Figure 3.

Figure 3 shows the standard deviation of ln(*TFP*) across countries over time, with and without allowance for knowledge spillovers. The bold line in the figure (named "incl. spillovers") is based on the raw TFP data and indicates the presence of σ-convergence among the industrialised countries over the past 120 years. The standard deviation has continually declined since the start of the data period in 1883 except for the interruptions during and around the two world wars. The null hypothesis of no σ-convergence is rejected at the 5% level (N(0,1) = 2.28), which suggests that convergence has taken place over the period from 1883 to 2004.



Notes:
Standard deviation of TFP among the G16 countries. Original TFP data in USD purchasing power parities are used in the estimates of the series 'Incl spillover', whereas the effects of international patent-stock-induced TFP growth is removed from the data used to construct the series 'Excl. Int. Patents' and the effects on TFP of international patent stock and knowledge spillovers through the channel of imports are removed from the data used to construct the series 'Excl. Total Spillover'. Tests of convergence: "Excl Int. Patents" (N(0,1) = 0.89), "Excl. Total Spillovers" (N(0,1) = 1.54), "Incl. Spillovers" (N(0,1) = 2.28).

The hatched bold line in Figure 3 is based on TFP in which the effects of international patent stock are removed from the data by subtracting $0.26\ln S_{it}^{I}$ from *ln*TFP for each country before computing the standard deviation and $\hat{\beta}$. The figure indicates that some convergence took place before 1900; however, there is almost no evidence of long-run convergence in the data since then. The convergence that took place from WWI to the mid 1960s was almost reversed by 2000. The visual evidence is supported by the convergence test. The null hypothesis of no convergence over the period from 1883 to 2004 cannot be rejected at any conventional significance ($N(0,1)$ = 0.89).

The thin line in Figure 3 is based on TFP in which the joint effects of international patent stock and the knowledge stock spillover through the channel of imports are removed from the raw TFP data by subtracting $0.26\ln S_{it}^{I}$ plus $0.17m\ln S_{it}^{T}$ from *ln*TFP for each country. Note that the vertical distance between the hatched bold line and the thin line cannot be attributed to the σ-effects of removing knowledge spillovers through the channel of imports from TFP because the distance between the two lines is also influenced by the covariance between S^I and S^T. The thin line shows that hardly any convergence would have taken place over the past 120 years, had ideas been prevented from travelling across borders. Some convergence took place between WWI and 1970, however, the trend has since been reversed and the standard deviation is of the same size today as it was a century ago. Statistically, the null hypothesis of no convergence during the period from 1883 to 2004 cannot be rejected at conventional significance levels ($N(0,1)$ = 1.54).

The results in this section suggest that TFP convergence among the G16 countries over the past 120 years would not have taken place in the absence of international knowledge spillovers through the channel of international patenting and through the channel of imports. This result is consistent with the evidence by De Long (1988) that the convergence among the countries, which are rich today, over the period 1870-1979 has been driven by a selection bias.[5] Including countries that were rich in 1870 such as Argentina, Portugal, Ireland, Spain and Chile in his sample, De Long finds no evidence of convergence. De Long’s evidence is consistent with the findings here that countries do not automatically tap into the world technological frontier but need to actively attract international knowledge through the channels of international patents and imports of knowledge to prosper.

5 CONCLUSION

This paper has shown that the cross-border flow of ideas has been highly influential for TFP growth in the industrialised countries over the past century. Three potential channels through which ideas transmit internationally were examined in the paper: International patenting, knowledge spillovers through the channel of imports and transmission of world knowledge through channels that are independent of trade and international patenting. The estimates showed that international patenting and knowledge spillovers through the channel of trade are important determinants of TFP in the OECD countries. The estimation results were robust to 1) whether 8% or 20% depreciation rates were used for the stock of knowledge; 2) small variations in the returns to scale assumptions in the estimates of TFP; 3) whether knowledge is based on patents applied for or patents granted; 4) whether time-dummies are included in the estimates; and 5) whether the propensity to import is controlled for in the estimates. Furthermore, the estimated coefficients of international knowledge were relatively stable before and after 1936.

Based of the estimated elasticities the data showed that the effects on TFP of bilateral flows of international patent stock were highly unevenly distributed across countries. Germany and the US followed by the UK, France and the Netherlands stood out as the main contributors to the growth in the international patent stock over the period from 1890 to 2001, while the contribution had been relatively modest among the other population-rich countries such as Italy and Spain. Normalizing the contribution of the growth in the international patent stock by population showed that Switzerland, Luxembourg and the Scandinavian countries were the top per capita contributors to international patenting. The largest beneficiaries of the growth in international patent spillovers in the period 1890-2001 were Japan, the Netherlands and Portugal, while Canada, Belgium and the UK benefited the least from international patents, which, to some extent, explains why these countries have experienced lower TFP growth rates over the past century than most other OECD countries.

Finally, the paper found evidence of σ-convergence among the G16 countries and attributed the convergence to international patents and knowledge spillovers through the channel of imports. This result is important because it shows that convergence among the G16 countries would not have taken place in the absence of cross-country knowledge spillovers. By implication countries do not automatically catch up to the world technology frontier through freely available knowledge but need to attract international knowledge and import products that embody knowledge.

The results suggest that attracting international knowledge is an important ingredient for having high economic growth. Policies to attract international knowledge should, therefore, be high on the policy agenda. Preliminary estimates in this paper suggested that a highly educated labour force is conducive to attracting international patents, while factors such as distance and size of the domestic market have little bearing on the inflow of international patents.

DATA APPENDIX

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Capital stock of equipment and non-residential structures. The perpetual inventory method is used with the following depreciation rates. 17.6% for Machinery and equipment, and 3% for non-residential buildings and structures. The stock of capital is initially set to the Solow model steady state value of $I_t/(\delta + g)$, where I is investment, δ is the depreciation rate and g is the growth in investment during the period from 1870 to 2004. The post 1950/60 data are from OECD, *National Accounts, Vol. II,* Paris*, (NA)*. Before 1950/60 the following sources are used for the countries at which historical data are available**.** Canada. 1870-1900: Both types of investment are assumed to follow total non-residential investment in nominal prices deflated by the CPI. 1901-1925: 5-year average disaggregated into 1-year intervals using total non-residential investment deflated by CPI. Source: F. H. Leacy (ed.), 1983, *Historical Statistics of Canada*, Statistics Canada: Ottawa. United States. Angus Maddison, 1995, *Explaining the Economic Performance of Nations*, Edward Elgar. Japan. 1885-1988: Maddison, 1995, *op cit.*, Backdated to 1870 using the growth rate in total investment from Maddison, 1995, *op cit*. 25.7% war damage to the 1945 capital stock is incorporated into the capital stock following Maddison, 1995, *op cit*. Australia: 1863-1902: C Clark, 1970, "Net Capital Stock," *Economic Record*, pp. 449-466. 1903-1950: M W Butlin, 1977, *A Preliminary Annual Database 1900/01 to 1973/74*, Research Discussion Paper 7701, Sydney: Reserve Bank of Australia. Belgium. M van Meerten, 2003, *Capital Formation in Belgium, 1900-1995*, Leuven: Leuven University Press. Before 1900: The ratio of investment and GDP in 1900 multiplied by real GDP is used backdate the data to 1870. War damage correction: WWI. 15.5% of 1913 GDP spread out evenly between the years 1914-1917. WWII 7.1% spread out evenly on the years 1943-45. The correction for war damage follows van Meerteen, 2003, *op cit.* (see his footnote no. 39). Denmark: 1870-1950: Kjeld Bjerke and Nils Ussing, 1958, *Studier Over Danmarks Nationalprodukt 1870-1950*, København: G E C Gads Forlag. Finland. R Hjerppe, 1989, *The Finnish Economy, 1860-1985*, Helsinki: Bank of Finland, Government Printing Centre. France. 1856-1895. Total investment deflated by industry prices. E Chadeau, 1989, *l'Economie Nationale Aux XIX et XX Siecles*, Paris: Presses de l'Ecole normale Superieure. 1896-1914 and 1921-1938. J-J Carre P Dubois and E Malinvaud, 1975, *French Economic Growth*, Stanford: Stanford

University Press. 1914-1921 and 1939-1949. Crude steel production adjusted. T Liesner, 1989, *One Hundred Years of Economic Statistics*, Oxford: The Economist. War damage of 2% is assumed each year over the periods 1914-17 and 1942-1945 following Maddison, 1995, *op cit*. Germany: W Kirner, 1968, *Zeitreihen fur das Anlagevermogen der Wirtschaftsbereiche in der Bundesreplublik Deutschland*, Deutsches Institut fur Wirtschaftsforschnung, Duncker & Humbolt: Berlin. The data are adjusted for war damage in the source. Non-residential buildings and structures 1850-1949. The following sectors are added together: Land und Forstwirtschaft, Energiewirtschaft, Bergbau, Grundstoff- und Productionguter-industrie, Investeringsguterindustrie, Verbrauchenguterindustrie, Nahrings- und Genussmittel-industrie, Industrie Kleinbetr. und Handwerk, Baugewerbe, Handel, Eisenbahnen, Schifffahrt, Ubringer Verkehr, Nachr. ubermittlg, Kreditintitutionen und Vers. gew., Wohnungsvermietung, Sonst. Dienstleist., Strassen und Brukken, Wasser strassen und Hafen, and Ubrige staatl. Bereiche. Machinery and equipment 1926-1949. The same sectors are added together as for investment in non-residential buildings and structures. 1870-1925: Scaled investment in machinery and equipment for Denmark, using the average over the period 1926-1930 as scaling factor. Italy. Instituto Centrale di Statistica, 1976, *Statistiche Storiche Dell'Italia 1861-1975*. Residential building investment is included in investment in buildings. Only 10-year averages are available before 1945. The data are uniformly distributed within the 10-year intervals. Netherlands. 1800-1913: J-P Smits, E Horlings, and J L van Zanden, 2000, *Dutch GNP and its Components, 1800-1913*, Groningen, http://www.eco.rug.nl/ggdc/PUB/dutchgnp.pdf. The general investment deflator is used as deflator. 1913-60: Central Bureau voor de Statistiek, 2001, *Tweehondred Jaar Statistiek in Tijdreeksen, 1800-1999*, Centraal Bureau voor de Statistiek, Voorburg. 10% war damage is evenly spread out over the years 1943-1945. Norway. Statistisk Sentralbyraa, 1968, *Nasjonalregnskap*, Oslo. 1865-1930: The investment data are derived from capital stock and official depreciation rates using the following formulae for buildings and equipment, respectively: $I_t^{eq} = K_t^{eq} - K_{t-1}^{eq}(1-0.15)$ and $I_t^{st} = K_t^{st} - K_{t-1}^{st}(1-0.02)$. 1930-1949: The data are interpolated from 1940 to 1945 using the algorithm which is suggested by V Gomez and A Maravall, 1994, "Estimation Prediction and Interpolation for Nonstationary Series with the Kalman Filter," *Journal of the American Statistical Association*, 89, 611-624. The general investment price deflator is used to adjust the *pre* 1940 data which are in 1938 prices, whereas the *post* 1945 data are in 1955 prices. Spain. A Carrearas (ed), 1989, *Estsdisticas Historicas De Espana*, Madrid: Fundacion Banco Exterior. 1850-1960: The growth rate in total investment is used to backdate investment in structures and machinery, respectively. Sweden. 1861-1949. O Krantz and C A. Nilsson, 1975, *Swedish National Product 1861-1970*, C W K Gleerup. Investment in buildings includes residential investment. Switzerland. Ritzmann-Blickenstorfer, 1996, *Historical Statistics of Switzerland*, Zurich: Chronos. The growth rate in total investment is used to backdate the data from 1922. UK. Maddison ,1995, *op cit*. An annual 3.5% war damage is corrected for in the estimates during the period 1943-45.

Economy-wide real GDP. The data are from OECD, *National Accounts*, after 1950. Before 1950: Maddison, 1995, *op cit.* except for the following countries. Australia. B Haig, 2001, "New estimates of Australian GDP 1861-1948/49," *Australian Economic History Review*, 41, 1-34. From 1939 onwards Maddison, 1995, *op cit*. Finland. Hjerppe, 1989, *op cit.* Italy. C Bardini, A Carreras, and P Lains, 1995, "The National Accounts for Italy, Spain and Portugal," *Scandinavian Economic History Review* XLII, 115-146. Netherlands. Central Bureau voor de Statistiek, 2001, *op cit*. Norway. O H Grytten, 2004, "The Gross Domestic Product for Norway 1830-2003," in Chapter 6 in Ø Eitrheim, J T Klovland and J F Qvigstad (eds), 2004, *Historical Monetary Statistics for Norway 1819-2003*, Norges Bank Occasional Papers No 35, Oslo, 241-288. Spain. Bardini *et al*., 1995, *op cit*. Sweden. O Johansson, 1967, *The Gross Domestic Product of Sweden and its Composition 1861-1955*, Stockholm: Almquist and Wiksell. Switzerland. Ritzmann-Blickenstorfer, 1996, *op cit*. C. H. Feinstein, 1976, *Statistical Tables of National Income, Expenditure and Output of the UK* 1855-1965, Cambridge: Cambridge University Press.

Economy-wide nominal GDP. Real GDP multiplied by economy-wide GDP-deflators from the following sources. Canada. M C Urquhart, 1988, "Canadian Economic Growth 1870-1980," Queens University Discussion Paper No 734. USA. 1870-1929: N S Balke and R J Gordon, 1986, *The American Business Cycle: Continuity and Change*, Chicago: University of Chicago Press. 1929-1960. Survey of Current Business August 1998, "GDP and Other Major NIPA Series 1927-97". Japan. K Ohkawa, M Shinchara and L Meissner, 1979, *Patterns of Japanese Economic Development: A Quantitative Appraisal*, New Haven: Yale University Press. Before 1885 CPI is used as deflator. Australia. W Vamplew, 1987, *Australian Historical Statistics*, Broadway, N.S.W: Fairfax. Belgium. Real GDP multiplied by CPI from B R Mitchell, 1975, *European Historical Statistics 1750-1975*, Macmillan: London. Denmark. S A Hansen, 1976, *Økonomisk Vækst I Danmark*, København: Akademisk Forlag. Finland. Hjerppe, 1989, *op cit*. France. P Villa, 1993, *Une Analyse Macroéconomique De La France Au XX^e^ Siècle*, Paris: CNRS Editions, and M Lévy-Leboyer and F Bourguignon, 1985, *The French Economy in the Nineteenth Century*, Cambridge: Cambridge University Press. Germany. Liesner, 1989, *op cit.,* and interpolated using CPI over the periods 1914-1924 and 1939-1949. Italy. Bardini *et al*., 1995, op cit. Netherlands. Central Bureau voor de Statistiek, 2001, *op cit*. Norway. Grytten, 2004, *op cit*. Spain. Carrearas *et al.*, 1989, *op cit*. Sweden. Johansson, 1967, *op cit.* Switzerland. 1913-49. Ritzmann-Blickenstorfer, 1996, *op cit*. Backdated to 1870 using real GDP multiplied by consumer prices, Mitchell, 1975, *op cit*. UK. Feinstein, 1976, *op cit*.

Average annual hours worked per employee. 1950-2004. Groningen Growth and Development Centre and the Conference Board, Total Economy Database, January 2005, http://www.ggdc.net. These data are predominantly based on OECD's database on annual hours worked. 1870-1950. Clark, 1957, *The Conditions of Economic Progress*, London: Macmillan, except when indicated. The algorithm which is suggested by Gomez and Maravall, 1994, *op. cit.*, is used to interpolate between the benchmark years as indicated for the individual countries. Canada. 1870, 1880, 1890, 1900, 1910, 1920, and 1926-1949. The US. 1868 ,1973, 1878, 1883, 1888, 1993, 1898, 1903, 1908, and 1913-1949. Japan. 1901, 1913, and 1919-1949. Hours worked in 1901 are used before 1901. Australia. 1891, 1901, and 1919-1949. Hours worked in 1901 are used before 1901. Belgium. 1870, 1895, 1913, and 1920-50. Denmark. 1870, and 1903-1949. Finland. 1913, and 1924-1949. The growth rate is assumed to follow the growth rate in Sweden before 1913. France. 1870, 1880, 1890, 1913, 1920-38, and 1947-50. Germany. 1860, 1877, 1883, 1890-1913, and 1925-1950. Italy. 1901-1949. Hours worked in 1901 are used before 1901. Netherlands. 1870-1913. Smits *et al.,* 2000, *op cit.* 1913-39. Bart van Ark and Herman de Jong, 1996, "Accounting for Economic Growth in the Netherlands since 1913," Research Memorandum GD-26. 1939-50. Clark, 1957, *op cit.* Norway. 1891, 1913, 1920-1939, and 1946-1949. Backward extrapolated using the algorithm of Gomez and Maravall, 1994, *op. cit*. Spain. Follows Italy before 1950. Sweden. The data are available for all years except for the years 1940-1944, where weekly hours worked from ILO, *Yearbook* are used to interpolate. Switzerland. 1890, 1895, 1899, 1924-50. UK. The data are available for all years.

Total employment. Include all economic active on full-time equivalents. 1950-2004: OECD, *Labour Force Statistics*. 1870-1949. The following sources are used. The algorithm which is suggested by Gomez and Maravall *op. cit.* is used to interpolate between the benchmark years as indicated for the individual countries. Canada. 1921-1959. F H Leacy (ed), 1983, *Historical Statistics of Canada*, Ottawa: Statistics Canada. 1870, 1890, and 1913, and A Maddison, 1991, *Dynamic Forces in Capitalist Development*, Oxford: Oxford University Press. USA. 1900-1949. Liesner, *op cit*. 1870, 1890, and 1893. Maddison, 1991, *op. cit.* Japan. K Ohkawa, *et al*., 1979, *op. cit.* Australia. 1901-1949. M W Butlin, 1977, *A Preliminary Annual Database 1900/01 to 1973/74*, Research Discussion Paper 7701, Sydney: Reserve Bank of Australia. Maddison, 1991, *op. cit.* Belgium. 1927-35 and 1945-1949. van Meerteen, 2003, *op cit*. Backdated from 1927 using population in working age (15-64) assuming a constant labour force participation rate, Mitchell, 1975, *op cit*. Denmark. 1870-1949. Hansen, 1976, *op cit*. Finland. 1870-1959. Hjerppe, 1989, *op. cit.* France. Villa, 1993, *op cit.* Germany. 1870-1872, 1874-1914, 1924-1940, and 1949. W G Hoffmann, F Grumbach, and H Hesse, 1965, *Das Wachstum der Deutschen Wirtschaft seit der mitte des 19. Jahrhunderts*, Berlin: Springer-Verlag. Italy. 1901-1949. Clark, 1957, *op. cit.* 1870, and 1990. Maddison, 1991, *op. cit.* Netherlands. Central Bureau voor de Statistiek, 2001, *op cit*. Norway. 1903-1919. P Flora, F Kraus, and W Phenning, 1987, *State, Economy, and Society in Western Europe* 1815-1975, London: Macmillan. 1920-1949. Clark, 1957, *op. cit.* 1870, and 1890.

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Labour's share. Is calculated as the economy-wide compensation to employees plus imputed compensation to self-employed divided by nominal GDP. The imputed compensation to employees is computed as the number of self-employed multiplied by economy-wide compensation to employees divided by economy-wide employment. The output elasticities of inputs are computed from the average factor shares using data up to 2002. The following starting dates are used (in parentheses): Canada (1926), USA, (1899), Japan (1906), Australia (1870), Belgium (1950), Denmark (1900), Finland (1870), France (1920), Germany (1870), Italy (1950), Netherlands (1870), Norway (1930), Spain (1950), Sweden (1870), Switzerland (1950) and UK (1870). OECD *National Accounts* are used for the post 1950 data.

Compensation to employees. Canada. Leacy, 1983, *op cit*. USA. T Liesner, *op cit*. Japan. Ohkawa *et al.*, 1979, *op cit*. Australia. Glenn Withers, Tony Endres and Len Perry, 1985, "Australian Historical Statistics: Labour Statistics," Australian National University, Source Papers in Economic History, No 7. Denmark. Johansen, 1985, *op cit.* Finland. Table 12A, Hjerppe, 1989, *op cit.* France. Table F.4*,* T Liesner, *op cit.* Include the non-agricultural sector. Germany. Table 122, Hoffmann, 1965, *op cit*. Netherlands. Central Bureau voor de Statistiek, 2001, *op cit*. Norway. Statistisk Sentralbyraa, 1968, *op cit.* Sweden. Karl G Jungenfelt, 1966, *Lonandelen och den Ekonomiska Utvecklingen*, Stockholm: Almquvist&Wiksell. UK. Table 1, C H Feinstein, 1976, *Statistical Tables of National Income, Expenditure and Output of the UK* 1855-1965, Cambridge: Cambridge University Press. Include all sectors in the economy.

Bilateral trade weights. The weights are based on bilateral imports and exports for 21 countries which include the 16 countries used in this study plus New Zealand, Austria, Greece, Ireland, Portugal. The data are interpolated between the following years: 1870, 1913, 1924, 1936, 1972 and 2004. The 1972 and 2004 data are from International Monetary Fond, *Direction of Trade Statistics*. The rest are from Mitchell, 1975, 1982, 1983, *op cit*.

Self employment. 1950-2002. OECD *Labour Force Statistics*. Before 1950 the number of self-employed is assumed to be a constant fraction of total employment.

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Human capital. Average educational attainment of population in the age of 15 and above. Andrea Bassanini and Stefano Scarpetta, 2001, "Does Human Capital Matter for Growth in OECD Countries? Evidence from Pooled Mean-Group Estimates," Economics Department Working Papers No. 282.

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NOTES

[1] Coe and Helpman (1995), Engelbrecht (1997), Lichtenberg and Van Pottelsberghe de la Potterie (1998), Lumenga-Nesco *et al*. (2001), Guellec and Van Pottelsberghe de la Potterie (2001, 2004), and Del Barrio-Castro *et al.* (2002).

[2] Domestic patents do not give protection against imitators in international countries beyond the first year after the patent application is filed (Dernis *et al*., 2001). Inventors, therefore, have strong incentives to protect innovations that have commercial promise abroad, and still have commercial promise one year after filing for a patent (OECD, 2001).

[3] Caballero and Jaffe (1993) use patent data to chart the development in knowledge; however, they do not consider the international diffusion of technology.

[4] The rate of unemployment was included in the estimates to allow for business cycle influences on the estimates. It was, however, omitted because its estimated coefficient was insignificant in all estimates.

[5] De Long and Bradford's (1988) data are based on per capita income and not on TFP. This should in theory not make much difference since labour productivity advances in standard growth models are TFP induced, provided that the discount factor and the taxes that affect the investment decision remain constant.