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Frontier Technology, Absorptive Capacity And Distance

By R. Kneller

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Abstract

The recent literature on international technology diffusion has demonstrated the positive effect improvements in foreign country productivity can have on domestic productivity. Using a sample of 9 manufacturing industries in 12 OECD countries over the period 1972 to 1992 we search for find evidence that absorptive capacity and physical distance are important for technology transfer. We find strong evidence that the level of productivity depends on human capital, that the effect of physical distance are weakest at the end of the time period and in some industries and that R&D is important for productivity but not technology transfer.

Outline

Non-Technical Summary

The recent literature on international technology diffusion has demonstrated the positive effects improvements in foreign country productivity can have on domestic productivity. In one estimate around 85 per cent of productivity growth in France, Germany and the UK in 1988 was due to foreign R&D, while the contribution was around 40 per cent even in the most productive economy the US.

In this paper we consider whether the positive effect of frontier technology on domestic productivity is affected by the effort and ability (its absorptive capacity) and its physical distance from the source of new ideas. Typically these have been considered as separate issues within the literature. Following a suggestion from elsewhere in the literature we measure absorptive capacity using the level of human capital and R&D spending. The positive effect of frontier technology on domestic productivity will vary with physical distance if, as recent evidence suggests, international trade and foreign direct investment act as channels for the international transfer of technology.

Using , a sample of 9 manufacturing industries in 12 OECD countries over the period 1972 to 1992 we find evidence in support of the hypothesis that absorptive capacity matters for technology transfer, whereas the results for physical distance are found to differ across time and across industries. The beneficial impact of foreign technology on domestic productivity increases as the level of human capital in the country increases and decreases as physical distance increases, but only in some industries and over some time periods. The effect of physical distance on technology transfer is found to be weakest at the end of the sample period. We infer from the this that advancements in transport and communication technology as well as increased economic integration amongst countries has weakened the negative effect of physical distance on technology transfer over time. The negative effect of distance on domestic productivity is also weakest in those industries that are widely traded on international markets, such machinery and equipment, and those in which trade is generally local, but the technologies used in production are low-tech, such as paper and wood products. In contrast to human the results for human capital domestic R&D is found to have a positive direct effect on productivity, but appears to aid technology transfer only in the smaller OECD countries.

1. Introduction

The recent literature on international technology diffusion has demonstrated the positive effect improvements in foreign country productivity can have on domestic productivity. Eaton & Kortum (1999) estimate that around 85 per cent of productivity growth in France, Germany and the UK in 1988 was due to foreign R&D, and the contribution was around 40 per cent even in the most productive economy the US. Similarly Coe & Helpman (1995) find that the benefits to domestic productivity are larger for foreign R&D than for domestic R&D.

In this paper we consider whether the positive effect of frontier technology on domestic productivity is affected by the absorptive capacity of the country and its physical distance from the source of new ideas. Typically these have been considered as separate issues within the literature (see for example Keller, 2001a,b; Griffiths et al., 2000). Absorptive capacity, as discussed by Arrow (1969), captures the idea that countries may differ in their effort and ability to adopt new technologies. In a more formal setting Abromovitz (1986) and Cohen & Levinthal (1989) model technical adoption as depending on the level of human capital, whereas Fagerberg (1988) and Verspagen (1991) develop models in which innovation improves the capacity to absorb foreign country technology.

The positive effect of frontier technology on domestic productivity will vary with physical distance if, as recent evidence suggests, international trade and foreign direct investment act as channels for the international transfer of technology (Coe & Helpman, 1995; di Mauro, 2000). The gravity model (Beckerman, 1956; Tinbergen, 1962; Leamer 1993) provides the link between the physical distance and technology transfer through international trade and FDI. Direct empirical evidence on the geographic limits to technology transfer can be found in Jaffe et al. (1993), Keller (2001a,b) and Bloom, Canning & Sevilla (2002).

Using a sample of 9 manufacturing industries in 12 OECD countries over the period 1972 to 1992 we find evidence in support of the hypothesis that absorptive capacity matters for technology transfer, whereas the results for physical distance are found to differ across time and across industries. The beneficial impact of foreign technology on domestic productivity is increasing in the level of human capital and is decreasing in physical distance in some industries and over some time periods. Domestic R&D is found to have a positive direct effect on productivity but appears to aid technology transfer only in the smaller OECD countries. Overall these results provide support for the use of absorptive capacity and physical distance as an explanation of differences in per capita income across countries (Prescott, 1998; Hall & Jones, 1999; Easterly & Levine, 2000; McGrattan & Schmitz, 1998).

The effect of physical distance on technology transfer is found to be weakest at the end of the sample period, and is found to vary between industries irrespective of whether international trade is relatively localised or not. We infer from the first of these that advancements in transport and communication technology as well as increased economic integration amongst countries has weakened the negative effect of physical distance on technology transfer over time. In some of the regressions we report physical distance is no longer a significant determinant of cross-country productivity differences by the end of the time period. From the second result we infer that the effect of distance is weakest in those industries that are widely traded on international markets, such machinery and equipment, and those in which trade is generally local, but the technologies used in production are low-tech, such as paper and wood products.

The results are found be robust to differences in the size of the technology gap between firms and the domination of European countries in the sample. Robustness across different measures of TFP and the right-hand-side variables is also considered. Finally, conditional on the effect of absorptive capacity and physical distance on the size of the productivity gap we find no effect from physical distance on the rate at which the technology gap is closed. In contrast, the level of human capital and R&D are both found to affect the rate of convergence.

The rest of the paper is organised as follows. The next section outlines the empirical methodology to be used in the paper and reviews some of the existing evidence that suggests absorptive capacity and physical distance are important. Section 3 outlines the data sources and methodology used to construct the variables of interest. The main empirical results of the paper are presented in Section 4, Section 5 develops these results further and tests their robustness, while finally Section 6 concludes.

2. Empirical Methodology

Recent developments in the productivity literature by Prescott (1998), McGrattan & Schmitz (1998), Hall & Jones (1999) and Easterly & Levine (2000), have argued that permanent differences in the *level* of per capita income across countries exist because of permanent differences in the level of productivity rather than physical and human capital. Three alternative explanations for these differences in productivity have been explored in the literature. The resistance to new technologies because of lower absorptive capacity (Eaton & Kortum, 1996; Griffiths, Redding & Van Reenan, 2000; Xu, 2000); resistance because of strong trade union power (Prescott, 1998; Parante & Prescott, 2000); and the effect of geographic distance on the spread of knowledge (Eaton & Kortum, 1999; Jaffe et al., 1993; Keller, 2001a,b). In this paper we consider more closely the role of absorptive capacity and physical distance.

Consistent with these papers the recent theoretical and empirical literature has also emphasised the positive impact improvements in foreign country productivity can have on the domestic economy. Coe & Helpman (1995) and Coe et al. (1997) find that domestic R&D and foreign R&D weighted by import shares are positively correlated with domestic productivity, while Park (1995) and Keller (2001a,b) find supportive results, using a different approach. In addition Eaton & Kortum (1997) using parameterised general equilibrium models find that the majority of productivity growth in Germany, France, Japan and the UK is explained by foreign R&D.

In order to motivate the empirical section of the paper we develop these points more formally. Output in industry j in country i at time t is a function of the production technology set out in equation (1). A measures total factor productivity (TFP) in the industry and country at a given point in time and K and L the factor inputs physical capital and labour. Equation (1) is assumed to be exhibit diminishing marginal returns in each of the factor inputs and constant returns to scale across the entire production technology.

$$Y_{ijt} = A_{ijt} f_j (K_{ijt}, L_{ijt}) \tag{1}$$

Based on the evidence presented in Coe & Helpman (1995), Eaton & Kortum (1999), Keller (2001a,b) and others, TFP in country *i* and industry *j* is assumed to be a function of domestically generated knowledge in the industry, D_{ijt}, and knowledge generated by foreign firms within the same industry and adopted by domestic firms, F_{jt}.

$$A_{ijt} = g(D_{ijt}, F_{jt}) \tag{2}$$

Consistent with modern theories of economic growth (Romer, 1990; Aghion & Howitt, 1992) and Griliches & Lichtenberg (1984) advances in technical knowledge are generated in the model by investing resources in R&D. The level of domestic knowledge within industry *j* is assumed to be a function of the sum of previous investments in R&D, the stock of R&D (RDST), where β measures the return to R&D.

$$D_{ijt} = RDST_{ijt}^{\beta_{ij}} \qquad 0>\beta>1 \tag{3}$$

It follows that if domestically generated knowledge is a function of the stock of R&D in the domestic industry then foreign technology is, in turn, a function of the R&D stock in the foreign country. We allow for the possibility of cross-industry spillovers in R&D by assuming that firms in country *i* benchmark their productivity level against the country in industry *j* with the highest level of productivity. That is, firms in countries that lie behind the technical frontier in each industry attempt to imitate the technologies adopted by firms in countries that lay on the technical frontier. Technical laggard countries are unable to observe directly the output from others R&D, but can observe and copy the application of this knowledge. The countries used in the empirical section of the paper lie between the two extremes suggested by equation (2). Some domestic R&D is undertaken, but they do not lie on the technical frontier.[1]

Domestic productivity levels are assumed to be lower than foreign country productivity levels because domestic firms are inefficient in their use of frontier technology and because knowledge disperses imperfectly across space.[2] The difference in the outcome from the application of technical knowledge within industry *j* in country *i* is given by v_{ij}. For ease we

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[1] The difficulty of measuring cross-industry spillovers leads us to deliberately excluded from the sample those observations with the highest level of TFP at each time *t* in each industry.

[2] In some industries, such as agriculture and medicine, geography may also be expected to affect the returns to different technology. See Bloom et al (2002) for the application of such a test.

label *v* as the level of efficiency, although it includes limits to the dispersion of knowledge across space.

$$F_{ijt} = A_{Fjt} v_{ij} \qquad \text{where } 0 > v > 1 \qquad (4)$$

Efficiency is assumed to be increasing in the absorptive capacity of the country and decreasing in physical distance.[3] Absorptive capacity measures the ability and effort of workers and managers to apply new technology (Xu, 2000; Papageorgiou, 2000; Griffiths et al, 2000). Ability is assumed to be increasing in the level of human capital within the country and effort increasing in R&D intensity (the ratio of R&D expenditure to output). The latter term is consistent with the second face for R&D discussed in Griffiths et al. (2000).

$$v_{ij} = A_{Fjt}[HUM^{\phi}_{ijt}, \frac{RD^{\lambda}_{ijt}}{Y_{ijt}}, DIST^{-\gamma}_{iFjt}] \qquad \phi, \lambda > 0; \gamma < 0 \qquad (5)$$

The effect of foreign technology on the domestic economy is also (indirectly) affected by physical distance. International trade and FDI have previously been found to be negatively correlated with physical distance (Caves, 1996; Leamer & Levinsohn, 1995; di Mauro, 2000). If, as Coe & Helpman (1995), Coe et al. (1997) and others suggest, these operate as channels for technological transfer then the effect of frontier technology on the domestic economy is declining with distance (Keller, 2001c). Physical distance captures the effect of distance on technology diffusion through a number of different channels, such as international trade, FDI and human contact and is measured by the number of miles between the technical laggard country and the technical frontier country within each industry at each point in time.

The model is summarised in the following equation (equation 6) used for estimation in the empirical section of the paper. In this equation domestic productivity is a function of domestically produced knowledge, the level of frontier technology and the efficiency with which frontier technology is applied, where this efficiency is increasing in absorptive capacity and decreasing in distance. The α*'s* are parameters to be estimated and ε, the usual

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[3] Rosenberg (1982), Baumol (1986) and Fagerberg (1994) provide some discussion of the idea of absorptive capacity.

classical error term. If human capital and R&D matter for technology transfer we would expect the coefficients α_2 and α_3 to be positive, whereas if physical distance hampers technology transfer we would expect α_4 to be negative.

$$\begin{aligned}\ln(A_{ij})_t &= \alpha_0 \ln(RDST_{ij})_t + \alpha_1 \ln(A_{Fj})_t + \alpha_2 \ln(A_{Fj}) HUM_{ij_t} + \alpha_3 \ln(A_{Fj})_t \ln(\frac{RD_{ij}}{Y_{ij}})_t \\ &\quad - \alpha_4 \ln(A_{Fj})_t \ln(Dist_{iFj})_t + \alpha_{5ij} + \varepsilon_{ijt}\end{aligned} \tag{6}$$

Industry and country specific fixed effects are included in equation (6) to capture differences in institutional design and regulations across countries. Prescott (1998) and Parante & Prescott (2000) argue that when trade union power is strong technologies are often used inefficiently or their introduction resisted altogether. Such effects are expected to vary across countries and across industries within a country and are assumed to operate independently of absorptive capacity and distance.

3. Data and TFP Measurement

Equation (6) is estimated for a sample of 9 manufacturing industries in 12 countries over the period 1972 to 1992. The total number of available observations is 2106, while the exact coverage for each industry and country is given in Table 1 below. The output (value added), capital stock and employment data used to construct estimates of TFP are all taken from the OECD ISDB database. This data is available on an international comparable basis having been deflated to 1985 prices and converted using measures of PPP to US$. Adjustment for hours worked is made to the employment data using OECD data for hours in the manufacturing sector as a whole.[4]

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[4] Data for hours worked is available for Canada, Belgium, Denmark, France, Germany, Japan, Norway, Sweden U.K., U.S. The data for Germany, Belgium, Denmark, and Sweden is expressed as an index and was converted using information contained in O'Mahony (1999), where missing data was converted using the average of hours worked in the UK, France and Germany in the base year. Data for Italy and the Netherlands is unavailable in either data source and was instead generated as the average for all European countries.

TFP in country i and industry j at time t is estimated using the following superlative TFP index (Caves, Christensen & Diewert, 1982). This index allows a flexible specification of production technology.

$$TFP_{ijt} = \ln(\frac{Y_{ijt}}{\bar{Y}_{jt}}) - \phi_{ijt}\ln(\frac{L_{ijt}}{\bar{L}_{jt}}) - (1-\phi_{ijt})\ln(\frac{K_{ijt}}{\bar{K}_{jt}}) \qquad (7)$$

where $i = 1...I$; $j = 1..J$; $t = 1...T$; $\bar{Y}_{jt} = \frac{1}{C}\sum Y_{ijt}$; $\bar{L}_{jt} = \frac{1}{C}\sum L_{ijt}$; $\bar{K}_{jt} = \frac{1}{C}\sum K_{ijt}$; i indexes country, j index industry and t indexes time. The labour cost share, ϕ_{ijt} , is calculated as $\phi_{ijt} = \frac{1}{2}(\alpha_{ijt} + \bar{\alpha}_{jt})$ and $\bar{\alpha}_{jt} = \frac{1}{C}\sum \alpha_{ijt}$.

Table 1: Available TFP data by country and industry.

SIC	31	32	33	34	35	36	37	38	39	
Sector	FOD	TEX	WOD	PAP	CHE	MNM	BMI	MEQ	MOT	**Total**
Can	70-90	70-90	70-90	70-90	70-90	70-90	70-90	70-90	70-90	**189**
Den	70-90	70-90	70-90	70-90	70-90	70-90	70-90	70-90	70-90	**189**
Fin	70-92		70-92	70-92	70-92	70-92	70-92	70-92	70-92	**184**
Fra	70-91	70-91	70-91	70-91	70-91	70-91	70-91	70-91		**176**
Germ	70-91	70-91	70-91	70-91	70-91	70-91	70-91	70-91	70-91	**198**
Itl	70-90	70-90		70-88	70-88	70-90	70-90	70-88	70-88	**160**
Jap	70-92	70-92		70-92	70-92	70-92	70-92	70-92	70-92	**184**
Neth	70-90	70-89	80-89	70-90	80-90	80-90	70-90	80-90	80-90	**137**
Nor	70-91	70-91	70-91		70-91	70-91	70-91		70-91	**154**
Swe	70-92	70-92	70-92	70-92	70-92		70-92	70-92		**161**
UK	70-91	70-91		70-91	70-91	70-91	70-91	70-91	70-91	**178**
US	70-91	70-91	70-91	70-91	70-91	70-91	70-91	70-91	70-91	**198**
Total	**263**	**239**	**186**	**239**	**251**	**230**	**263**	**229**	**206**	**2106**

Note: FOD = food, beverages & tobacco; TEX = textiles, wearing apparel; WOD = wood products; PAP = paper products; CHE = chemicals etc.; MNM = non-metallic mineral products; BMI = basis metal industries; MEQ = machinery & equipment; MOT = other manufacture industries.

Frontier technology is measured using the highest level of measured TFP in each industry at each point in time. This measure of the technical frontier allows for leap-frogging in the technical leader over time. The US dominates the measured technical frontier, although others such as Japan and Germany appear as the technical leader frequently. The technical leader in each industry in 1970, 1980 and 1990 are listed in Table 2 as an example of the data. The frontier observations are excluded from the data-set in order to concentrate on the determinants of backwardness. Physical distance between country i and the technical frontier is measured in the number of miles between capital cities using data provided by Jon Haveman.

Table 2: Technical frontier country by industry, 1970, 1980, 1990.

SIC	31	32	33	34	35	36	37	38	39
Sector	FOD	TEX	WOD	PAP	CHE	MNM	BMI	MEQ	MOT
1970	Jap	Fra	US	US	Germ	US	US	US	Fin
1980	Jap	US	US	US	Germ	US	Jap	Can	Neth
1990	UK	US	US	US	US	US	Jap	US	US

Note: FOD = food, beverages & tobacco; TEX = textiles, wearing apparel; WOD = wood products; PAP = paper products; CHE = chemicals etc.; MNM = non-metallic mineral products; BMI = basis metal industries; MEQ = machinery & equipment; MOT = other manufacture industries.

The stock of R&D is estimated by accumulating R&D expenditures by industry from the OECD EBRD dataset for the period 1973 to 1992. A perpetual inventory method of the form given in equation (4) is used to produce R&D stocks from this expenditure flow data. The rate of depreciation (δ) is set equal to 10 per cent. The initial stock of R&D is estimated in the usual way, where the term g^{RD} is the average annual growth rate of R&D over the period.

$$\begin{aligned} RDST_{ijt} &= (1-\delta)RDST_{ijt-1} + RD_{ijt-1} \\ RDST_{ij0} &= RD_{ij} \Big/ (g^{RD} + \delta) \end{aligned} \qquad (8)$$

Finally, human capital is measured using the proportion of the population aged 25 and over with secondary level education and is taken from Barro & Lee (2000). Restrictions on the availability of R&D expenditures and the exclusion of those observations that form the technical frontier in each industry means that a total of 1527 observations are available for estimation.

4. Empirical Results

We begin by estimating the effect of frontier technology on the level of domestic productivity without controlling for differences in absorptive capacity and physical distance. In Table 3 the results from regression 3.1 show that domestic productivity is increasing in both domestic R&D and foreign technology. As expected both domestic and frontier technology contribute positively to domestic productivity.[5] According to the results a one percentage point increase in the stock of domestic R&D in industry *j* raises productivity by 0.04 percentage points. The estimated effect from frontier technology is larger than that for domestic productivity. A one percentage point increase in the TFP of the frontier economy raises the productivity of the domestic economy by 0.29 percentage points. The point estimate on the domestic R&D stock is slightly smaller than that found in Coe & Helpman (1995) and Keller (2001a), but lies close to those estimated in Keller (2001b). The effect of frontier technology on domestic productivity estimated in regression 3.1 are, despite differences in the construction of foreign country technology levels, close to those found by Coe & Helpman (1995) and Keller (2001a,b).

In the model outlined in Section 3 heterogeneity in the effect of frontier technology on domestic productivity across countries occurs because of differences in absorptive capacity and physical limitations to the spread of knowledge. We explore this heterogeneity in the remaining regressions of Table 3. In regression 3.2 the effect of frontier technology is allowed to differ according to the ability of the workforce to absorb and apply new technology, captured through the interaction between foreign productivity and the percentage of the workforce aged over 25 years with secondary level education. In regression 3.3 the role of absorptive capacity is explored using the percentage ratio of current R&D expenditure to industry output in country *i*, the effort with which is applied to understand new technology. In regression 3.4 frontier technology is interacted with the geographic distance between country *i* and the frontier country. If knowledge does not disperse freely across space we would expect the effect of frontier technology on domestic productivity to be weaker the greater the geographic distance between the frontier and laggard countries.

There is strong evidence of heterogeneity in the regressions and in the directions expected. The effect of foreign technology is found to be increasing in absorptive capacity and decreasing in physical distance. The impact of frontier technology on the domestic economy is larger the greater is the level of human capital within the laggard country.[6] This result is supportive of evidence found in Griffiths et al. (2000) and the discussion made in

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[5] The results for domestic R&D are robust to the use of alternative values for the rate of depreciation in the calculation of the stock of R&D.

Fagerberg (1994) that human capital is important for technology transfer. In regressions 3.3 there is however, little evidence of a 'second face' for domestic R&D, although the estimated parameter on R&D intensity has the expected positive coefficient. Domestic R&D appears to contribute directly to domestic R&D but not the understanding of frontier technology. [7] Unfortunately, because the data set does not allow us to differentiate between R&D directed at innovation from that directed at imitation we cannot directly test the robustness of this result. However, some evidence may be inferred if, as seems likely, the innovative aspect of R&D is smaller for less R&D intensive OECD economies. Of the 12 countries included in the sample five, France, Germany, Japan, UK and US , contribute 89 per cent of the estimated total R&D stock of the 12 countries in 1990. In regression 3.4 we consider the effect on the results of excluding these five countries from the sample. For this smaller sample of countries evidence for a dual role for R&D is found. The coefficient on the interaction between frontier technology and R&D is now statistically significant at conventional levels. The smaller OECD economies do appear to benefit significantly from efforts to imitate frontier technologies.[8]

In regression 3.4 the impact of frontier technology on domestic productivity is also found to differ across countries according to the physical distance between laggard countries and the frontier country. Knowledge does not appear to disperse freely across physical space and proximity to the source of new ideas is important. This finding supports those already in the literature. Jaffe, Trajtenberg & Henderson (1993) find that U.S. patents are more commonly cited in other U.S. patents than in foreign patents. Also Redding & Venables (2000) find that market access, which is determined by distance, helps to explain differences in per capita GDP across countries, while in Bloom et al. (2002) geographic variables added to a convergence regression are found to explain permanent differences in GDP. In addition Keller (2001a,b) studies the cross-country benefits from foreign R&D using industry level data from the OECD economies.[9] Keller finds that physical distance significantly affects the potency of foreign R&D on the domestic economy.[10]

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[6] The results are robust to alternative measures of human capital, namely mean school years of education and the proportion of the population with tertiary level education.

[7] This result is unchanged if the R&D stock is used to approximate for effort in equation (5). It is also robust to the inclusion of the human capital and physical distance interaction terms in the regression.

[8] Further evidence can be found if R&D is allowed to affect domestic productivity only though its effect on the absorption of frontier technology. In such a regression for the full sample of countries the interaction term is statistically significant, albeit at the 10 per cent level.

[9] Keller (2001a) studies 9 of the smaller OECD economies and Keller (2001b) the G-7 economies.

[10] For additional evidence see the review in Keller (2001c).

Despite the significance of the distance-frontier parameter the magnitude of the effect of distance on technology transfer is quite small. The shortest distance between any two sets of countries in the sample is that between the UK and France, 340 miles, and the longest between Japan and the US, 10,910 miles. Using these distances and the mean level of frontier technology, the effect of distance on domestic productivity relative to the industry mean at time *t* lies in a range that can be at a maximum of between 0.10 and 0.15. The standard deviation of the distribution of domestic productivity levels is 0.31. One plausible explanation for the weak effect of distance on technology transfer is that OECD countries are integrated by trade and FDI to such an extent that distance is unlikely to be quantitatively important, even if it is statistically significant. An alternative explanation we explore in the next section of the paper is that there are significant differences in the effect of distance across industries. The average effect is weak, but distance matters within some industries.

Finally, in regression 3.6 we include the interaction terms for human capital and distance in the same regression. Given the results for R&D we choose to omit this term from the regression, although the results from regression 3.6 and those presented elsewhere in the paper are robust to its inclusion. The effect of absorptive capacity and physical distance are unchanged, both contributing significantly to the effect of frontier technology on domestic productivity.[11]

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[11] The results are robust to the exclusion of any one country and industry from the sample.

Table 3: Initial Regression Results.

	3.1	3.2	3.3	3.4	3.5	3.6
RDST	0.043 (4.70)**	0.021 (2.17)*	0.037 (4.61)**	0.046 (4.92)**	0.043 (4.68)**	0.021 (2.14)*
A_F	0.293 (2.48)*	0.176 (1.55)	0.268 (2.54)*	0.165 (1.66)	0.803 (6.00)**	0.708 (5.15)**
A_F*HUM		0.150 (3.12)**				0.159 (3.32)**
A_F*RD			0.036 (1.17)	0.080 (2.15)*		
A_F*$Dist_{iF}$					-0.062 (4.34)**	-0.066 (4.58)**
Constant	-1.089 (5.44)**	-1.279 (5.96)**	-0.980 (5.61)**	-1.151 (6.20)**	-1.103 (5.35)**	-1.304 (5.90)**
Observations	1527	1527	1527	901	1527	1527
R-squared	0.87	0.87	0.87	0.84	0.87	0.87

Note: Robust t-statistics in parentheses
* significant at 5%; ** significant at 1%

5. Further Results

In Table 4 we explore the results for absorptive capacity and physical distance further. We test whether the results for human capital and distance vary across time and in the case of distance also across industries. The results are also compared for different sizes of the technological gap as well their possible dependence on the large number of European countries in the sample. The effect of absorptive capacity and distance on the rate at which the productivity gap is closed is also studied in this section. The analysis highlights some important differences in the effect of absorptive capacity and physical distance not found in Table 3.

In regressions 4.1 and 4.2 we consider the evidence that the effect of absorptive capacity and physical distance has altered over time. Evidence of skill bias technical change (Krueger, 1993; Bresnahan, 1999) may suggest that human capital will have become more important for absorbing frontier technologies over time. Similarly technological advances in the transport and distribution sector as well as changes in trade policy may have affected the importance of international trade and FDI as channels for technology transfer. The interaction between absorptive capacity and frontier productivity are allowed to vary across time in regression 4.1 and the relationship between physical distance and frontier technology allowed to vary across time in regression 4.2. In equation (6) above, α_2 and α_3 become α_{2t} and α_{2t}, where *t=1* if year = 1972-1976; *t=2* if year = 1977-1981; *t=3* if year = 1982-1986; *t=4* if year = 1987-1992. Keller (2001a) estimates a similar regression to 4.2, but without controlling for differences in the effect of absorptive capacity on productivity. The parameters are arranged such that they test for differences in the absorptive capacity/distance-frontier coefficients relative to the estimates for the first time period.

To test the robustness of the results for physical distance we consider an alternative measure of distance. The gravity model suggests that trade between two countries is a function of the geographic distance and their combined economic wealth. In its most simple form this is given by equation (9) below. Using this equation we test whether the results from regression 4.2 are generated because of wealth induced increases in international trade, rather than because technological advancements in transport and communication have led to a reduction in the importance of physical distance. GDP is measured using data from the Penn World Tables.

$$Trade_{ij} = {\alpha GDP_i GDP_j}\Big/{Dist_{ij}^{\beta}} \qquad (9)$$

In regression 4.1 there is no evidence that skill-biased technical change has increased the importance of human capital for the understanding of foreign technology, at least over the time period studied in this paper. The time dummies on the various sub-periods are small in size and far from statistical significance. There is better evidence that physical distance as an impediment to technology transfer has become less important across time in regression 4.2. The point estimate of the effect of distance in the 1982-1986 and 1987-1992 sub-periods is around 0.60 compared to around 0.76 within the first half of the sample. Despite the similarity in the effect of distance in the second half of the sample only that for the 1982-1986 sub-period is statistically different from the first time period. Re-estimating the same regression but entering the distance-frontier variable separately for each time period we find that although the estimated coefficient on the distance-frontier variable is smaller in the second half of the sample it remains statistically significant.

The estimated effect of physical distance is slightly weaker in regression 4.3 compared to that estimated in regression 4.2, the point estimate for the effect of distance in the first time period is 0.75 in regression 4.2 and is 0.45 in regression 4.3. The results from the regression confirm however that advances in transport and communication technology and changes in trade policy have reduced the importance of physical distance as an impediment to the convergence of TFP levels. The coefficients in the periods 1982-1986 and 1987-1992 are of a similar size, but now both are statistically significantly different from the first time period. Technological improvement in the transport and distribution sector and greater integration of international economies would appear to have encouraged the convergence of productivity levels among OECD countries over the sample period. Moreover when we again re-estimate this regression with the distance-frontier measures entered independently across time we find that the estimated parameter in the final time period is, although negative, insignificantly different from zero. This differs from findings elsewhere in the literature and suggests that tests for the robustness of this finding to alternative methodologies and later time periods would be an interesting extension of the paper.

The effect of physical distance might be expected to vary across industries if, as previous empirical applications of the gravity model find, the effect of distance on international trade differs across commodities. Leamer & Storper (2001) report the effect of distance on international trade to be weaker for trade in machinery & equipment and textiles compared to that for wood and paper products. Secondly, the effect of distance on technological transfer may differ across industries because of differences in the complexity of the technology used within the industry. Even though wood and paper products are traded more locally than other products the technology used in their production is generally low-tech and therefore physical proximity to the source of technical knowledge may be less important.

Evidence for such an relationship is indeed found in regression 4.4. The effect of distance is lower in all industries relative to the basis metals industry, significantly so in the case of paper products, the food industry, chemicals, textiles, non-metallic products and the machinery and equipment industry. It is interesting to note that this list of industries includes those that Leamer & Storper (2001) find trade to be relatively localised such as paper and which *ceteris paribus* we would therefore expect physical distance to be an more of an impediment to technology transfer. This would appear to confirm the belief that differences in technical complexity may be important when assessing the likely barriers to technology transfer. When the distance-frontier variable is entered into the regression separately across industries the coefficients for the paper, textiles and wood sectors are insignificantly different from zero. Physical distance does not appear to explain differences in the level of productivity across OECD countries for these industries.

Table 4:Further investigation of the results.

	4.1	**4.2**	**4.3**	**4.4**	**4.5**	**4.6**	**4.7**
RDST	0.022 (1.89)	0.005 (0.55)	0.013 (1.35)	0.018 (2.10) *	-0.002 (0.20)	0.025 (2.42) *	0.008 (1.07)
A_F	0.651 (4.34) **	0.755 (4.46) **	0.325 (1.96)	0.742 (5.83) **	0.228 (1.21)	0.742 (5.03) **	0.390 (2.03) *
A_F*HUM*	0.174 (3.39) **	0.121 (2.36) *	0.123 (2.44) *	0.139 (2.80) **	-0.006 (0.13)	0.132 (2.64) **	0.153 (3.51) **
A_F*Dist_{iF}	-0.062 (4.35) **	-0.075 (5.23) **	-0.045 (3.09) **	-0.153 (7.16) **	-0.009 (0.46)	-0.087 (5.83) **	-0.071 (3.33) **
1977-81	-0.002 (0.57)	0.002 (0.41)	0.004 (0.74)				
982-86	0.002 (0.54)	0.016 (2.40) *	0.019 (2.92) **				
987-92	-0.004 (0.72)	0.017 (1.32)	0.027 (2.20) *				
GDP_iGDP_F			-0.032 (6.18) **				
$A_F*Dist_{iF}*CHE$				0.044 (1.64)			
$A_F*Dist_{iF}*FOD$				0.066 (3.19) **			
$A_F*Dist_{iF}*MEQ$				0.087 (2.73) **			
$A_F*Dist_{iF}*MNM$				0.086 (2.97) **			
$A_F*Dist_{iF}*MOT$				0.112 (5.25) **			
$A_F*Dist_{iF}*PAP$				0.100			

				(1.58)			
A_F*$Dist_{iF}$*TEX				0.138 (5.99) **			
A_F*$Dist_{iF}$*WOD				0.112 (1.30)			
bservations	1527	1527	1526	1527	1527	1182	1549
-squared	0.87	0.88	0.88	0.88		0.86	0.86

Note: Robust t-statistics in parentheses
* significant at 5%; ** significant at 1%

Given the mean level of frontier technology within each industry, we can quantify the maximum range of the effect of distance on technology transfer in the same manner as above. The minimum effect is calculated for 340 miles and the maximum effect calculated for 10,910 miles. These are listed in Table 4a along with the standard error for TFP in that industry and the parameter estimate. This table makes it clear that physical distance is important for technology transfer in industries such as Basis Metals and Chemicals, but is much less important in industries such as Textiles and Wood.

Table 4a: The effect of distance on technology transfer by industry

Industry	*Estimated Parameter*	*Minimum effect*	*Maximum effect*	*Standard rror of TFP*
BMI	-0.153	-0.273	-0.436	0.38
CHE	-0.109	-0.170	-0.271	0.31
FOD	-0.087	-0.097	-0.154	0.26
MEQ	-0.067	-0.079	-0.126	0.21
MNM	-0.068	-0.091	-0.145	0.29
MOT	-0.041	-0.093	-0.149	0.27
PAP	-0.053	-0.091	-0.145	0.35
TEX	-0.016	-0.032	-0.051	0.37
WOD	-0.042	-0.034	-0.054	0.19

Note: FOD = food, beverages & tobacco; TEX = textiles, wearing apparel; WOD = wood products; PAP = paper products; CHE = chemicals etc.; MNM = non-metallic mineral products; BMI = basis metal industries; MEQ = machinery & equipment; MOT = other manufacture industries.

In regressions 4.5 we test whether human capital and geography are more or less important the closer the country is to the technical frontier, the smaller is the technology gap. Fagerberg (1994) has previously argued, albeit for developed and developing countries, that the technology gap may need to be sufficiently small for human capital to significantly aid technology transfer. Below this critical level increases in human capital may be unimportant. Regression 4.5 reproduces the results from a test of differences in the estimated parameters at the 25th and 75th percentiles.

The results from regression 4.5 suggest that the effect of frontier technology on domestic productivity is greater the closer the country is to the industry frontier, but this difference is far from significant and small in size. Similarly, although the effect of domestic R&D, human capital and physical distance are found to be more important at the bottom of the productivity distribution, the greater the technological distance, once again these differences are small and statistically insignificant. Given the arguments made in Fagerberg (1994) it is still perhaps premature to generalise from these results for OECD countries to explain productivity differences in less developed countries.

Next we consider whether the results hold for European countries only. Countries from Europe dominate the data set, 9 of the 12 countries used are European countries. In contrast non-European countries dominate the technical frontier. The three non-European countries, Canada, Japan and the US, make up 81 per cent of the frontier observations. European countries are obviously geographically closer than the 3 remaining countries and due to initiatives such as the Single Market Programme also more integrated in their trade. In regression 4.6 below we test whether the above results are generated because all of the variation in productivity, absorptive capacity and geography is between Europe and the remaining three countries. The results from regression 4.6 indicate that the inclusion of the three geographical outlier countries does not affect the results. All of the coefficients from this reduced sample remain significant at conventional levels and variations in the estimated parameters are small compared to earlier regressions. Interestingly the results suggest for the European sample that human capital is relatively less important than for the larger sample and the effect of distance more important.

Finally in regression 4.7 we test the robustness of the results to alternative measure of TFP. The TFP index calculated using equation (8) assumes constant returns to scale. Hall (1990) argues that the violation of this assumption can lead to a bias in TFP estimates. Here we employ estimates of mark-up ratios provided by Martins et al. (1996), which are based on OECD data. Aggregation to the 2-digit level is made using the share of value added as weights. We also construct this alternative measure of TFP using industry specific PPP values. Pilat (1996) shows that PPP measures may vary substantially by industry. This data is from Pilat (1996).[12] Once again aggregation to the 2-digit level is made using the share of value added as weights. There is some sensitivity of the results to this change in TFP, although this is mostly for the stock of domestic R&D. Foreign technology, absorptive capacity and distance have the same effect on domestic economy as those found above.

Convergence

Given the evidence that absorptive capacity and distance help to determine the size of the productivity gap between a country and the technical frontier it is interesting to test whether such factors also affect the rate at which the technology gap is closed. That is whether absorptive capacity and physical distance affect the rate of convergence. The effect of absorptive capacity on the rate of convergence is studied here using a similar framework to Griffiths et al (2000). The question of whether countries that are physically further from the technical frontier converge more slowly has not been previously considered in the literature.[13]

In equation (10) catch-up is assumed to occur towards the country with the highest TFP. The coefficient β_1 is expected to be negative. Countries that are further behind the technical frontier, the greater the technology gap, have greater scope for imitation and therefore grow more quickly than countries that are closer to the frontier at a given point in time. The coefficient on β_0 in equation (10) captures the effect of instantaneous spillover from the technical frontier on the domestic economy. If absorptive capacity increases the rate of convergence then β_2 and β_3 would be expected to be negative. In contrast if countries that are geographically further from the technical frontier converge more slowly to the technical frontier then β_4 could be expected to be positive.

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[12] Data is unavailable for Denmark, Finland, Italy and Norway. Estimates for these countries are made using the average of the other European countries, but using own country shares of value added to aggregate to the 2-digit level.

[13] The regressions estimated in Bloom et al. (2002) allow geographic variables to affect the level of productivity not the rate of catch-up in a convergence regression.

$$\Delta \ln A_{ijt} = \beta_{0i}\Delta A_{Fjt} - \beta_{1i}\ln(\frac{A_{ijt-1}}{A_{Fjt-1}}) + \beta_{2i}\ln(\frac{A_{ijt-1}}{A_{Fjt-1}})HUM_{ijt-1} + \beta_{3i}\ln(\frac{A_{ijt-1}}{A_{Fjt-1}})RDST_{ijt-1}$$
$$+ \beta_{4i}\ln(\frac{A_{ijt-1}}{A_{Fjt-1}})DIST_{iFt-1} + \beta_{5ij} + \varepsilon_{it} \qquad (10)$$

In regression 5.1 the results for the basic convergence regression are reported. The results from this regression are in line with those from Griffiths et al. (2000). In regressions 5.2 to 5.3 we allow the rate of convergence to vary according to the absorptive capacity and physical distance. Like Griffiths et al. (2000) we find evidence that absorptive capacity increases the rate of convergence to the technical frontier, the coefficients on the R&D and human capital variables are negative and significant. The result for R&D is interesting given the results in Table 3. Once again this may be explained by limitations to the R&D data, and in a regression not reported we find the effect of R&D on technology transfer to be stronger for the smaller OECD economies.

In contrast we find no evidence in Table 5 to suggest that physical distance affects the rate at which the productivity gap is closed in these results. The point estimate suggests that countries in which the physical gap is greater converge towards the technical frontier more slowly, but the estimated coefficient is far from being significant at conventional levels.[14] Physical distance affects the size of the technology gap not how quickly it is closed.

Table 5: Evidence for convergence.

	5.1	5.2	5.3	5.4
A_F	0.407 (2.45)*	0.430 (2.76)**	0.442 (2.68)**	0.441 (2.67)**
i/A_F	-0.190 (6.08)**	-0.114 (3.17)**	-0.208 (6.21)**	-0.216 (5.33)**
$(Ai/A_F)*HUM$		-0.002 (3.09)**		
$(Ai/A_F)*RDST$			-0.499 (3.15)**	
$(Ai/A_F)*DIST$				0.124 (0.42)
bservations	1632	1547	1499	1547
-squared	0.20	0.25	0.24	0.23

Note: Robust t-statistics in parentheses
* significant at 5%; ** significant at 1%
The coefficient $(Ai/A_F)*RDST$ is equal to $(Ai/A_F)*RDSTe^{-12}$

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[14] Griffiths et al. (2000) find weak evidence that measures of international trade affect the rate of productivity convergence.

The coefficient $(Ai/A_F)*DIST$ is equal to $(Ai/A_F)*RDSTe^{-6}$

6. Conclusions

Recent evidence has established a positive role for improvements in foreign country technology on domestic productivity. In this paper we have studied whether the effect of frontier technology on domestic productivity varies according to the absorptive capacity and physical distance from the source of new ideas. Evidence is found from 9 manufacturing industries in 12 OECD countries over the period 1973 to 1992 that this is indeed the case. Domestic productivity is positively correlated with level of domestically generated knowledge and frontier technology. The effect of frontier technology on domestic productivity is increasing in the level of human capital and decreasing in physical distance. No role for learning through R&D is uncovered in the broadest sample of countries, but when the focus is narrowed to the 7 smallest OECD countries some evidence is found. This is attributed to limitations in the data in discriminating between R&D used for innovation from that used for imitation.

Issues of skill biased technical change increasing the importance of human capital and improvements in transport and communication technologies decreasing the importance of distance were also considered. No evidence exists in this data to suggest skill biased technical change has affected the parameter estimates, but there does appear to have been some impact from improvements in transport and communication technology on distance. By the end of the sample period distance was not found to help explain cross-country productivity differences. Whilst this is supportive of the new-economy view of the ‘death of distance’ we suggest caution and further research before such a conclusion is reached.

The effects of distance also found to vary significantly across industries. The general pattern in the data is that in industries in which international trade is extensive, such as machinery and equipment, and in industries in which technology is likely to be low-tech, such as paper and wood products, the effect of distance is noticeably weaker. The latter effect occurs even if international trade in the industry is relatively localised. This would appear to imply that for some industries OECD countries are sufficiently integrated or technology sufficiently low-tech for distance to not act as a barrier to technology transfer. This suggests caution when generalising the results from cross-country studies of the effects of distance on productivity to less aggregated studies. An obvious extension of the results from this paper is to test for the robustness of this result in a broader sample of countries. The effect of absorptive capacity and distance were not found to differ at different sizes of the technology gap, although absorptive capacity was found to affect the rate at which the technology gap is closed, as was R&D. In contrast, although physical distance appears to affect the level of TFP it was not found to affect the rate of convergence.

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