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Relative Backwardness or Absorptive Capacity: How Does Knowledge Spill Over Across Borders?

by

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Abstract

In this paper we search for evidence of North-South trade-related knowledge spillovers from a sample of five major OECD countries to 45 developing countries using panel data. We then extend the analysis to examine whether the impact of domestic factors affects the extent of knowledge spillovers. In particular, we investigate whether knowledge spillovers are stronger, the further a country is behind the technological leader, or whether they are stronger in countries with higher levels of absorptive capacity. Our results suggest that the impact of trade-related knowledge spillovers on growth does not depend upon how far a country is behind the technological leader, but that knowledge spillovers are stronger in countries with higher levels of absorptive capacity.

JEL Classifications: F43, O30, O40

Keywords: Absorptive Capacity, Backwardness, Economic Growth, Knowledge Spillovers.

Outline

Non-Technical Summary

It has long been recognised that international technology transfer is an important source of economic growth, and knowledge spillovers are a significant part of this process. It is also apparent that there are significant differences in the effectiveness of individual countries in accessing and exploiting foreign technology. Since most innovation occurs in a handful of the world's richest countries, the importance for the others of identifying the determinants of successful technology diffusion is clear. It is then natural to relate differences in countries' abilities to access and exploit foreign knowledge to differences in the characteristics of the countries involved.

Two broad hypotheses have emerged from this comparison. The first argues that, since it is countries behind the technology leader that have the opportunity to benefit from foreign knowledge spillovers, the further behind a country is the greater the backlog of technology and knowledge available for diffusion, and therefore the larger the potential spillovers. This hypothesis is often referred to as the *advantages of backwardness*. The second hypothesis qualifies the first by arguing that the size of the technology gap alone does not determine the magnitude of any foreign knowledge spillovers. To take advantage of the technology gap a country needs to have appropriate capabilities and policies in place. These factors have been labelled *social capability* or *absorptive capacity*.

In this paper we test these two hypotheses with regard to foreign knowledge spillovers through a particular channel. Following Coe and Helpman (1995) a growing empirical literature has investigated the impact of foreign knowledge spillovers through trade on growth. Evidence of growth enhancing spillovers has been found among developed countries and from developed to developing countries. Our aim is to examine the extent to which North-South knowledge spillovers are dependent on relative backwardness and the level of absorptive capacity of recipient countries.

Our results suggest that trade related knowledge spillovers are indeed an important source of growth for developing countries. We also examine whether the impact on growth of such spillovers depends upon relative backwardness and education levels, using interaction terms and recently developed threshold regression models. Our results suggest that if a relationship does exist between these variables and spillovers, it does not take this form. The results of the threshold regression analysis suggest that while relative backwardness does not seem to affect the relationship between foreign knowledge spillovers and growth, the level of education does. We find that those countries with the highest levels of education benefit more in terms of growth from foreign knowledge spillovers than those with lower levels of education. As such it appears that absorptive capacity, as measured by education, helps a country take advantage of knowledge and technology produced in advanced countries. In terms of relative backwardness it does not appear to matter how far you are behind the technological leader, the impact of foreign knowledge spillovers is similar regardless of a country's distance from the technological leader.

1. **Introduction**

It has long been recognised that international technology transfer is an important source of economic growth, and knowledge spillovers are a significant part of this process. It is also apparent that there are significant differences in the effectiveness of individual countries in accessing and exploiting foreign technology. Since most innovation occurs in a handful of the world's richest countries, the importance for the others of identifying the determinants of successful technology diffusion is clear. It is then natural to relate differences in countries' abilities to access and exploit foreign knowledge to differences in the characteristics of the countries involved.

Two broad hypotheses have emerged from this comparison. The first argues that, since it is countries behind the technology leader that have the opportunity to benefit from foreign knowledge spillovers, the further behind a country is the greater the backlog of technology and knowledge available for diffusion, and therefore the larger the potential spillovers. This hypothesis is often referred to as the *advantages of backwardness*. The second hypothesis qualifies the first by arguing that the size of the technology gap alone does not determine the magnitude of any foreign knowledge spillovers. To take advantage of the technology gap a country needs to have appropriate capabilities and policies in place. These factors have been labelled *social capability* or *absorptive capacity*[1].

In this paper we test these two hypotheses with regard to foreign knowledge spillovers through a particular channel. Following the seminal contribution of Coe and Helpman (1995) (CH) a growing empirical literature has investigated the impact of foreign knowledge spillovers through trade on growth. Evidence of growth enhancing knowledge spillovers has been found among developed countries and from developed to developing countries. Our aim is to examine the extent to which North-South knowledge spillovers are dependent on relative backwardness and the level of absorptive capacity of recipient countries. We find no evidence

[1] There is a microeconometric literature which parallels this macro literature in some respects. This focuses largely on a single transmission channel, the multinational firm. The relevant empirical literature searches for technology spillovers, often using an industry's distance from the technology frontier as an explanatory variable. See Gorg and Greenaway (2004) for a review of the literature.

that the growth enhancing effects of trade related foreign knowledge spillovers (hereafter TRKS) are sensitive to the degree of "backwardness" of the country concerned. We do however find evidence that these effects are influenced by absorptive capacity (as measured by education levels). TRKS have a stronger growth enhancing effect where populations have higher education above an estimated threshold.

The remainder of the paper is organised as follows. In Section 2 we discuss the theoretical background and related empirical literature. Section 3 provides our empirical set-up. Section 4 presents our results, while Section 5 offers some conclusions.

2. **Background**

The notion that countries may gain from access to each others' knowledge or technology is not new. More than a generation ago Gerschenkron (1962) and Kuznets (1973) discussed the so-called 'advantage of backwardness', whereby countries positioned inside the world technological frontier obtain a nonreciprocal benefit by learning from the technological leaders. Gerschenkron observed that "*Industrialisation always seemed the more promising the greater the backlog of technological innovations which the backward country could take over from the more advanced country*" (1962, p. 8). One implication of this statement is that the further a country is behind the leader the greater the backlog of knowledge available for diffusion and so the larger the potential knowledge spillovers. There are contrary views, however. Matthews (1969) for example argues that as convergence of income per capita with the technological leaders takes place consumption and production patterns should also converge, making it easier to borrow foreign technology the closer a country is to the technological frontier[2].

Abramovitz (1986) accepts that being backward carries the potential for rapid advance, and that this should imply convergence over long periods of time. But backwardness in itself is unlikely to lead to greater knowledge diffusion and catch-up, unless certain preconditions exist

[2] Again there is a parallel microeconomic literature relating to the potential attractiveness of locations to multinational firms. Findlay (1978) emphasises the attractions of relative backwardness to inward investment, arguing that it signals a backlog of opportunities. By contrast, Glass and Saggi (1998) argue that relative backwardness is a deterrent to multinationals on the grounds that it limits the kind of technology that can be transferred.

that allow countries to absorb the inflow of foreign ideas and knowledge. These preconditions have been termed ‘social capability’ or ‘absorptive capacity’. Abramovitz has a broad concept in mind, grouping the relevant factors under three headings. Firstly, facilities for the diffusion of knowledge, such as the level of international trade, foreign direct investment and other channels of international technical communication. Secondly, conditions that facilitate or hinder structural change in production, in the allocation of labour, and in the location of industry. Here the level of human capital embodied in the workforce is likely to be important. Finally, macroeconomic and monetary conditions that encourage and sustain investment and the growth of demand. Given the large number of factors potentially relevant, it is unsurprising that there have been few attempts to measure such a broad concept[3]. Instead most studies isolate one or more aspects of absorptive capacity, such as human capital (education) or openness to trade, and we follow this approach for the same reasons.

From the theoretical literature, Coe, Helpman and Hoffmaister (1997) (CHH) identify four channels through which knowledge produced in one country can affect productivity and growth in others. Firstly, through the importation of intermediate and capital goods, which may enhance the productivity of domestic resources. Secondly, through the cross-border learning of production methods, product design, organizational structures and market conditions that can result in a more efficient allocation of domestic resources. Thirdly, through the imitation of new products. Finally, through the development of new technologies or the imitation of foreign technology. In each case the relevant knowledge can be transmitted directly, or indirectly through trade in the products in which it is embodied, thereby generating TRKS.

An empirical literature has developed examining the importance of foreign knowledge spillovers on productivity growth. The approach has generally been to construct a ‘stock of knowledge’ for each country based on past cumulative R&D and then to measure the access of other countries to this by weighting these stocks by the volume or share of bilateral trade. This is the approach taken by CH who test for the presence of TRKS among 22 OECD countries over the period 1971-1990. They conclude that both foreign and domestic knowledge stocks

[3] Adelmann and Morris (1965) employ factor analysis to construct an index of social capability using a large number of variables. Temple and Johnson (1998) have since shown that growth is strongly related to initial social capability as measured by the index developed by Adelmann and Morris.

are important for growth, with the countries gaining most from TRKS being those that are more open to trade. CHH employ the same techniques to examine North-to-South spillovers from these OECD countries to a sample of 77 developing countries over the same period. No domestic knowledge stock can be included for the developing countries, however, because of inadequate R&D data. The results suggest that North-South TRKS are substantial.

These two studies have generated a growing empirical literature broadly confirming the growth-enhancing effects of TRKS[4]. The role of backwardness and domestic factors in facilitating these spillovers has received much less attention, however. A measure of backwardness (such as a country's initial GDP per capita or the ratio of its initial GDP per capita to that of the US) is typically included in growth regressions to account for convergence implied by knowledge spillovers in general, the sources of which may be quite diverse (Dowrick and Nguyen, 1989). When included along with TRKS, such a "catch-up" term will account for knowledge spillovers through other channels. The catch-up results generally support the hypothesis that there are advantages of backwardness through other channels[5]. Including a measure of the educational attainment of the population in growth regressions, intended to capture human capital, generates mixed results. Many recent cross-section and panel studies find that economic growth appears to be unrelated to increases in educational attainment, with other studies finding a negative relationship between these two variables.[6] Using educational attainment as a proxy for absorptive capacity, and interacting it with a knowledge spillover variable (catch-up or TRKS) allows a test of the absorptive capacity hypothesis. The results from the interaction with catch-up generally support the hypothesis that absorptive capacity enhances the advantages of backwardness (Benhabib and Spiegel, 1994;

[4] To date the literature has concentrated on the role of imports as the conduit for knowledge spillovers, although exports (Funk, 2001; Falvey, Foster and Greenaway 2004) and both inward and outward FDI (Xu and Wang, 2000) have also been investigated. In general weighting foreign knowledge stocks by imports provides the most consistent evidence of TRKS. See Keller (2004) for a review of the evidence.

[5] See Engelbrecht (1997)

[6] See for example Benhabib and Spiegel (1994), and Caselli et al, (1996) and Pritchett (1996). Temple (1999) argues that the weak correlation between growth and increases in educational attainment may be due to influential outliers, and that omitting these observations leads to the expected positive and significant coefficient on educational attainment.

Engelbrecht, 1997, 2002). But the interaction with TRKS does not indicate a significant role for absorptive capacity in this channel (CHH, Engelbrecht, 1997, 2002)[7].

When interpreting these outcomes it is important to bear in mind the differences between these two foreign knowledge spillover variables. Catch-up is included in an attempt to capture in a very general way the available foreign knowledge that might have growth enhancing effects once transmitted to the recipient economy. Its sign and significance in growth regressions indicates that the more knowledge there is available the larger the growth enhancing spillovers. If catch-up is interacted with education (absorptive capacity), then one is testing an implicit hypothesis about this transmission process; namely that these general growth-enhancing spillovers are larger the higher the level of education of the recipient population. This hypothesis is broadly confirmed.

Contrast this with TRKS, which deals with knowledge created in a particular way (through R&D) *and* transmitted through a particular channel (trade). When this variable is included in growth regressions, we find that growth enhancing spillovers are larger, the higher the stock of knowledge available and the higher the share of trade of the recipient. The latter confirms the importance of the openness aspect of absorptive capacity. If TRKS is further interacted with education, then one is testing an implicit hypothesis that these spillovers are increasing in the product of openness and education. The evidence has so far rejected the existence of such a relationship, an outcome we confirm below. But interactions of this form are not the only dimension through which education could influence the transmission of TRKS. While the evidence rejects the hypothesis that the growth-enhancing effects of TRKS rise linearly with education, there might still be threshold effects and it is these that we investigate in the next section.

[7] Attempts to detect a role for education in international technology transfer through more specific channels have been more successful. Caselli, and Coleman (2001) use data on imports of office, computing and accounting machinery as a measure of inward technology, arguing that since most countries have no domestic computer industry computer technology comes from abroad. They find that imports of computer equipment are significantly positively related to secondary and higher schooling depending on the sample, but not primary schooling. Eaton and Kortum (1996) use patent data as a measure of technological diffusion on a sample of 19 OECD countries and find that the extent of technological diffusion is rising in the level of human capital.

The apparent absence of a positive relationship between average years of schooling and growth has raised the issue of whether both the composition and level of education of the workforce are important for spillovers. There is evidence of complementarities among different types of human capital, with higher education important for understanding and adopting new technologies, and secondary education important in their application (World Bank, 1998). As Ramcharan (2004) observes, similar average years of schooling could mask potentially important differences in its composition. He also conjectures that for developing countries, TRKS may substitute for higher education, noting that "..it may well be that developing economies need only invest in secondary schooling, importing higher-skilled education embodied in the foreign goods" (2004, p320). These views suggest that the relationship between spillovers and the level and composition of education is worth a closer look.

3. Empirical Specification

In our empirical analysis we concentrate on knowledge spillovers from five OECD 'donor' economies that conduct the bulk of the world's R&D to a sample of 45 developing 'recipient' economies[8]. We use panel data on 3 five-year time periods, 1975-79, 1980-84 and 1985-89, giving a total of 135 observations. The use of five-year averages follows CHH and is due to the fact that estimates of education are interpolated for some years. We follow Evenson and Singh (1997) and Falvey, Foster and Greenaway (2002) (FFG) by examining the impact of knowledge spillovers directly on output growth. Focusing on output growth avoids errors one might introduce in calculating TFP and allows consideration of variables normally included in growth regressions that may be important conduits for knowledge diffusion, but which may not adequately be accounted for in TFP calculations.

[8] The five donor economies are France, Germany, Japan, the UK and the USA. These countries undertook 90% of the real R&D expenditure of the 15 OECD countries for which we have data (average 1973-1990). Eaton and Kortum (1999) note that in the late 1980s, 80 percent of OECD research scientists and engineers were employed in our five donor economies. Funk (2001) concludes from his analysis that knowledge flows primarily from the most advanced members of the OECD.

The empirical specification for our growth model follows that of FFG and relates growth of per capita output (*GROW*) to changes in the foreign knowledge stock (*DKS*) and other variables considered important for growth[9]. The initial model is:

$$GROW_{rt} = \beta_1 GAP_{rt} + \beta_2 INV_{rt} + \beta_3 POPGROW_{rt} + \beta_4 SYR_{rt} + \beta_5 EXPGDP_{rt} + \\ \delta_1 DKS_{rt} + \mu_r + \iota_t + \varepsilon_{rt}$$

where INV_{rt} is the log of the average gross domestic investment (for recipient country *r* in time *t*), *POPGROW* is the average population growth, *SYR* is the average years of secondary schooling in the population over 25 in the initial year of the period[10], *EXPGDP* is the average ratio of exports to GDP in each period (included as a measure of openness), $_i$ and $_t$ are country and time fixed effects respectively and $_{rt}$ is an error term with zero mean and constant variance. Our measure of relative backwardness is

$$GAP_{r,t} = \left(\frac{INITGDP_{US,t}}{INITGDP_{r,t}} \right) - 1$$

where $INITGDP_{r,t}$ is the log of initial GDP per capita of the recipient country and $INITGDP_{US,t}$ is the corresponding value for the US. This variable is included to account for other forms of catch-up, including disembodied foreign knowledge spillovers. The higher the degree of backwardness the larger is the value that *GAP* takes.

A number of specifications of the foreign knowledge spillover variable have been proposed in the empirical literature. The specification that we use is[11]

$$KS_{rt} = \frac{M_{rt}}{GDP_{rt}} \sum_{d=1}^{5} \theta_{drt} \frac{S_{dt}}{GDP_{dt}}$$

where GDP_{rt} is the level of GDP in the recipient economy and M_{rt} is the level of manufacturing imports from the 5 donor economies to the recipient economy, $_{drt}$ is the share

[9] Considering the relationship between the growth of either TFP or GDP and the change in the foreign knowledge stock rather than between the level of TFP or GDP on the level of the foreign knowledge stock as in CH, also avoids the problem that the levels of the knowledge stocks tend to be non-stationary (see Kao et al, 1999).

[10] Temple (1999) argues that the use of average years of education rather than enrolment ratios has the advantage that they are an indicator of the stock of human capital available for current production, whereas enrolment ratios reflect current flows of education (See also Barro and Lee, 1993; Engelbrecht, 1997, 2002; Pritchett, 1996).

[11] The change in the foreign knowledge spillover variable is constructed as the annual average change in the variable within each five year period.

of imports of donor *d* out of total imports from the five donor countries, S_{dt} the stock of knowledge in the donor[12] and GDP_{dt} the level of GDP of the donor economy. Note that this measure allows a role for the volume of trade (relative to GDP) as well as its distribution among donors. In this way it accounts for the openness component of absorptive capacity.

Our objective here is to determine whether and to what extent relative backwardness and education levels and composition of the recipient country affect the relationship between TRKS and growth. As mentioned above, the multidimensional nature of "absorptive capacity" makes it difficult to capture in a single variable, but it is generally accepted that human capital (education) is a critical component. We therefore take the average years of secondary and higher schooling (EDU) and its de-composition into average years of secondary (*SYR*) and higher (*HYR*) schooling in the population over 25 as our alternative indicators of absorptive capacity[13]. We also report results on the average total years of education in the population over 25 (TYR).

4.1. ***Initial Results***

Our initial results are reported in Table 1. In Column 1 we include only core variables. These tend to have the expected sign and are mostly significant[14]. The coefficient on *GAP* is positive and significant as expected (i.e. higher values of *GAP* indicate a higher degree of backwardness, so the more backward a country is the higher is growth). The coefficient on *SYR* is positive as expected, but insignificant, which is a common outcome as noted above.

In Column 2 we add our measure of foreign knowledge spillovers. This does not affect either the sign or significance of the core variables and is itself positive and significant indicating that North-South spillovers are a significant source of growth in developing countries. The coefficient on *GAP* falls slightly suggesting that these trade related knowledge spillovers are to

[12] Details on the construction of the knowledge stocks and data sources are provided in the Appendix.
[13] This also has the advantage that data is widely available for a large number of countries over a relatively long period of time. Replacing *SYR* in our core variables with *HYR* or *EDU* does not affect the results that follow in any significant way. We have chosen to use secondary schooling because that is the education and human capital measure most commonly employed in the literature.
[14] The coefficient on *POPGROW* is positive and insignificant, which is not what we would expect, and appears to be due to the inclusion of country and time dummies. Excluding these dummies and estimating a random effects model resulted in the usual negative coefficient on population growth.

an extent captured by the standard catch-up variable. In the final five columns we include, separately, interactions between the foreign knowledge spillover and our measures of relative backwardness (*GAP*) and schooling. The coefficients on the interactions give the additional impact of foreign knowledge spillovers on growth for countries with higher values of backwardness or absorptive capacity. Once again the core variables are little affected, and none of the interaction terms are significant. Neither the level nor composition of education is significant when interacted with TRKS, which is consistent with the literature reviewed above. That literature also tends to report a positive and significant coefficient when the degree of backwardness and therefore the potential for catch-up is interacted with human capital. Our results from this exercise are reported in Table 2[15].

Table 1: Initial Results and Interactions with TRKS

GROW	1	2	3	4	5	6	7
GAP	0.6	0.56	0.56	0.56	0.57	0.56	0.56
	(5.62)***	(5.95)***	(5.76)***	(5.92)***	(6.17)***	(5.95)***	(5.92)***
INV	0.04	0.05	0.05	0.05	0.05	0.05	0.05
	(4.12)***	(4.63)***	(4.60)***	(4.68)***	(4.69)***	(4.70)***	(4.64)***
POPGROW	0.31	0.13	0.23	0.14	0.14	0.15	0.14
	(0.34)	(0.17)	(0.29)	(0.19)	(0.18)	(0.19)	(0.18)
SYR	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	(1.14)	(0.96)	(1.01)	(1.04)	(1.06)	(1.06)	(0.97)
EXPGDP	0.11	0.08	0.08	0.08	0.08	0.08	0.08
	(2.16)**	(1.71)*	(1.58)	(1.51)	(1.51)	(1.49)	(1.59)
DKS		0.08	0.12	0.06	0.07	0.06	0.07
		(3.80)***	(2.28)**	(1.93)*	(2.62)**	(1.91)*	(1.77)*
DKS x GAP			-0.08				
			(-0.80)				

[15] The results are essentially unaffected if *DKS* is dropped from the specification.

DKS x SYR				0.03			
				(0.65)			
DKS x HYR					0.03		
					(0.76)		
DKS x EDU						0.03	
						(0.76)	
DKS x TYR							0.003
							(0.26)
F-Stat	12.7***	12.7***	12.8***	13.4***	14.0***	13.8***	11.95***
R^2	0.77	0.81	0.81	0.81	0.81	0.81	0.79

All equations include a full set of unreported country and time dummies. t-statistics in brackets. All models estimated using White Heteroscedasticity-Consistent standard errors. *, **, *** indicate significance at the 10, 5 and 1 percent level respectively.

An interesting pattern emerges. For disembodied spillovers the composition of education is important. The absence of a significant interaction between catch-up and average total years of secondary and higher schooling (EDU) and between catch-up and average total years of schooling (TYR) is a reflection of two opposing effects. Only for secondary education do we see the positive interaction reported in the literature. Other things equal, more secondary education raises growth-enhancing disembodied spillovers, but more higher education reduces them. This pattern is confirmed when both the SYR and HYR interactions are included simultaneously. Now we have evidence of substitutability between higher education and foreign knowledge spillovers as Ramcharan (2004) conjectured, but associated with disembodied spillovers swept up in the catch-up term, rather than trade related spillovers embodied in DKS. These results are consistent with the view that countries with high levels of HYR have the capacity and are therefore more likely to undertake innovative activities on their own account, which appear to substitute for the disembodied spillovers that those countries with high levels of SYR, but low levels of HYR benefit from.

Table 2: Interactions with Catch-up.

GROW	1	2	3	4	50
GAP	0.52	0.61	0.54	0.52	0.56
	(5.36)***	(6.55)***	(5.55)***	(5.05)***	(5.93)***
INV	0.05	0.04	0.05	0.05	0.04
	(4.75)***	(4.64)***	(4.65)***	(4.79)***	(4.78)***
POPGROW	-0.12	-0.11	0.06	0.01	-0.44
	(-0.15)	(-0.15)	(0.08)	(0.02)	(-0.56)
SYR	-0.006	0.02	0.01	0.01	-0.001
	(-0.26)	(1.52)	(0.27)	(0.51)	(-0.06)
EXPGDP	0.09	0.09	0.09	0.09	0.1
	(1.90)*	(1.77)*	(1.76)*	(1.82)*	(2.01)**
DKS	0.08	0.08	0.08	0.08	0.08
	(3.77)***	(3.91)***	(3.75)***	(3.68)***	(3.92)***
GAP x SYR	0.09				0.11
	(1.79)*				(2.20)**
GAP x HYR		-0.31			-0.35
		(-2.41)**			(-2.84)***
GAP x EDU			0.03		
			(0.71)		
GAP x TYR				0.02	
				(1.07)	
F-Stat	22.1***	16.57***	11.91***	11.23***	12.8***
R^2	0.81	0.82	0.81	0.80	0.83

All equations include a full set of unreported country and time dummies. t-statistics in brackets. All models estimated using White Heteroscedasticity-Consistent standard errors. *, **, *** indicate significance at the 10, 5 and 1 percent level respectively.

4.2. ***Threshold Effects***

Results reported so far do not support the view that either relative backwardness or education significantly affect the relationship between TRKS and growth. If there are advantages of backwardness, and absorptive capacity constraints are present, the interaction terms are not capturing them. We therefore turn to an alternative formulation that searches for threshold effects, using a method developed by Hansen (1996, 1999 and 2000) based on a threshold regression where observations fall into regimes dependent upon an unknown value of an observed variable. Hansen provides an econometric technique that allows the data to determine the number and location of thresholds. This allows the parameter associated with TRKS to depend directly on the level of a third variable, in our case either relative backwardness[16] or one of our education variables. In the case of relative backwardness, for example, we estimate the following:

$$GROW_{rt} = \beta_1 GAP_{rt} + \beta_2 INV_{rt} + \beta_3 POPGROW_{rt} + \beta_4 SYR_{rt} + \beta_5 EXPGDP_{rt} +$$
$$\delta_1 DKS_{rt} I(GAP_{rt} \leq \lambda) + \delta_2 DKS_{rt} I(GAP_{rt} > \lambda) + \mu_r + \iota_t + \varepsilon_{rt}$$

where is the breakpoint. Here the observations are divided into two regimes depending on whether the threshold variable, *GAP*, is smaller or larger than the value . The impact of foreign knowledge spillovers on growth will be $_1$ for countries in the low regime and $_2$ for countries in the high regime.

To estimate this model we firstly need to jointly estimate the threshold value and the slope parameters. Chan (1993) and Hansen (2000) recommend obtaining the least squares estimate of as the value that minimises the concentrated sum of squared errors. We estimate our growth

[16] Note that while the DKS variable takes account of the distribution of imports and the ratio of imports to GDP of the recipient country, it takes no account of the knowledge gap between donors and recipient.

model for all values of the threshold variable between the 10th and 90th percentile[17]. After obtaining a value of , we can estimate the parameters of our growth equation. Having found a threshold we need to identify whether it is statistically significant. This involves testing the null hypothesis that $_1 = \ _2$, where rejecting the null allows us to conclude that a threshold exists. One complication is that the threshold   is not identified under the null hypothesis, implying that classical tests do not have standard distributions and critical values cannot be read off standard distribution tables. We follow Hansen (1996) and bootstrap to obtain the p-value for the test of a significant threshold.

Table 3 reports results for a single threshold of each of our five threshold variables. Again the core variables are largely unaffected. Column 1 reports results for a relative backwardness threshold. In both the high and low regimes we find significant knowledge spillovers, with the coefficient in the low regime (i.e. the least backward countries) being larger. So, if anything, it is countries closer to the technological frontier that benefit more from knowledge spillovers through trade, which would fit more closely the view of Matthews (1969) discussed above[18]. But the reported p-value indicates that we cannot reject the hypothesis that the coefficients are the same at standard significance levels. There is no significant evidence of an advantage to backwardness in TRKS.

Does absorptive capacity as embodied in education levels, assist knowledge spillovers through trade? Columns 2 through 5 report the relevant results. There is evidence of a significant threshold at around the 80th percentile in the case of SYR, HYR and EDU, and in each we find that foreign knowledge spillovers impact significantly on growth in both the high and low schooling regimes. But the impact is significantly larger for those countries that have higher levels of schooling. No significant threshold is found for TYR. Collectively these results offer clear evidence that absorptive capacity, in terms of the education of the population, can facilitate knowledge spillovers through trade. Such spillovers are always growth improving, but those countries with levels of post-primary education above a threshold benefit more.

[17] That is we constrain each of the thresholds estimated below so that at least 10% of observations fall in each regime.
[18] But recall that the coefficient on the catchup term remains significant and negative, indicating the advantages of backwardness remain for spillovers through other channels.

Table 3: Threshold Results

GROW	GAP	SYR	HYR	EDU	TYR
GAP	0.54	0.56	0.59	0.57	0.57
	(5.67)***	(5.98)***	(6.51)***	(6.07)***	(6.15)***
INV	0.04	0.05	0.05	0.05	0.05
	(4.71)***	(5.08)***	(5.26)***	(5.12)***	(4.98)***
POPGROW	-0.25	-0.48	-0.70	-0.46	-0.39
	(-0.30)	(-0.60)	(-0.87)	(-0.58)	(-0.50)
SYR	0.002	0.001	-0.003	0.003	0.001
	(0.08)	(0.07)	(-0.13)	(0.17)	(0.04)
EXPGDP	0.08	0.08	0.08	0.08	0.08
	(1.68)*	(1.84)*	(1.84)*	(1.83)*	(1.54)
GAP x SYR	0.1	0.1	0.10	0.11	0.11
	(1.94)*	(2.37)**	(2.23)**	(2.46)**	(2.29)**
GAP x HYR	-0.34	-0.33	-0.30	-0.35	-0.35
	(-2.72)***	(-2.57)**	(-2.40)**	(-2.75)***	(-2.82)***
DKSL	0.11	0.07	0.07	0.07	0.06
	(3.17)***	(3.58)***	(3.35)***	(3.51)***	(2.61)***
DKSH	0.06	0.21	0.22	0.21	0.10
	(2.61)***	(5.13)***	(5.80)***	(5.19)***	(3.14)***
Threshold	0.513	1.178	0.231	1.426	2.92
	(61st Percentile)	(79th Percentile)	(81st Percentile)	(81st Percentile)	(41st Percentile)
Bootstrapped p-value	0.25	0.02**	0.00***	0.02**	0.26
F-Stat	13.02***	13.1***	13.64***	12.93***	12.67***
R^2	0.83	0.84	0.85	0.84	0.83

All equations include a full set of unreported country and time dummies. t-statistics in brackets. All models estimated using White Heteroscedasticity-Consistent standard errors. *, **, *** indicate significance at the 10, 5 and 1 percent level respectively.

The evidence of significant individual threshold effects for three of our education measures leads one to ask whether these thresholds should be combined in some way. To illustrate this we take each of our cases where a significant first threshold was estimated and search for a second based on GAP and each of the four education variables alternatively for observations in the low regime (which make up about 80% of the observations). No significant second thresholds were found.

Since EDU is the sum of SYR and HYR, we expect EDU and its components to be positively correlated. This is confirmed in Appendix Table A2. The very high correlation between EDU and SYR (0.99) also reflects the requirement that an individual must have a high score on SYR in order to proceed to HYR. Despite this there are still significant differences in the composition of post-primary education across countries, as indicated by a correlation of 0.71 between SYR and HYR, and by their significantly opposite impacts when interacted with the catch-up variable. But for DKS we obtain a significant threshold at the 80th percentile no matter which education variable is used. This suggests that while the level of education is clearly important, its composition may not be in determining the growth-enhancing effects of TRKS.

4.3. Confidence Intervals

Once the presence of a significant threshold is confirmed, it is useful to be able to form some kind of confidence interval around it so that countries can be allocated to the different regimes. Once again however, standard methods are not ideal when estimating an unknown threshold (Dufour, 1997). Hansen (2000) derives the correct distribution function and provides the appropriate critical values for the likelihood ratio statistic. The confidence interval of the threshold estimate consists of those values of the threshold variable for which the likelihood ratio statistic is less than the critical value. According to Hansen (2000) the 90% critical value is 5.94, which is the value we use. Table 4 below reports the confidence intervals for the cases where a significant threshold was found (i.e. SYR and HYR individually in the one threshold model, and collectively in the two threshold case).

Table 4: Confidence intervals

	Minimum	*Maximum*	*Threshold*	*Confidence Interval*
SYR	0.03	2.83	1.178	$1.07 \leq c(\alpha) \leq 2.83$
HYR	0.01	0.71	0.231	$0.195 \leq c(\alpha) \leq 0.251$
EDU	0.04	3.24	1.426	$0.74 \leq c(\alpha) \leq 3.24$

For the SYR threshold we can classify 97 observations as being in the low regime at the 95% level, but for the remaining 38 we cannot classify them as either in the low or high regime. For HYR the confidence interval is much smaller. Here 103 observations are classed as being in the low regime, while 21 are in the high regime. Only for 11 observations are we not able to classify in either regime. Finally, for EDU we find a quite wide interval again. While 63 observations are in the low regime we cannot place the remaining 72 observations in either the low or high regime.

5. Conclusions

Knowledge spillovers are acknowledged as important to the process of economic growth and the factors associated with their effective transmission have been subject to extensive empirical scrutiny. In this paper we investigate the impact of trade related foreign knowledge spillovers on the growth rates of a large and diverse sample of developing countries, using panel data spanning the period 1975-1989. The origin of spillovers in our analysis are the five largest OECD economies.

Our results suggest that TRKS are indeed an important source of growth for developing countries. We then examined whether the impact on growth of such spillovers depends upon relative backwardness and education levels, using interaction terms and recently developed threshold regression models. The results on the interaction terms suggested that if a relationship did exist between these variables and spillovers, it did not take this form. The results of the threshold regression analysis suggest that while relative backwardness does not seem to affect the relationship between foreign knowledge spillovers and growth, the level of education does. We find that those countries with the highest levels of education benefit more in terms of growth from foreign knowledge spillovers than those countries with lower levels of education. As such it appears that absorptive capacity, as measured by education, helps a country take advantage of knowledge and technology produced in advanced countries. In terms of relative backwardness it doesn't appear to matter how far you are behind the technological leader, the impact of foreign knowledge spillovers is similar regardless of a country's distance from the technological leader.

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Appendix: Data Sources and Variable Construction

Our data covers a sample of 45 countries[19] over 3 time periods; 1975-79, 1980-84 and 1985-89. Data on GDP, growth rates, investment and exports are drawn from the World Bank's *World Development Indicators* (2001). Data on education variables are from Barro and Lee (2000). R&D for the five donor economies was taken from the OECD's *ANBERD* dataset and were deflated using the GDP deflator and converted into US dollars. The import data are total manufacturing exports from the donor to the recipient and are taken from the OECD's *International Trade by Commodity Statistic*.

Knowledge stocks for the donor economies were constructed using the perpetual inventory method (Griliches, 1979). This involves constructing a beginning period stock of knowledge using,

$$S_0 = R_0 /(g + \delta),$$

where is the depreciation rate, assumed to be 5% following CH, g is the average annual logarithmic growth of R&D expenditures over the period for which data were available and R_0 is the level of R&D expenditure in the first year for which data were available.

The knowledge stocks for subsequent years are then constructed using the following equation,

$$S_t = (1-\delta)S_{t-1} + R_{t-1}$$

In Tables A1 and A2 below we report summary statistics for the variables employed in our analysis and the correlation matrix.

[19] The 45 developing countries are Algeria, Argentina, Bangladesh, Bolivia, Brazil, Cameroon, Central African Republic, Chile, Columbia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Ghana, Guatemala, Haiti, Honduras, India, Indonesia, Israel, Jamaica, Kenya, Korea, Malawi, Malaysia, Mauritius, Mexico, Nicaragua, Niger, Pakistan, Panama, Paraguay, Peru, Philippines, South Africa, Senegal, Sri Lanka, Thailand, Togo, Trinidad and Tobago, Uruguay, Venezuela, Zaire (Democratic Republic of Congo), Zambia and Zimbabwe.

Table A1: Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
GROW	0.01	0.03	-0.07	0.08
GAP	0.44	0.21	0.06	0.98
INV	21.73	1.77	17.54	25.70
POPGROW	0.02	0.007	0.005	0.04
EXPGDP	0.26	0.12	0.04	0.63
DKS	-0.04	0.11	-0.25	0.61
SYR	0.78	0.53	0.03	2.83
HYR	0.13	0.14	0.01	0.71
TYR	3.62	1.85	0.39	9.12
EDU	0.91	0.64	0.04	3.24

Table A2: Correlation Between Variables

	GROW	GAP	INV	POPGROW	EXPGDP	DKS	SYR	HYR	TYR	EDU
GROW	1.0									
GAP	-0.07	1.0								
INV	0.32	-0.45	1.0							

POPGROW	-0.18	0.47	-0.18	1.0						
EXPGDP	0.14	-0.23	-0.29	-0.12	1.0					
DKS	0.36	-0.05	0.02	-0.06	-0.01	1.0				
SYR	0.19	-0.61	0.37	-0.58	0.22	0.06	1.0			
HYR	0.01	-0.57	0.36	-0.30	0.06	0.04	0.71	1.0		
TYR	0.16	-0.72	0.41	-0.54	0.24	0.06	0.90	0.79	1.0	
EDU	0.16	-0.63	0.38	-0.55	0.19	0.06	0.99	0.81	0.92	1.0

Table A3: Spearman Rank Correlation Coefficients

Variable 1	*Variable 2*	*Spearman Rank Coefficient*
SYR	*HYR*	0.80

SYR	*EDU*	0.99
SYR	*TYR*	0.90
HYR	*EDU*	0.85
HYR	*TYR*	0.80
EDU	*TYR*	0.92

Table A4: Average Values By Regime

		Second Threshold (*TH2*)			
		SYR	*HYR*	*EDU*	*TYR*
First Threshold (*TH1*)	*SYR*				
	$TH1 > \lambda_1$	1.56	1.56	1.56	1.56
	$TH1 \leq \lambda_1; TH2 \leq \lambda_2$	0.11	0.26/0.02	0.18/0.21	0.29/1.56
	$TH1 \leq \lambda_1; TH2 > \lambda_2$	0.65	0.69/0.12	0.72/0.84	0.73/3.77
	HYR				
	$TH1 > \lambda_1$	0.36	0.36	0.36	0.36
	$TH1 \leq \lambda_1; TH2 \leq \lambda_2$	0.01/0.11	0.06	0.02/0.21	0.03/1.55
	$TH1 \leq \lambda_1; TH2 > \lambda_2$	0.09/0.70	0.19	0.10/0.89	0.11/3.87
	EDU				
	$TH1 > \lambda_1$	1.96	1.96	1.96	1.96

	$TH1 \leq \lambda_1; TH2 \leq \lambda_2$	0.12/0.11	0.27/0.02	0.21	0.32/1.55
	$TH1 \leq \lambda_1; TH2 > \lambda_2$	0.78/0.68	0.85/0.12	0.87	0.88/3.82

Notes: The table reports the average value of the threshold variables for each regime. *TH1* refers to the first (fixed) threshold variable and *TH2* to the second threshold variable. Where the first and second threshold variables are not the same the averages for both are reported as average for *TH1*/average for *TH2*.