International Technology Diffusion and Growth in the Manufacturing Sector of Developing Economies

Andreas Savvides*   Marios Zachariadis†

October 2002

Abstract

This paper evaluates various channels through which foreign technology diffuses to the manufacturing sector of selected developing economies. These economies carry out very little (if any) own R&D so they rely on foreign technology to a much larger extent than developed economies. We investigate the direct effect of foreign R&D, as well as technology embodied in imports of intermediate and capital goods and foreign direct investment, on the growth of manufacturing total factor productivity and value added in 32 developing economies during the 1965-1992 period. We find that foreign R&D typically has the biggest positive impact on domestic productivity and value added growth. Imports of technology goods and foreign direct investment also play a similar positive role but their effect is of smaller magnitude and is not always significant.

Keywords: Technology diffusion, R&D Spillovers, Technology Imports, FDI.

JEL Classification: O40

*Department of Economics, Oklahoma State University, Stillwater, OK 74078. e-mail: asavvid@okstate.edu

†Corresponding author. Department of Economics, Louisiana State University, Baton Rouge, LA 70803. e-mail: zachariadis@lsu.edu

1 Introduction

To what extent do the benefits of technological progress spill across national frontiers? This question has received considerable attention by both academic researchers and policy makers in recent years in light of the high concentration of research and development (R & D) activity in a handful of developed economies. According to UNESCO (2001, Table 1), in 1996/97 the developed economies accounted for 84% of total world R & D expenditures and just two countries (the United States and Japan) accounted for 61% of that amount.[1] The literature has investigated almost exclusively technology diffusion across the OECD economies and a number of papers have shown that foreign sources of technology are an important contributor to productivity growth for the developed economies.[2] Less developed economies (LDCs) carry out very little own R & D and for these economies the degree of technology diffusion from countries close to the frontier is likely to be a key question for the growth of total factor productivity (TFP). Despite the importance of this issue, very little research has been carried out on the magnitude and significance of international technology diffusion for the low and middle income economies.[3]

Theory suggests various channels by which technology can be transmitted across countries. Technology is embodied in capital and intermediate goods so the direct import of these goods is one channel of transmission. This channel is consistent with the models of Grossman and Helpman (1991), and Eaton and Kortum (2001). Foreign direct investment by MNCs may be another channel

[1] The share of the developed economies in world R&D spending has, in fact, decreased from the early 1990s when they accounted for over 95% of total world R&D expenditures.

[2] See, *inter alia*, Coe and Helpman (1995), Eaton and Kortum (1999), Griffith *et al.* (1999), and Keller (2002.)

[3] A review of the literature reveals only a handful of papers including Coe *et al.* (1997), Connolly (2001) and Mayer (2001) who report regression-based results and Bayoumi *et al.* (1999) who report simulation results from the IMF's MULTIMOD model.

for the international transmission of technology and this is indeed one of the (reputed) benefits of FDI that many theories emphasize. Finally, R & D carried out in advanced economies may have direct spillover effects in terms of generating knowledge and ideas that can be used in the production process by firms other than those carrying out the R & D. These firms may be located within the borders of the country or across the border. This is in line with Parente and Prescott (2000) where a global pool of knowledge is available to everybody and differences in TFP growth can be explained by the ability of each country to adopt new technologies. They argue that differential access to the global pool of knowledge is the result of human barriers to technology; and institutional arrangements that minimize these barriers will yield faster rates of technological adoption.

The theoretical framework we consider here is similar to Coe and Helpman (1995) in that it allows for trade in intermediate capital goods which embody new technologies. In addition, we consider the flow of ideas stemming from foreign R & D and benefiting the production process directly. R & D spillovers due to the flow of ideas rather than trade in goods is consistent with Howitt (2000.)[4]

The objective of our study is to examine the importance of several channels of international technology diffusion for the growth of TFP and output (value added) in the manufacturing sector in a number of low and middle income economies. We focus on developing economies because, as mentioned previously, the extent of technology diffusion is especially important for these economies and studies on this topic have been rare. Our concern is the manufac-

[4] In Howitt (2000) the international diffusion of ideas benefits domestic R&D-performing innovators of new intermediate products. Here, we allow the flow of foreign-R&D-induced ideas to benefit domestic manufacturing directly so there can be foreign R&D spillovers to non-R&D-performing economies.

turing sector of these economies rather than aggregate output and productivity because it is the sector where international technology spillovers are most likely to materialize and the sector investigated by studies (both theoretical and empirical) on technology diffusion across developed economies mentioned in the previous paragraph.[5]

2 Theoretical Considerations

The importance of R & D in expanding the technology frontier is emphasized by "first generation" theories of R & D-based endogenous growth developed by Segerstrom, Anant, and Dinopoulos (1990), Grossman and Helpman (1991), Rivera-Batiz and Romer (1991), and Aghion and Howitt (1992). These theories emphasize the nonrival nature of technology and the possibility of spillovers (a positive externality) as attributes distinguishing R & D from the traditional inputs. The possibility and size of these spillovers has generated a lot of interest among economists. Rivera-Batiz and Romer (1991) introduce a model where inputs are differentiated horizontally and greater input variety raises productivity growth. They examine diffusion of technology when economies are relatively similar in terms of endowments and technology. They focus on two channels: the first emphasizes the transmission of knowledge and ideas and corresponds to the knowledge-driven R & D model. The other emphasizes the role of intermediate goods imports that embody new (potentially R & D-induced) technologies, referred to as the lab equipment model. Grossman and Helpman (1991) also consider economies where inputs are differentiated horizontally but are not symmetric in terms of endowments or technology. Productivity is enhanced by the accumulation of R & D so that open economies benefit from foreign R &

[5] The few studies on international technology diffusion for developing economies have focused exclusively on aggregate productivity and output.

D spillovers. The same conclusions are reached by the quality-ladder models of Aghion and Howitt (1992) and Segerstrom, Anant, and Dinopoulos (1990) where inputs are differentiated vertically.

One drawback to first generation models is the scale effect implication: the prediction that a higher level of R & D expenditures (or a more populous country) implies higher rates of productivity growth. Consequently, we consider a "second generation" framework of R & D-based endogenous growth that is rid of the problematic scale-effect implication. This framework includes Dinopoulos and Thompson (1998), Howitt (1999 and 2000), and Segerstrom (2000). A basic implication of this framework is that there exists a positive relationship between productivity growth and research intensity, the latter defined as the ratio of R & D expenditures to output.[6] R & D effort undertaken by any one firm (in any one country) results in the accumulation of a stock of knowledge that benefits all R & D-performing firms in all countries when they attempt to innovate an intermediate product. In this study we allow for the stock of knowledge accumulated by R & D activities in advanced economies to benefit production in the manufacturing sector of low or middle income economies directly so that even non-R & D performing producers/countries benefit from R & D spillovers.

[6] In Howitt (1999) and Howitt (2000), for example, there exists a positive relationship between the rate of technological progress, g_t, and research intensity, $\eta_t = \frac{R_t}{A_t^{\max}}$, where η_t is the ratio of R&D expenditures (R_t) to the leading-edge productivity parameter ($A_t^{\max}$). Research expenditures should increase at the same rate as the technology frontier shifts outwards in order to keep the flow of innovations constant, or $g_t = \beta\phi(\frac{R_t}{A_t^{\max}}), \phi^{'} > 0, \phi^{''} \leq 0$, where $\beta = \sigma\lambda$, σ is the innovation size, and $\lambda > 0$ the flow probability of an innovation. The empirical specification for the relationship between productivity growth and R&D intensity makes the simplifying assumption that $\phi(\frac{R_t}{A_t^{\max}}) = n_t^{\gamma}$, $\gamma = 1$, so we can consider a linear relation between technological change and R&D intensity. In steady state $\frac{R_t}{A_t^{\max}}$ and $\frac{R_t}{Y_t}$ will exhibit similar time-series behavior and this allows us to proxy the former with the latter which is more straightforward to construct and thus subject to less measurement error. While the models of Howitt and others consider countries that perform own R&D, Coe *et al.* (1997) have extended the framework to low and middle income economies that perform no own R&D to consider spillovers from foreign R&D. While previous researchers have considered stocks of foreign R&D, we consider foreign R&D intensities that are more in line with second generation models of endogenous growth.

Our primary objective is to evaluate the contribution of several channels of technology diffusion to the growth of manufacturing TFP productivity and value added for a group of low and middle income economies. Following the insights of R & D endogenous growth models, we include two indicators of technology diffusion as determinants of manufacturing growth in developing economies. The first is a measure of foreign R & D intensity and the second is an indicator of imports of technology goods. For each developing economy, the measure of foreign R & D intensity is a weighted average of the R & D intensity of each of the five major advanced countries (G-5) where the weights are the share of each LDC's technology imports from each of the G-5.[7] The second measures the intensity of technology imports and is given by the share of technology imports (SITC code 7) in a country's total imports. Therefore, an increase in technology imports can potentially influence manufacturing growth both directly (by increasing the indicator of imports of technology goods as implied by the lab equipment model) and also indirectly (to the extent that the increased technology imports originate from a G-5 country with higher R & D intensity thus increasing the measure of foreign R & D intensity). An increase in the R & D intensity of a G-5 country is consistent with both the knowledge-driven model (greater access to the R & D of the G-5 and ability to implement new ideas and designs) and the lab equipment model (increased "R & D intensity" of technology imports from that G-5 country.) Finally, it should be noted that an increase in R & D intensity in any one of the G-5 will have a larger impact in countries that import technology goods more intensively from that G-5 country.

In addition to these two channels of technology diffusion, we consider a third:

[7] Coe *et al.* (1997) and Keller (2002) also use technology goods imports as weights for foreign R&D stocks in constructing their foreign R&D variable. Additional details on the measurement of this variable are provided in the following section.

foreign direct investment (FDI).[8] There is an extensive theoretical literature on the mechanisms by which the inflow of FDI enhances the flow of technology across frontiers and our intention here is not to review the literature. Doubtless, FDI operates through the channels considered above: imports of technology goods by the subsidiaries of multinational corporations (MNCs) and the flow of knowledge generated by R & D carried out in the parent country. In addition, FDI frequently involves the movement of employees/managerial talent across countries as well as links between MNC subsidiaries and local firms, all potential channels for the transfer of novel production techniques or methods of organizational structure and control.

Most of the empirical literature on FDI spillovers has been carried out at the firm level.[9] FDI spillovers is an issue that has also been investigated at the aggregate productivity or output level for (i) developed economies (van Pottelsberghe and Lichtenberg, 2001), (ii) developing economies (Borensztein *et al.*, 1998) or (iii) a panel of both (Xu, 2000). These studies use different indicators to capture the benefits (if any) of FDI spillovers such as using FDI flows as weights for foreign R & D stocks (van Pottelsberghe and Lichtenberg, 2001), royalty and license fees paid by US MNC foreign affiliates as a percent of host country GDP (Xu, 2000) or the ratio of FDI inflows to GDP (Borensztein *et al.*, 1998). While the first two measures capture more accurately the technology transfer implied by FDI, in this study we use the third measure (FDI inflows/GDP). This is because it is the most comprehensive measure of FDI available and allows widest coverage of countries/time.[10]

[8] This is suggested, but not pursued, in the analysis of Coe *et al.* (1997). Technology transfer to LDCs through FDI is examined theoretically by Glass and Saggi (1998) who explore how the quality of technology transferred through FDI is linked to innovation and imitation for developing countries with limited absorptive capacity.

[9] See Branstetter (2001), Haskel *et al.* (2002) for a developed country and Aitken and Harrison (1999) for a developing economy.

[10] We do realize, however and as noted by Xu (2000), that this indicator may not reflect

Finally, we note that the degree of technology diffusion will also depend on the 'absorptive capacity' of each country. One of the main determinants of 'absorptive capacity' is the level of a country's human capital, as emphasized by the seminal paper of Nelson and Phelps (1966). Indeed, the ability of Asian economies to absorb foreign technologies due to their educated/skilled labor force is one of the factors stressed by Nelson and Pack (1999) as a main contributor to their economic success. In order to capture a country's capacity to absorb new technologies, we consider interaction effects between human capital (as measured by education levels) and foreign technology sources. The rationale is that a more highly educated workforce can better take advantage of foreign R & D-induced ideas, but is also more likely to use technology imports (embodying advanced foreign technologies) more effectively or render FDI more productive and profitable for foreign investors to undertake. In fact Coe *et al.* (1997) consider an interaction effect between foreign R & D stocks and education levels while Borensztein *et al.* (1998) and Xu (2000) find a threshold level of human capital that is necessary for foreign direct investment to exert beneficial effects on growth.

3 Methodology and Data

The focus of our study is the impact of foreign technology transfer on the growth of TFP in the manufacturing sector of developing economies. Therefore, it is necessary to derive estimates of manufacturing TFP growth. To accomplish this we resort to the well-known growth accounting methodology. Specifically, we estimate the following model:

$$GMFD_{it} = \alpha + \alpha_{Ki} GK_{it} + \alpha_{Li} GL_{it} + \varepsilon_{it} \tag{1}$$

accurately the technology transfer characteristics of FDI but is rather a general indicator of the benefits/costs associated with FDI as a form of foreign capital inflow.

where $GMFD_{it}$ refers to the growth of value added in the manufacturing sector of country i during time period t, GK is growth of the capital stock in the manufacturing sector, and GL is growth in manufacturing labor. Estimation of (1) has so far been problematic due to the unavailability of the requisite data. To render feasible the estimation of (1), we exploit estimates of the capital stock in the manufacturing sector (in constant dollars) contained in a new data set by Larson *et al.* (2000). As for the other two variables the most comprehensive data set on the manufacturing sector of developing economies is the UNIDO (2001) data base. This data base contains data on manufacturing value added in local currency. In order to convert it to constant dollars we employed data on an economy-wide deflator (data on a manufacturing sector deflator would be more appropriate but are not available for a wide cross section of economies) and the nominal exchange rate. Finally, our estimates of the number of manufacturing sector employees are also from the UNIDO data base. The model in (1) differs from standard growth accounting exercises by allowing the estimate of labor and capital elasticity to differ by country. Given the variety of countries included in our sample, the assumption of constant labor and capital elasticities does not seem reasonable to us.[11] We have data on 32 low- and middle-income economies for the period 1965 to 1992.[12]

[11] It is well known that under perfectly competitive conditions, in the Cobb-Douglas specification in (1) labor and capital elasticities are equivalent to income shares. Bernanke and Gürkaynak (2001) report shares of labor in national income for a variety of countries and find significant divergence across countries.

[12] Our sample is constrained by the intersection of the UNIDO and Larson *et al.* (2000) data sets, especially the latter that ends in 1992. The 32 countries included are: Chile, Colombia, Costa Rica, Cyprus, Ecuador, Egypt, El Salvador, Greece, Guatemala, India, Indonesia, Iran, Iraq, Jamaica, Kenya, Korea, Madagascar, Malawi, Malta, Mauritius, Pakistan, Philippines, Portugal, South Africa, Sri Lanka, Syria, Taiwan, Trinidad and Tobago, Tunisia, Turkey, Venezuela and Zimbabwe.

To test the primary hypotheses of our study we estimate the following model:

$$g_{it} = \beta + \beta_i + \beta_t + \sum_{k=1}^{K} \gamma_k FRD_{it-k} + \sum_{k=1}^{K} \delta_k MTEC_{it-k} + \sum_{k=1}^{K} \theta_k FDI_{it-k} + e_{it} \quad (2)$$

where g is manufacturing TFP growth, FRD is the implied R & D intensity for each country (its measurement is discussed in the next paragraph), $MTEC$ is technology goods import intensity (imports of technology goods divided by total imports for each country), FDI is the foreign direct investment to GDP ratio, and β_i and β_t are country- and time-specific dummy variables. Country-specific dummies are included to capture idiosyncratic shocks to productivity growth. Given existing evidence that TFP growth may be procyclical, time-specific dummies are also included to account for year-specific shocks common across countries. Our principal interest is in estimating the impact of the explanatory variables on TFP growth over time. Since this involves technology spillovers from the frontier countries to "economically distant" countries, we want to account for the fact that this transfer of knowledge is not instantaneous. Therefore, we allow a lag structure for the explanatory variables in (2) and report estimates of the sum of the lagged terms.[13] The use of a lag structure also mitigates any problems associated with the possible endogeneity of the explanatory variables in (2). While in the next section we report estimates for two lags, we experimented with alternative lag structures and (results available on request) we confirm the robustness of our results.

There is a lengthy discussion in the literature on the measurement of the foreign R & D variable. In particular, the weighting scheme adopted has come under scrutiny. Given our interest in estimating the effects of foreign R &D

[13] Kocherlataka and Yi (1997) also use the sum of lags to measure the effects of policy variables on economic growth over time.

embodied through the trade channel we measure FRD as follows:

$$FRD_{it} = \sum_{j=1}^{5} \frac{M_{ijt}}{M_{it}} RDINT_{jt} \qquad (3)$$

where $M_{it} = \sum_{j=1}^{5} M_{ijt}$, M_{ijt} represents imports of technology goods of developing economy i from country j ($j = 1, ...5$ represents each of the G-5 economies: France, Germany, Japan, UK and USA) and $RDINT_{jt}$ is the R & D intensity of each of the G-5. Several comments are in order concerning the measure in (3). First, previous work in this area used weighted sums of foreign R & D stocks rather than R & D intensity. As indicated in the previous section, R & D intensity is the more appropriate concept of the R & D input and that emphasized by second-generation R & D models. Moreover, given that $RDINT$ is measured as the fraction of output devoted to R & D expenditures, it eschews the question of how to compute appropriate measures of R & D stocks, an issue that has presented problems in previous work. In (3), we choose technology goods import shares rather than total import shares because, conceptually, these imports measure more appropriately the embodiment of foreign R & D. Xu and Wang (1999) demonstrate they are preferable to total import shares on empirical grounds. Imports of technology goods of a developing economy from each of the G-5 are obtained from partner data in the form of exports of each of the G-5 to the 32 developing economies in our sample. Partner data sources are more accurate than developing country sources and also have wider coverage. We measure technology goods imports as SITC code 7, machinery and transportation equipment. The source of the data is the International Trade by Commodity Statistics of the OECD (2002). R & D expenditure data for the G-5 for the period 1973-92 (necessary to compute the R & D intensity for each G-5) come from the 2000 OECD ANBERD database[14]. GDP data for the G5 were

[14] Comparable R&D data for the period 1965-1972 were kindly provided by Wolfgang Keller.

also obtained from the 1998 OECD International Sectoral Database (ISDB.) We restrict our study to the G-5 because, as indicated in the introduction, they represent the great bulk of global R & D activity and are also the major sources of capital equipment for developing economies.

In addition to the model in (2), we also estimate a number of alternative specifications to test the hypotheses outlined in the previous section. Specifically, we introduce a number of interaction terms between the various channels of technology diffusion and human capital to test the absorptive capacity hypothesis: in order for foreign technology to influence beneficially domestic productivity a requisite level of educational infrastructure may be necessary. We measure human capital ($EDUC$) by the secondary enrollment ratio. We consider secondary education because it is the level of education more appropriate for the implementation and diffusion of foreign technologies in low and middle income economies. Finally, we also consider an interaction term between the foreign R&D variable (FRD) and imports of technology goods ($MTEC$) to test the Coe *et al.* (1997) hypothesis that the effectiveness of foreign R & D is dependent on an economy's import capacity or conversely the effectiveness of technology imports in transmitting foreign technology is dependent on a country's foreign R & D.

As mentioned, imports of technology goods are defined as SITC code 7, a category that includes both machinery and transportation equipment. Mayer (2001) suggests that there may be differences in effectiveness between these broad import categories as far as per capita income growth is concerned. In order to explore further the impact of technology imports, we subdivide SITC code 7 into two categories: imports of machinery ($MMACH$) and imports of transportation equipment ($MTRANS$). In the next section, we examine separately the relevance of these two categories of imports for the growth of manufacturing TFP in developing economies.

Our discussion so far has concentrated on the impact of foreign technology on the growth of manufacturing TFP. This is the focus of this and previous studies in this area. In reviewing the literature, Helpman (1999) suggests that foreign technology contributes to domestic output (value added) growth not only by raising TFP growth but also by making it more profitable to invest in machines and equipment, thus raising capital accumulation and output. Therefore, we examine the impact of foreign technology directly on the growth of value added in the manufacturing sector by reestimating the model in (2) with $GMFD$ as the dependent variable. We also present these results in the next section.

4 Empirical Findings

We begin with a test for the null of stationarity assumed in our empirical model (2) using Park's (1990) $G(p, q)$ test.[15] Under the null of stationarity, the $G(p, q)$ test has an asymptotic chi-square distribution with $q - p$ degrees of freedom, after removing a maintained deterministic time trend of a polynomial of order p.[16] Kahn and Ogaki (1992) perform Monte Carlo experiments on the $G(p, q)$ test and conclude that a small q is advisable for small samples. Thus, we consider the$G(1, 2)$, $G(1, 3)$, and $G(1, 4)$ stationarity tests. In Table 1, we present

[15] Keller (2002) argues that whether a time series is deemed to be stationary or not depends on the level of heterogeneity in the data generation processes across industries that one allows for and suggests, following Edmond (2000), that assuming stationarity is closer to economic theory and intuition. While sympathetic to this point view, we believe that economic theory and intuition should be used to determine the priors regarding the appropriate null hypothesis for the problem at hand rather than to reach specific conclusions regarding the properties of the data.

[16] These tests are based on spurious regression results. Consider the regression $x_t = \sum_{t=0}^{p} \mu_\tau t^\tau + \sum_{t=p+1}^{q} \mu_\tau t^\tau + \eta_t$, where t represents a time trend. The maintained hypothesis is that variable x possesses deterministic time polynomials up to order p and additional time polynomials are spurious time trends.

probability values for the null of stationarity under Park's $G(1,3)$ test for the variables in (2). These probability values are similar to those obtained using either the $G(1,2)$ or $G(1,4)$ tests. A panel test that uses the Bonferroni bound implies that the null of stationarity cannot be rejected at the ten percent level of significance for either of the three tests. In general, using a Bonferroni bound one would reject the null hypothesis at the ten percent level of significance for a panel of n countries if one can reject the null hypothesis at the $10/n$ level of significance for any of the n countries.

Results from the estimation of the model in (2) are in Table 2. The first column of the table shows estimates of the specification in (2). In parentheses below each estimated coefficient is the t-ratio statistic with heteroskedasticity-consistent standard errors. Next to each coefficient in brackets are standardized (beta) coefficients.[17] All three variables measuring foreign technology transfer exert a significant effect on the growth of TFP of low and middle income economies. Of the three, the effect of foreign R & D is the largest in magnitude: a one standard deviation in foreign R & D increases TFP growth by 0.26 standard deviations. The effect is important in magnitude as well. For example, if Madagascar, the country with the lowest average foreign R & D intensity during the period (1.37%) were to increase this ratio to the average for the 32-country sample (1.56), it would have experienced an additional annual TFP growth of approximately 4 percent.

The remainder of Table 2 adds interaction effects to the model in (2). Column (2) includes an interaction effect between foreign R & D and schooling.

[17] In our sample, the average value of foreign R&D intensity, technology imports ratio, and the FDI ratio is equal to 1.56%, 21.6%, and 1.0% respectively. Standardized coefficients take into account the scale of measurement of the explanatory variables to make feasible a comparison of each explanatory variable's effect on the dependent variable. That is, they measure the change in the dependent variable (in standard-deviation units) from a unit change in each explanatory variable (in standard-deviation units), holding other variables constant.

The estimate of the interaction effect is highly significant indicating that the higher a country's level of schooling the greater the effect of foreign R & D on TFP growth. This result confirms the absorptive capacity hypothesis outlined in the previous section. In the same column we also present the total effect of foreign R & D on TFP growth (along with its t-statistic) that takes into account the interaction effect.[18] The total effect of foreign R & D is significant and this variable exerts the largest effect (in terms of standardized units) on TFP growth. Columns (3) and (4) examine the absorptive capacity hypothesis with respect to the other two channels of technology. There is a significant interaction between schooling and FDI in column (3). This is consistent with the results of Borensztein *et al.* (1998) and Xu (2000). At low levels of schooling the effect of FDI on TFP growth is negative and reverts to positive when the secondary enrollment rate reaches 18 percent. The total effect of FDI evaluated at the mean level of schooling is positive, though not significant. On the other hand, in column (4) the interaction effect between schooling and technology goods imports is insignificant, as is the total effect of technology goods imports.

Column (5) examines the Coe *et al.* (1997) hypothesis that the effect of foreign R & D also operates through its interaction with technology goods imports. Our results find no support for this hypothesis: the interaction effect is not significant. The total effect of foreign R & D is positive and marginally (in)significant while the total effect of technology imports is positive but not significant. This result, together with column (2), would appear to indicate that schooling is the relevant variable that interacts with foreign R & D. This is confirmed in column (6) where foreign R & D is interacted with both schooling

[18] The total effect is evaluated at the mean of schooling. For example, the model estimated in column (2) is $g_{it} = \beta + \beta_i + \beta_t + \sum_{k=1}^{K} \gamma_k FRD_{it-k} + \sum_{k=1}^{K} \delta_k MTEC_{it-k} + \sum_{k=1}^{K} \theta_k FDI_{it-k} + \sum_{k=1}^{K} \lambda_k FRD_{it-k} EDUC_{it-k} + e_{it}$. The total effect of FRD is equal to $\sum_{k=1}^{K} \gamma_k + \sum_{k=1}^{K} \lambda_k \overline{EDUC}_k$ where $\overline{EDUC}_k$ is the mean level of schooling for lag k.

and technology imports. While the former interaction effect is highly significant, the latter is insignificant.

In sum, the results in Table 2 indicate that foreign R & D is a consistently significant determinant of manufacturing TFP growth. This is the case when it is included without interaction effects (as in columns 1, 3, and 4) or with interaction effects (as shown by the total effect in columns 2 and 5). The evidence for the other two variables is mixed: when included without interaction terms they tend to be significant but the introduction of interaction effects renders the total effect insignificant. There is some evidence that the impact of FDI on TFP growth may operate with a longer lag.[19] We shall investigate further the impact of technology imports on TFP growth by decomposing these into two categories. Before we discuss this decomposition, however, we present the results for the growth of value added in manufacturing.

Table 3 reestimates the various specifications with growth in value added as the dependent variable. All three variables are highly significant determinants of value added growth in column (1). Results including interaction effects are broadly similar with those for TFP growth with the exception of the interaction between technology imports and schooling which is now (highly) significant and the interaction between FDI and schooling which is now (marginally) insignificant. A word on the magnitude of the estimated coefficients in Tables 2 and 3 is in order. The estimated coefficients for the foreign R & D intensity are roughly similar in magnitude in Tables 2 and 3, a result that would seem to indicate the impact of foreign R & D on value added is primarily by boosting TFP growth (Table 2) and any additional beneficial effects of foreign R & D on the productivity of individual factors of production (captured by the estimates

[19] Results (not reported here) with 3 and 5 lags for FDI show the effect becomes larger and significant as the number of lags for FDI increases.

in Table 3) are weak. On the other hand, the effects of technology imports and FDI on value added growth are much larger than their effect on TFP growth. This should hardly be surprising because both FDI and technology imports contribute directly to value added growth by raising domestic capital formation, as well as by increasing TFP and possibly the productivity of factors. The estimates in Table 3 include all the channels by which technology imports and FDI increase value added growth and are unable to distinguish between the various channels. Given that the estimates for FDI and technology imports in Table 3 are roughly twice those of Table 2, we hazard to guess that there is an even breakdown between the TFP effect and the addition to the domestic capital stock (and possibly the productivity of individual factors).

Next we investigate further the impact of technology imports on TFP growth by decomposing these into two categories: imports of machinery ($MMACH$) and transportation equipment ($MTRANS$). The results are in Table 4.[20] We note, first, that only imports of transportation equipment contribute significantly to the growth of TFP. This is true when no interaction effects are included, as in column (1), or by the total effect when technology imports are interacted with schooling, as in column (4). Second, in column (4), schooling interacts positively with imports of machinery but negatively with imports of transportation equipment. The positive interaction effect with machinery imports accords with intuition. The negative interaction with transportation imports is, perhaps, counterintuitive. We note, however, that when the total effect of transportation imports is evaluated at the mean value of schooling it is

[20] Imports of machinery are made up of SITC codes 71 (power generating machinery and equipment), 72 (machinery specialized for particular industries), 73 (metalworking machinery), 74 (general industrial machinery and equipment), 75 (office machines and automatic data processing equipment) 76 (telecommunications and sound recording apparatus) and 77 (electrical machinery). Imports of transportation equipment are made up of SITC codes 78 (road vehicles) and 79 (other transportation equipment). The results in Table 4 exclude three countries (Guatemala, Malawi and Tunisia) due to the unavailability of this decomposition.

positive and significant. The remainder of the results in Table 4 are similar to those of Table 2. In the case of Table 4, however, the import of transportation equipment is a significant determinant of TFP growth either with interaction effects (the total effect in column 4) or without interaction effects (columns 1,2, and 3). Moreover, the effect of FDI on TFP growth is also significant either with interaction effects (the total effect in column 3) or without interaction effects (columns 1,2, and 4).[21]

5 Conclusions

This paper investigates various channels by which foreign technology may be transferred to the manufacturing sector of low and middle-income economies. In particular, we look into whether the weighted foreign R & D intensity, technology imports and foreign direct investment are significant determinants of TFP and value added growth in the manufacturing sector of 32 developing economies. We find that the impact of foreign R & D on domestic productivity and value added growth is positive, and that imports of technology goods and foreign direct investment also play a positive, albeit often smaller, role. We also investigate several interaction effects and find that education interacts significantly with both technology imports and R & D in influencing value added growth and interacts significantly with R & D and FDI in influencing TFP growth.

[21] Results from the breakdown of capital goods imports on manufacturing value added growth are similar to those in Table 4 and are available from the authors upon request.

References

Aghion P. and P. Howitt, 1992, "A Model of Growth through Creative Destruction," *Econometrica*, 60, 323-51.

Aitken, B. J. and A. E. Harrison, 1999, "Do Domestic Firms Benefit from Direct Foreign Investment? Evidence from Venezuela," *American Economic Review*, 89, 605-18.

Bayoumi, T., D. T. Coe and E. Helpman, 1999, "R & D Spillovers and Global Growth," *Journal of International Economics*, 47, 399-428.

Bernanke, B. S. and R. S. Gürkaynak, 2001, "Is Growth Exogenous? Taking Mankiw Romer and Weil Seriously," *NBER Macroeconomics Annual*, 16, 11-57.

Borensztein, E., J. De Gregorio, and J-W Lee, 1998, "How Does Foreign Direct Investment Affect Economic Growth," *Journal of International Economics*, 45, 115-35.

Branstetter, L., 2001, "Is Foreign Direct Investment a Channel of Knowledge Spillovers? Evidence from Japan's FDI in the United States," NBER Working Paper No. 8015.

Coe, D. T. and E. Helpman,1995, "International R & D Spillovers," *European Economic Review*, 39, 859-87.

Coe, D. T., E. Helpman, A. W. Hoffmaister, 1997, "North-South R & D Spillovers," *Economic Journal*, 107, 134-49.

Connolly, M., 2001, "The Dual Nature of Trade: Measuring its Impact on Imitation and Growth," Manuscript, Duke University.

Dinopoulos, E., and P. Thompson, 1998, "Schumpeterian Growth Without Scale Effects," *Journal of Economic Growth*, 3, 313-35.

Eaton, J. and S. Kortum, 2001, "Trade in Capital Goods," *European Economic Review*, 45, 1195-1235.

Edmond, C., 2001, "Some Panel Cointegration Models of International R&D spillovers," *Journal of Macroeconomics*, 23, 241-260.

Glass, A. and K. Saggi, 1998, "International Technology Transfer and the Technology Gap," *Journal of Development Economics*, 55, 369-398.

Griffith, R., R. Stephen, and J. Van Reenen, 2000, "Mapping the two faces of R & D: Productivity Growth in a Panel of OECD Industries," Centre for

Economic Policy Research, Discussion Paper No. 2547.

Grossman G. and E. Helpman, 1991, *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, MA.

Haskel, J. E., S. C. Pereira, and M. J. Slaughter, 2002, "Does Inward Foreign Direct Investment Boost the Productivity of Domestic Firms?," NBER Working Paper No. 8724.

Helpman, E., 1999, "R&D and Productivity: The International Connection," in *The Economics of Globalization: Policy Perspectives from Public Economics*, Assaf Razin and Efraim Sadka (eds.), New York: Cambridge University Press.

Howitt, P., 1999, "Steady Endogenous Growth with Population and R & D Inputs Growing," *Journal of Political Economy*, 107, 715-30.

Howitt, P., 2000, "Endogenous Growth and Cross-Country Income Differences," *American Economic Revie*w, 90, 829-46.

Kahn, J.A., and M. Ogaki, 1992, "A Consistent Test for the Null of Stationarity against the Alternative of a Unit Root," *Economic Letters*, 39, 7-11.

Keller, W., 2002, "Trade and the Transmission of Technology," *Journal of Economic Growth*, 7, 5-24.

Kocherlakota, Narayana, and Kei-Mu Yi, 1997, "Is There Endogenous Long-Run Growth? Evidence from the United States and the United Kingdom," *Journal of Money Credit and Banking*, 29, 235-62.

Larson, D. F., R. Butzer, Y. Mundlak, and A. Crego, 2000, "A Cross-Country Database for Sector Investment and Capital," *The World Bank Economic Review*, 14, 371-91.

Mayer, J., 2001, "Technology Diffusion, Human Capital and Economic Growth in Developing Countries," UNCTAD Discussion Paper No. 154.

Navaretti, G. B. and D. G. Tarr, 2000, "International Knowledge Flows and Economic Performance," *The World Bank Economic Review*, 14, 1-15.

Nelson, R. R. and H. Pack, 1999, "The Asian Miracle and Modern Growth Theory," *Economic Journal*, 109, 416-36.

Nelson, R. R. and E. Phelps, 1966, "Investment in Humans, Technological Diffusion, and Economic Growth," *American Economic Review*, 56, 69-75.

Organisation for Economic Co-Operation and Development, 2002, International Trade by Commodity Statistics, available at: *http://www.Sourceoecd.org*

Parente, S. and E. Prescott, 2000, *Barriers to Riches*, Cambridge MA: MIT Press.

Park, J. Y., 1990, Testing for Unit Roots and Cointegration by Variable Addition, *Advances in Econometrics*, 8, 107-133.

van Pottelsberghe de la Potterie, B. and F. Lichtenberg, 2001, "Does Foreign Direct Investment Transfer Technology Across Borders?," *Review of Economics and Statistics*, 83, 490-497.

Rivera-Batiz, L. and P. M. Romer, 1991, "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, 106, 531-55.

Romer, P. M., 1990, "Endogenous Technological Change," *Journal of Political Economy*, 98, 71-102.

Segerstrom, P., T. C. A. Anant and E. Dinopoulos, 1990, "A Shumpeterian Model of the Product Life Cycle", *American Economic Review*, 80, 1077-92.

Segerstrom, P., 2000, "The Long-Run Growth Effects of R & D Subsidies," *Journal of Economic Growth*, 5, 277-305.

United Nations Educational, Scientific and Cultural Organization (UNESCO), 2001, *The State of Science and Technology in the World*, UNESCO: Institute of Statistics.

United Nations Industrial Development Organization (UNIDO), 2001, *Industrial Statistics Database*, CD-Rom.

Xu, B., 2000, "Multinational Enterprises, Technology Diffusion, and Host Country Productivity Growth," *Journal of Development Economics*, 62, 477-93.

Xu, B. and J. Wang, 1999, "Capital Goods Trade and R&D Spillovers in the OECD," *Canadian Journal of Economics*, 32, 1258-74.

Table 1: P VALUES FOR STATIONARITY
NULL: PARK (1990) G(1,3) TEST

Country	**FRD**	**MTEC**	**FDI**	**GTFP**	**GMFD**
Chile	0.121	0.097	0.254	0.142	0.165
Colombia	0.115	0.074	0.171	0.349	0.088
Costa Rica	0.147	0.167	0.012	0.286	0.393
Cyprus	0.312	0.089	0.045	0.377	0.774
Ecuador	0.131	0.194	0.280	0.146	0.045
Egypt	0.506	0.608	0.159	0.248	0.236
El Salvador	0.120	0.695	0.475	0.546	0.113
Greece	0.171	0.030	0.185	0.054	0.165
Guatemala	0.097	0.251	0.965	0.916	0.364
India	0.219	0.086	0.079	0.255	0.834
Indonesia	0.356	0.099	0.034	0.322	0.170
Iran	0.149	0.106	0.594	0.019	0.037
Iraq	0.076	0.473	0.469	0.633	0.324
Jamaica	0.097	0.244	0.138	0.055	0.465
Kenya	0.215	0.547	0.781	0.039	0.934
Madagascar	0.224	0.778	0.015	0.299	0.399
Malawi	0.042	0.761	0.036	0.273	0.039
Malta	0.191	0.124	0.092	0.464	0.467
Mauritius	0.058	0.464	0.572	0.099	0.549
Pakistan	0.161	0.223	0.065	0.098	0.436
Philippines	0.119	0.275	0.853	0.639	0.455
Portugal	0.329	0.130	0.158	0.152	0.259
S. Africa	0.111	0.156	0.166	0.146	0.406
S. Korea	0.264	0.309	0.545	0.122	0.389
Sri Lanka	0.110	0.268	0.534	0.118	0.172
Syria	0.232	0.333	0.163	0.488	0.580
Taiwan	0.064	0.016	0.352	0.281	0.907
Trinidad	0.083	0.147	0.081	0.339	0.257
Tunisia	0.107	0.246	0.657	0.622	0.049
Turkey	0.101	0.141	0.111	0.147	0.479
Venezuela	0.103	0.035	0.048	0.726	0.112
Zimbabwe	0.092	0.042	0.051	0.025	0.542

Table 2: DETERMINANTS OF MANUFACTURING TFP GROWTH

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
FRD	21.21 [.26]	10.88	19.03 [.23]	19.63 [.24]	25.05	18.82
	(2.49)**	(1.11)	(2.23)*	(2.28)**	(1.94)*	(1.41)
MTEC	.255 [.10]	.242 [.10]	.215 [.09]	.174	.554	.837
	(1.79)*	(1.72)*	(1.52)	(1.02)	(.87)	(1.29)
FDI	1.062 [.10]	1.229 [.12]	-.869	1.075 [.10]	1.077 [.10]	1.263 [.12]
	(1.63)*	(1.83)*	(-.73)	(1.64)*	(1.66)*	(1.87)*
FRD×*EDU*		11.71				12.44
		(2.59)***				(2.71)***
FDI×*EDU*			4.817			
			(1.80)*			
MTEC×*EDU*				.223		
				(.89)		
FRD×*MTEC*					-19.99	-40.25
					(-.48)	(-.95)
FRD (total impact)		16.15 [.25]			20.69 [.28]	15.69 [.28]
		(1.65)*			(1.60)	(1.18)
FDI (total impact)			1.214 [.01]			
			(1.02)			
MTEC (total impact)				.257 [.09]	.222 [.22]	.189 [.33]
				(1.50)	(.31)	(.29)
R^2	.259	.266	.262	.262	.262	.269
No. Obs.	675	675	675	675	675	675

Notes: Reporting t-tests of the hypothesis that the parameter equals zero in parentheses and standardized coefficients in square brackets. * p-value<0.10, ** p-value<0.05, *** p-value<0.01

Table 3: Determinants of Manufacturing Output Growth

	(1)	(2)	(3)	(4)	(5)	(6)
FRD	20.48 [.19]	5.561	18.46 [.18]	15.79 [.15]	33.30	23.76
	(2.11)**	(0.50)	(1.88)*	(1.61)	(1.91)*	(1.37)
MTEC	.575 [.18]	.555 [.17]	.226 [.17]	.256	1.460	1.866
	(2.55)**	(2.47)**	(2.39)**	(1.11)	(1.64)*	(2.00)**
FDI	2.061 [.15]	2.297 [.16]	-.101	2.146 [.15]	2.095 [.15]	2.366 [.17]
	(2.38)**	(2.59)**	(-.08)	(2.45)**	(2.42)**	(2.67)***
FRD×*EDU*		16.66				18.34
		(2.99)***				(3.35)***
FDI×*EDU*			5.330			
			(1.58)			
MTEC×*EDU*				.817		
				(2.57)***		
FRD×*MTEC*					-59.61	-88.37
					(-.98)	(-1.39)
FRD (total impact)		12.88 [.18]			20.39 [.26]	12.64 [.26]
		(1.17)			(1.17)	(.73)
FDI (total impact)			2.258 [.08]			
			(1.76)*			
MTEC (total impact)				.594 [.15]	.496 [.45]	.447 [.57]
				(2.59)***	(.56)	(.48)
R^2	.307	.313	.310	.311	.313	.321
No. Obs.	689	689	689	689	689	689

Notes: Reporting t-tests of the hypothesis that the parameter equals zero in parentheses and standardized coefficients in square brackets. * p-value <0.10, ** p-value<0.05, *** p-value<0.01

Table 4: Determinants of Manufacturing TFP Growth

	(1)	**(2)**	**(3)**	**(4)**
FRD	30.11 [.33]	13.01	32.11 [.36]	23.21 [.26]
	(2.65)***	(1.01)	(2.75)***	(1.96)**
MMACH	-.247 [-.06]	-.289 [-.07]	-.386 [-.10]	-.964
	(-.94)	(-1.09)	(-1.47)	(-2.55)**
MTRANS	1.375 [.25]	1.394 [.25]	1.455 [.26]	2.284
	(3.14)***	(3.18)***	(3.24)***	(3.46)***
FDI	3.232 [.27]	3.494 [.29]	-1.012	3.195 [.26]
	(2.56)**	(2.66)***	(-.56)	(2.50)**
FRD×*EDU*		17.49		
		(3.28)***		
FDI×*EDU*			11.26	
			(2.69)***	
MMACH×*EDU*				1.509
				(3.09)***
MTRANS×*EDU*				-1.689
				(-2.11)**
FRD×*MMACH*				
FRD×*MTRANS*				
FRD (total impact)		20.94 [.30]		
		(1.62)		
FDI (total impact)			4.058 [.12]	
			(2.25)**	
MMACH (total impact)				-.318 [-.12]
				(-.84)
MTRANS (total impact)				1.525 [.32]
				(2.31)**
R^2	.328	.337	.339	.337
No. Obs.	464	464	464	464

Notes: Reporting t-tests of the hypothesis that the parameter equals zero in parentheses and standardized coefficients in square brackets. * p-value <0.10, ** p-value<0.05, *** p-value<0.01