14

Technology Diffusion and Productivity: Evidence from the South African Manufacturing Sector

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Declaration

This work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work. Each significant contribution to, and quotation in, this dissertation from the work, or works, of other people has been attributed, and has been cited and referenced.

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Table of Contents

List of Figures

List of Tables

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IZAK ODENDAAL

Abstract

This paper builds on a growing literature on trade-related international technology diffusion. It examines whether South Africa can enhance its productivity by importing machinery and equipment that embodies foreign knowledge from trading partners that do significant amounts of research and development. The focus is on South Africa's manufacturing sector. Furthermore, the paper also examines the role of human capital in the facilitation of the effective adoption of foreign technology. Using trade data from 1976 to 2001 – imports from the European Union, industrialized countries and 'advanced' developing countries - the relationship between capital imports and total factor productivity growth and human capital is analysed using the autoregressive distributed lag (ARDL) approach to cointegration. The results show that there is evidence of an equilibrium relationship between the variables; that foreign technology spillovers have taken place in the manufacturing sector, and that the effect on productivity is enhanced by the presence of quality human capital.

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1. Introduction

Different levels of productivity across countries are a critical determinant of the differences in national incomes that are such a central feature of the modern world. Variation in incomes across countries cannot be reasonably explained by factor accumulation alone (Easterly and Levine, 2000). Understanding the sources of productivity differences is thus clearly important. Technology is one of these sources often emphasised. The bulk of technology is developed in industrialised countries, most of it in the G7 (Coe et al, 1997). It follows that international productivity differences are, to an important extent, determined by the process of international technology diffusion (Keller, 2004).

This process of international technology diffusion is itself determined by a number of factors and occurs through a number of channels. One of these is of course international trade. In neoclassical growth models, trade does not affect the equilibrium growth rate of an economy since technological progress occurs exogenously. Endogenous growth theory, however, tries to explain technological change and to incorporate the impact of trade. In these models, trade can have a number of generalised positive impacts, providing channels that link productivity levels in different countries. Three channels are especially prominent (Grossman and Helpman, 1991; Coe *et al*, 1997). Firstly, a country can improve its productivity through the import of a range of intermediate products and capital equipment that are superior inputs into the production process. Secondly, trade allows trading partners to learn from one another about production and organisational design, market conditions and the like. Thirdly, international contacts facilitate the imitation of foreign technology and subsequent adaptation for local use.

In short, through international trade a country has access to *goods* that embody foreign knowledge and has access to information. This gives rise to spillovers to the extent that the goods cost less than their opportunity costs, namely R&D costs. Trade also allows access to people (although probably to a lesser extent) that are important in the technological diffusion process. This is because technology is to a considerable extent 'tacit' or non-codified. This tacit information can only be transferred through person-to-person instructions and demonstrations (Keller, 2004). It follows then that by trading with more developed countries, less developed countries can enhance productivity, and thus growth, in ways that would otherwise not have been possible. And the bigger the stock of knowledge in a developing country's trading partner, the more it will stand to benefit from trade.

Clearly, developing countries face constraints not just in producing technology, but also in identifying, adopting, adapting and learning from implementing foreign technology. Chief among these constraints is human capital, although other factors are also mentioned below. In developing countries, human capital has the role of facilitating the absorption of foreign technology (as opposed to original research and development). It is thus not treated as a separate factor of production as such. The paucity of the requisite skills in developing countries, including South Africa, is unfortunately a well-known phenomenon and is considerably exacerbated by the outflow of educated people (the so-called 'brain-drain').

While the relationship between trade, technological change and growth has been investigated in cross-sectional studies (De Long and Summers (1993), Coe *et al* (1997), Keller (1998), Mayer (2001)), the contribution of the present paper is to look for dynamic evidence in the context of a middle-income country, namely South Africa. In particular, this paper will employ machinery and equipment imports as a measure of technology transfer. Coe *et al* (1997) and Mayer (2001) have shown that developing countries' openness to imports of machinery and equipment allow them to achieve faster growth in total factor productivity through access to the R&D of the world's technology leaders, contingent on there being sufficient stocks of domestic human capital to implement these technologies. That hypothesis is tested here for the South African manufacturing sector.

The structure of the paper is as follows: Section 2 presents a theoretical framework within which the role of technology transfer via imports and human capital in total factor productivity can be examined. Section 3 provides background information on total factor productivity growth in South Africa. Section 4 focuses on the manufacturing sector. Section 5 discusses the data and Section 6 presents the estimation results of regressions employing Pesaran, Smith and Shin's (1996) autoregressive-distributed lag (ARDL) approach to cointegration. Some concluding remarks are provided in Section 7.

2. Theory

Globalisation (and particularly increased international trade) has improved the ability of less developed nations to access the international technology frontier. However, absorbing this technology requires, first and foremost, human capital. This interaction of human capital and technology in productivity growth can be shown in simple formal presentation of Mayer (2000, 2001), which in turn builds on that of Nelson and Phelps (1966):

$$\frac{\dot{A}(t)}{A(t)} = \phi(H)\left[\frac{T(t) - A(t)}{A(t)}\right] \quad (1)$$

In this model, A represents the level of technology in the developing country under consideration, while T is the world level of best practice technology. The speed at which a developing country can adopt technology developed in the industrialised countries is a positive function of its level of human capital H and is proportional to the gap between its level of technology and that of the industrialised countries.

If technology in the industrialised countries grows exogenously at φ per cent annually, such that $T(t) = T_0 e^{\varphi t}$, and $A_0 = 0$, then the equilibrium path of the follower country is given by:

$$A(t) = \left[\frac{\phi(H)}{(\phi(H) + \varphi)}\right] T_0 e^{\varphi t} \quad (2)$$

In other words, the potential level of technology that is used in the follower (developing) country will depend on its own level of human capital and on the technological improvement in the leader (developed) countries that becomes available to it. An increase in the stock of human capital will not have an effect on output generated with conventional inputs, unless technology is continuously improving

(Mayer, 2000; Nelson and Phelps, 1966; Lucas, 1993). In this view, skill accumulation thus depends on the amount of new technology introduced, particularly assuming the existence of a technology ladder, i.e. that the production of goods is ordered by increasing technical sophistication. The introduction of a new technology can, depending on its sectoral bias, alter the structure of production in terms of its sectoral composition, and cause a movement up the technology ladder.

Following Rogers (2004), $\phi(\bullet)$ can be more generally interpreted as a function representing the 'absorptive capability' of technology of a follower country. This capability depends not only on being able to adopt and imitate (associated with educational levels and research skills) but also on the ability to access to foreign technology. It also depends on the incentives firms have to implement the foreign technology domestically. Accessibility to foreign technology, as said above, improves greatly with trade links and thus with openness to trade. Thus Harding and Rattso (2005) interpret $\phi(\bullet)$ as a barrier to technology adoption.[1] Either way, the ability to pay for imports with export earnings is important – many developing countries are subject to balance of payments constraints (Mayer, 2000).

Identifying and accessing foreign technology also depends, however, on social and educational links (language similarities for instance), and foreign direct investment (FDI). The role of FDI in transferring technology is often emphasised, also by governments, who provide (often lucrative) incentives to attract multinational enterprises. While the role FDI is outside the scope of this paper (see Keller (2004) for a discussion of the FDI literature), it suffices to say that the extent of FDI-related technology spillovers will also depend on a host of similar factors.

The distance between two countries is another factor that can influence technology diffusion from the one to the other. While this effect will be lessened as transport and communication improvements lead the globalisation process, evidence from the

[1] More specifically, Harding and Rattso (2005) regress growth in TFP of South African manufacturing on tariff levels (as a measure of trade policy), and find a statistically significant negative relationship. In their study, the world technology frontier is measured by US manufacturing labour productivity and is included as an explanatory variable. Their finding is that the long-run coefficient between South African TFP and the world technology frontier is about one, but that growth in SA TFP is explained by reduced tariffs.

literature suggests that distance is still important (Keller, 2004). For instance, Schiff and Wang (2003) find that Mexico experienced substantial and statistically significant productivity gains due to its trade with the US and Canada. Gains from trade with other OECD countries were not significant. This, they argue, is because trade involves not only exchanges of goods but also other forms of interaction, such as sub-contracting, the effects of which decline with distance. The localised nature of technology spillovers thus carries a negative implication for income convergence (Keller, 2004). The distance between South Africa and the G7 countries carries potentially similar negative implications, but this is not examined here any further.

Rogers (2004) also stresses the importance of the incentives to implement new technologies. From a microeconomic perspective, this will depend on the existence of property rights and the enforcement of contracts (and thus also on the rule of law in general). Furthermore, the regulatory and taxation environments are also important. On the macroeconomic side, low real interest rates and the stability of the exchange rate should also tend to enhance incentives to implement new technology. The quality of local infrastructure (often proxied by telephones per 100 population as in Rogers, 2004) would also improve absorptive capacity of foreign technology. Political stability is another factor, as is the security environment where high crime rates impose a range of costs.

International technology diffusion involves both market transactions and spillovers, with the former being relatively easy to measure and the latter relatively difficult. One method is to employ international R&D spillover regressions – relating R&D of one country/sector/firm to TFP in another (Keller, 2004). Along this line of inquiry, Coe and Helpman (1995) has been an important and influential paper linking foreign R&D with domestic productivity growth through imports. They construct a variable for the 'foreign stock of knowledge' of a given country – the cumulative R&D spending in the country's trading partners, weighted by bilateral import shares. They then test for, and find, R&D spillovers from the G7 to other OECD countries. In Coe *et al* (1997), this analysis was extended to test for trade-related R&D spillovers from developed to developing countries. To this end, a measure of the openness to trade with the industrial countries, defined as the GDP ratio of imports of machinery and equipment, was added. They then regress total factor productivity (A) on this measure (M), together with a measure for foreign R&D stock (*S*), and a human capital variable (*E*; high school enrolments).

$$\text{Log } A_{it} = \alpha_i^0 + \alpha_i^S \log S_{it} + \alpha_i^M M_{it} + \alpha_i^E E_{it} + \mu_{it} \qquad (3)$$

Mayer (2001) observes that there has been some debate over whether or not it is necessary to use bilateral imports as weights on the foreign capital stock term *S*, as in Coe *et al* (1997). He also argues that it is in fact not necessary to include the *S* term, as it represents the world technology stock that is the same for all developing countries. "[I]t matters for a developing country how much technology it imports from the technologically more advanced countries, but it is unimportant whether it imports 50 per cent from the United States and 30 per cent from Japan, or the other way round."

From a Cobb-Douglas function, that treats human capital as affecting productivity instead of as an input factor – $Y_t = A_t(H_t)K_t^{\alpha}L_t^{\beta}$ – Mayer (2001) presents the following model,

$$\text{Log } A_{it} = \alpha_i^0 + \alpha_i^M M + \alpha_i^H H_{it} + \alpha_i^{HM} HM_{it} + \mu_{it} \qquad (4)$$

where *M* also represents the GDP ratio of imports of machinery and equipment and *H* human capital. In this specification, technology transfer is measured as the interaction of human capital and technology imports *H*M*, the argument being that imported machinery and equipment will only enhance productivity when the labour force is skilled enough to use it efficiently.

If one assumes that the role of human capital in a developing country is solely to implement imported technology – not to develop new technology from scratch – the TFP equation can be amended as follows, providing another testable equation:

$$\text{Log } A_{it} = \alpha_i^0 + \alpha_i^{HM} HM_{it} + \mu_{it} \qquad (5)$$

3. The Growth Structure of the South African Economy

Du Toit *et al*, (2004) presents evidence showing that structural adjustments have taken place in the South African economy, and that this is specifically true of the underlying the production structure. Technological change has become the 'engine' of economic growth. Du Toit *et al* (2004) decompose growth in the economy to the contribution of factors, first assuming constant returns to scale and then decreasing returns. They find that the relative contribution of technology has increased over the last three decades with the contribution of capital and labour declining. The relative contribution of labour to growth has actually been negative in the 1990s, mirroring the result in Fedderke (2002). Assuming decreasing returns also renders the finding that the contribution of technology has increased since the 1970s and has been particularly strong in the 1990s. This Du Toit *et al* (2004) attribute to policy and institutional changes during that period. These include policies for social upliftment – focusing on education, health, crime and infrastructure – and increased access to world markets and economies. Arora and Bhundia (2003) find that an increase in trend GDP growth after 1994 is attributable to higher TFP growth which is in turn attributable to trade liberalisation and greater private sector participation.

However, the evidence relating to the aggregate economy hides important sectoral differences (Fedderke, 2002). Harberger (1998) argues that total factor productivity growth tends to be concentrated in specific sectors. Other sectors contain productivity "winners" and "losers" that tend cancel each other out in the aggregate. Thus, technological progress is a "mushroom" process, rather than a "yeast" process infusing all sectors and affecting them equally.

Accordingly, a study such as that of Coe *et al* (1997) where TFP growth for the economy as a whole is used as dependent variable is likely to encounter aggregation problems. Some industries are likely to experience productivity growth, others might suffer losses. Similarly, the time-series regressions in Jonsson and Subramanian (2000) may be seen as problematic: TFP growth for the whole South African economy is regressed on trade openness variables. For this reason, the present study uses as dependent variable TFP in the South African manufacturing industry.[2] In doing so, the heterogeneity problem is not solved – productivity performance differs also at the three and four digit level – but is considerably lessened. Manufacturing is the sector of the economy where imported machinery technological spillovers are likely to have the largest effect on productivity.

4. The Manufacturing Sector

Manufacturing is a very important sector of South Africa's economy, contributing in the region of 18.5% of gross domestic product and 50% of exports. It is also the second largest employer in the country. And yet, there are signs that over the last decade, the manufacturing sector has underperformed, especially regarding employment creation and export growth (NACI, 2003). Fedderke's (2002) study examines the performance of the key sectors of the South African economy. His findings echo the mushroom versus yeast view of the technology growth process for South Africa. The contribution of technology growth has been the most consistent in the agricultural sector throughout the 1970s, 1980s and 1990s. In the mining sector, the contribution of technology has improved in the 1990s coming off very low growth in the previous two decades. The same is true for the service sector. The performance of the manufacturing sector, however, has been the poorest when it comes to technological progress.

Considering the manufacturing sector by itself, Fedderke (2002) finds that the correlation between output growth and TFP growth was stronger than the correlation between output growth and growth in capital and labour in the 1970s and 1980s. In the 1990s, the correlation between growth in the capital stock and output growth is the strongest. There is thus evidence of a structural break in the nature of growth in the manufacturing sector. His implication is that the manufacturing (three digit) sectors that experienced high rates of output growth in the 1970s and 1980s were also likely to be strong technological innovators. In the 1990s, however, sectors with strong output growth were those with expanding stocks of capital. The explanation put forward for this is that during the 1970s and 1980s, capital markets were highly

[2] The alternative modelling approach would of course be a panel analysis of the different sectors of the economy of a single country (Fedderke, 2001, Schiff and Wang, 2003), or as in Schiff, Wang and Olarreaga (2001), where a panel is set up covering 16 manufacturing sectors across 25 countries.

distorted due to government interventions. During the 1990s capital markets have become more liberalised causing a reallocation of capital away from sectors with strong state involvement towards manufacturing. He also points out that South Africa's isolation in the 1970s and 1980s prevented firms from accessing international technological improvements, effectively forcing them to be more innovative.

It must be noted that Wakeford (2004) finds Fedderke's (2002) result that total factor productivity growth in the manufacturing sector was negative in the 1980s and 1990s implausible given South Africa's recent shift towards high-technology manufactured exports and the role of the 'information revolution'. His explanation for this counter-intuitive result is that "a large portion of technology is embedded in capital equipment," especially in the manufacturing sector. He argues that while Fedderke (2002) takes differences in the quality of labour inputs into account by disaggregating by skill level, no such adjustment is made for changes in the quality of capital inputs.

Nevertheless, there are other signs of productivity problems in manufacturing. In an international comparison, for instance, Van Dijk (2003) found that there is a considerable (labour) productivity gap between South Africa and the United States and that this gap has widened over time. He also suggests that South African manufacturing is uncompetitive relative to other middle-income countries. Edwards and Golub (2003) also find that growth in both TFP and labour productivity has been weak in the manufacturing sector in the 1980s and 1990s, specifically relative to the Asian 'tigers' and other developing countries. Manufacturing value added (MVA) in South Africa has also grown comparatively slowly in the 1990s (Kaplan, 2003). The upshot is that the productivity of the South African manufacturing sector has been both weak and inconsistent.

The policy response has come in the form of the Department of Trade and Industry's (the dti) Integrated Manufacturing Strategy (IMS), and the Department of Science and Technology's National Research and Development Strategy (NRDS) and Advanced Manufacturing Technology Strategy (AMTS). These strategies call for a shift in focus to high technology manufacturing, specifically to improve international competitiveness. Over the past decade, the high technology segment of the manufacturing sector has consistently outgrown the medium and low technology sectors. Improving technology intensity requires increased technology spending per capita, including domestic R&D and foreign technology imports. This will require greater collaboration between different sectors and disciplines. To this end the AMTS calls for sets of facilitating mechanisms that perform a generic function or that support sector-specific initiatives. The strategy will be implemented through Innovation centres (existing and new), Innovation Networks and specific projects. (NACI, 2003).

5. Data and Variables

The variable measuring technology transfer, *M*, is defined as the GDP ratio of machinery and equipment imports with the trade data sourced from COMTRADE for the years 1976 – 2001 and the GDP data from the IMF's World Economic Outlook. Because of missing observations in South African import data, imports are measured from the country of origin (i.e. as exports from the developed countries to South Africa).

Mayer's (2001) paper builds on that of Coe *et al* (1997) in the sense that technology diffusion in developing countries is measured in a cross-country study as the GDP ratio of machinery and equipment imports. His analysis, and the approach followed here differs from Coe *et al* (1997) in three respects. Firstly, Mayer (2001) does not weight the technology imports of developing countries according the domestic R&D stocks of their trading partners for the reasons alluded to above.

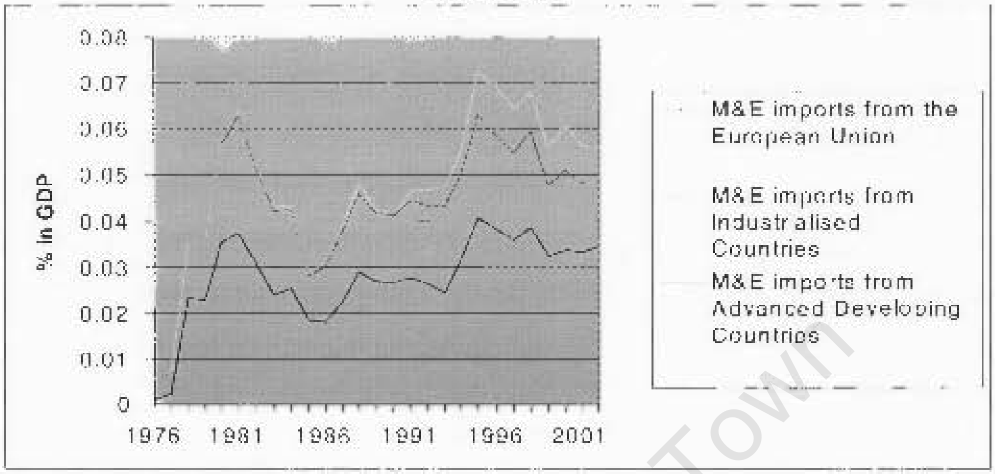
Secondly, he takes technology imports from more advanced developing nations into account, while Coe *et al* (1997) focuses only on imports from industrialised countries. Including imports from more advanced developing countries makes sense if one considers that such countries would have, to some extent, adapted technology from the industrialised countries for use in a less technologically sophisticated environment. In this paper *M* is sourced from three groups of countries (1) the European Union (15 pre-2004 members) as South Africa's largest trading partner, (2) the Industrialised countries[3] (including the EU), and (3) the countries in group (2) as well as a group of advanced developing countries[4].

Thirdly, for their *M* variable, Coe *et al* (1997) use machinery and transport equipment aggregates (section 7 of SITC rev.2 as a whole). Mayer (2001) on the other hand proposes a finer breakdown of the data for the following reasons: Parts of machinery and equipment imports - e.g. television sets and household-type equipment – should rather be considered as consumption goods. Moreover, several items in the machinery and equipment category are classified as 'parts and components' that developing countries import only to be exported again (without necessarily adding much value).

More specifically, four such items stand out: parts of office machines, telecommunications equipment, switch gear, and transistors and semi-conductors. Thus the present study considers both machinery and equipment imports[5] (as in Coe *et al*) and the narrower category of 'machinery'[6].

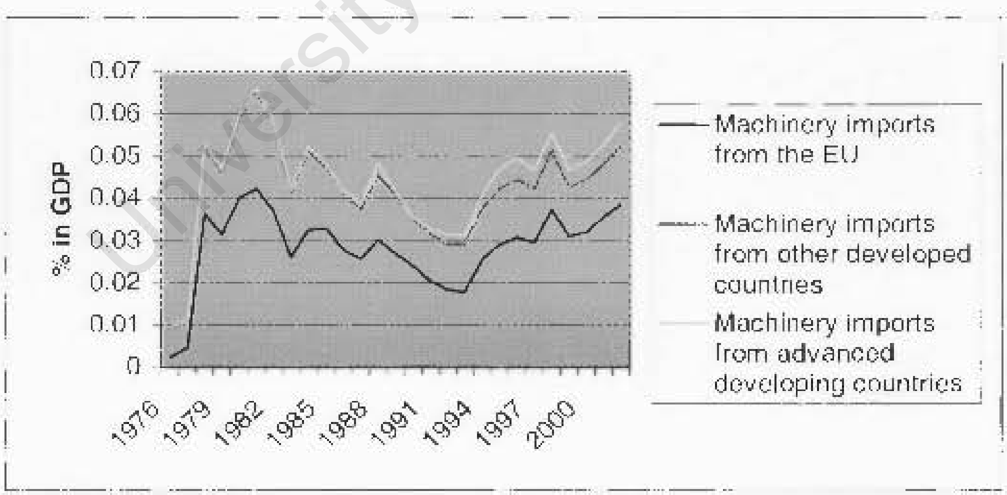
[3] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States. In the cointegration tests in Appendix A, this group is labelled 'IND'.
[4] Argentina, Brazil, Chile, China Hong Kong, India, Indonesia, Korean Republic, Malaysia, Mexico, Pakistan, Singapore, Taiwan, Thailand, Turkey, Venezuela. In the cointegration tests in Appendix A these countries, together with the above, are labelled 'ALL'.
[5] SITC review 2, section 7.
[6] SITC review 2, section 71 – 77, less 761-3 and 775 - 776

Figure 1
GDP-ratio of South African machinery and equipment imports, 1976 -2002



Source: COMTRADE
Note: Each group of countries in the graph includes the group below it, such that imports from advanced developing countries should be read as the difference between the top two lines.

Figure 2
GDP – ratio of South African machinery imports, 1976 -2002



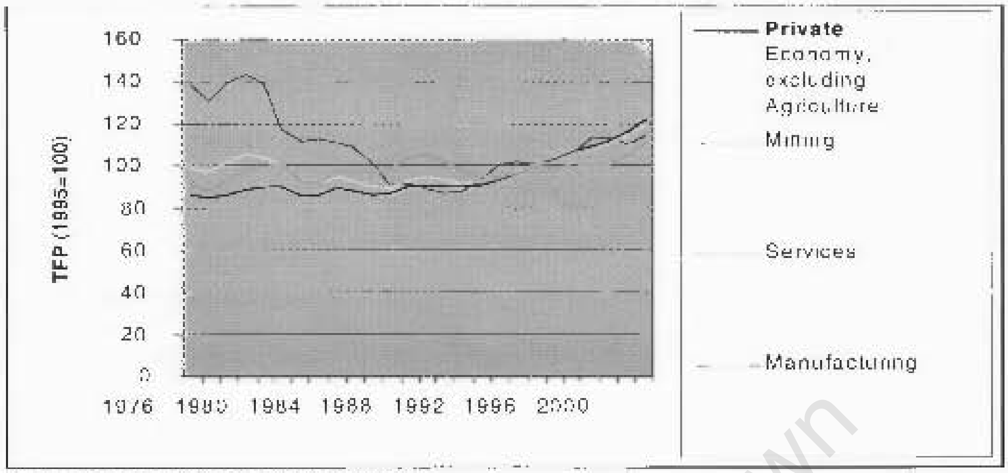
Source: COMTRADE
Note: Each group of countries in the graph includes the group below it, such that imports from advanced developing countries should be read as the difference between the top two lines

Figure 1 shows the GDP ratio of South African machinery and equipment imports for the period 1976 – 2001. These imports are distinguished in terms of their regions of origin. From the graph, one can see that these imports rose substantially in the late 1970s, only to fall again in following years. They then pick up again in the late 1980s. The figure also shows that imports of machinery and equipment from technologically more advanced developing countries have increased over the course of the last decade. This is consistent with Mayer's (2001) finding that developing country machinery imports from middle income countries have increased in importance. Figure 2 tells roughly the same story, this time for general machinery imports.

A discussion of imports would not be complete without examining changes in South Africa's trade patterns, given the country's history of relative international isolation as well as the much vaunted liberalisation of the past decade. Fedderke and Vaze (2001) calculate effective protection rates (ERPs) – looking at the tariff structure of the output of a sector as well as the protection of its inputs – for the major sectors of the South African economy. They find that the machinery and equipment sector experienced little or no change in its ERP in the course of the 1990s.[7] Regarding import penetration – value of imports divided by value of sales – they find that import penetration has been high and rising in technology sectors, including machinery and equipment. They also consider the openness ratio – exports and imports to total output – and find strong sectoral differences, pointing to structural changes in the economy in the 1990s. The machinery and equipment sector experienced 10,25 per cent growth in openness during the 1990s, and 4,75 per cent over the last three decades.

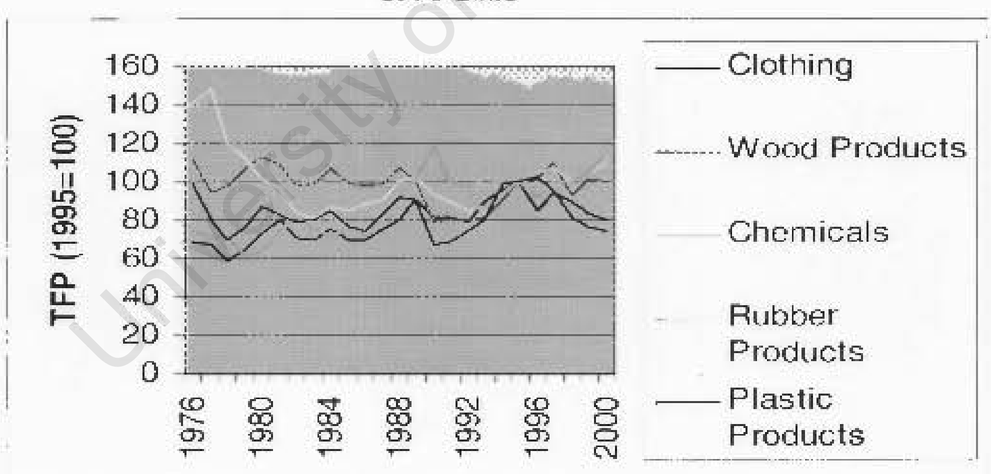
[7] Note, however, that Fedderke and Vaze (2001) use the SIC version 3 classification of sectors, while the data in the present paper is categorised according to SITC version 2.

Figure 3
Selected Total Factor Productivity Indices, 1976 –2001



Source: National Productivity Institute

Figure 4
Total Factor Productivity Indices for Selected Manufacturing Sectors, 1976-2001



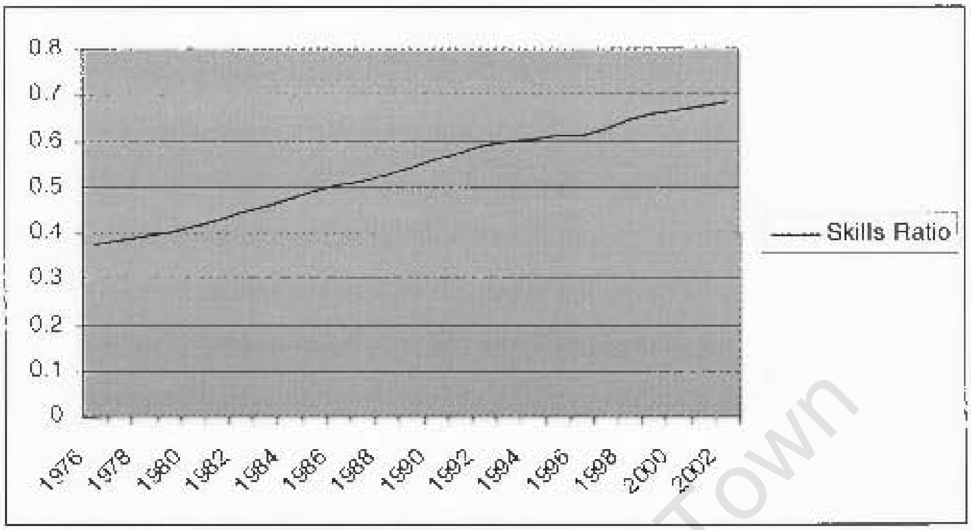
Source: National Productivity Institute

As discussed above, the dependant variable is TFP[8] of the South African manufacturing sector and is from the National Productivity Institute. It is entered into the regressions in natural log form. Figure 3 compares manufacturing TFP with that of other sectors such as mining and services as well as with the private economy as a whole (excluding agriculture). Figure 4 shows TFP for selected manufacturing sectors. Both graphs indicate the variation in productivity growth that is hidden in aggregate measures (see above). The variable *K*, defined as the capital-output ratio minus *M*, is included to control for the contribution of capital beyond what is implied by its income share (Fedderke, 2001 and De Long and Summers, 1993). The data are from the SARB Quarterly Bulletin.

Finally, the human capital variables: the ratio of highly skilled and skilled to unskilled and semi-skilled labour in the manufacturing sector is denoted as *SKRAT* and is calculated using data from the Trade and Industrial Policy Strategies (TIPS) database. Figure 5 shows the skills ratio increasing quite strongly over time. Figure 6 suggests that the increasing skills ratio is (at least partly) due to the shedding of unskilled labour in the manufacturing sector, especially during the 1990s. The number of natural and engineering science degrees awarded annually by South African Universities, *NESDEG*, is included to test for human capital spillovers. This series is from Du Toit *et al* (2004) who extended the series from Fedderke *et al* (2003) to the year 2000. It is entered into the regressions in natural log form. ADF tests were performed on all the variables and the results are shown in Appendix B.

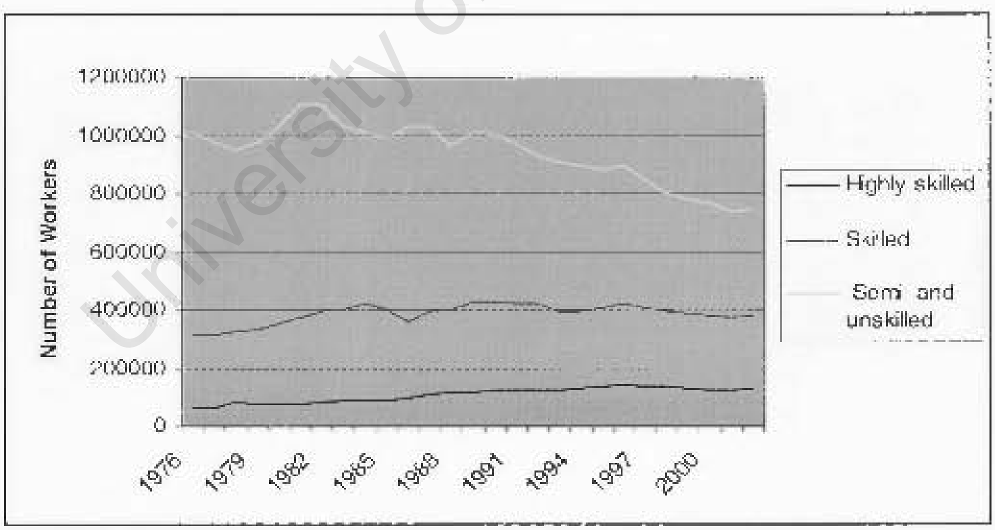
[8] The use of a TFP variable, while standard, is not without its shortcomings. As discussed in Fedderke (2001) and Harding and Rattso (2005), the main challenge is the endogeneity of factor inputs and the fact that factor inputs are not disaggregated by quality classes. Despite these shortcomings, the predominant approach in the literature is growth accounting decomposition approach.

Figure 5
Skills Ratio of South African Manufacturing, 1976-2002



Source: Trade and Industrial Policy Strategies

Figure 6
Skills Composition of the Manufacturing Workforce, 1976-2002



Source: Trade and Industrial Policy Strategies

6. Estimation Results

6.1 The Estimator

The theoretical framework within which this discussion is taking place is more suited to the medium- to long term (Coe *et al*, 1997). Accordingly, the ARDL approach of Pesaran and Shin (1995) and Pesaran *et al* (1995) is applied. This approach is advantageous because it can be applied regardless of whether variables are $I(1)$ or $I(0)$, thus avoiding the pre-testing problems that are associated with other cointegration approaches (Pesaran and Pesaran, 1997).

To start, the existence of a unique long-run relation between the variables has to be established. This is crucial for valid estimation and inference. The approach is as follows: start by estimating (OLS) an error-correction model given by:

$$y_t = \alpha_0 + \eta t + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \sum_{j=1}^{k} \sum_{t=1}^{p} \gamma_{ji} \Delta x_{j,t-1} + \left(\delta_1 y_{t-i} + \sum_{j=1}^{k} \delta_{j+1} x_j \right) + \omega_t \quad (6)$$

and then testing the significance of a joint zero restriction on the coefficients of the lagged contemporaneous terms ($\delta_1 = \delta_2 = \delta_3 = 0$). This is done by means of an F-test that has critical values with a non-standard distribution. Pesaran *et al* (1996) present a lower and an upper critical bound value. If the F is less than the lower bound, H_0 cannot be rejected, i.e. there is no long-run relationship. If F exceeds the upper critical value, H_0 is rejected. If F falls within the critical value bound, the results are inconclusive and a long-run relationship depends on whether the underlying variables are $I(1)$ or $I(0)$ (in which case one may turn to unit root tests). But because of this inconclusive critical value band, it is often better to test for the presence of cointegrating vectors using Johansen techniques, as is done in the present study.

Once evidence of a long-run relation between y_t and x_t has been found, the relationship can be established by estimating the ARDL(p,q) model:

$$y_t = \alpha + \beta t + \sum_{i=1}^{p} \gamma_i y_{t-i} + \sum_{i=0}^{q} \delta_i x_{t-i} + \varepsilon_t \quad (7)$$

This provides the long run coefficients

$$y_t = \varsigma + \eta t + \theta x_t + \upsilon_t \tag{8}$$

From

$$\hat{\varsigma} = \frac{\hat{\alpha}}{1 - \sum_{i=1}^{p} \hat{\gamma}_i}, \ \hat{\eta} = \frac{\hat{\beta}}{1 - \sum_{i=1}^{p} \hat{\gamma}_i} \text{ and } \hat{\theta} = \frac{\sum_{i=0}^{q} \hat{\delta}}{1 - \sum_{i=1}^{p} \hat{\gamma}_i}. \tag{9}$$

6.2 Results

From the outset, it is important to note that the dataset, which is limited by the availability of import data, is rather small. The limited number of annual observations and thus degrees of freedom is a constraint on the specification of the model in terms of the lag structure of the ARDL as well as the number of variables included. The possibility also exists that the estimation results can be biased due the short span of the data, especially since business cycle effects are problematic to productivity measures in short data spans (Ferreira and Rossi (2003)). Some caution is thus advisable when interpreting the estimation results. The small sample size also rules out other estimation methods such as Johansen's VECM.

From the trace and maximal eigenvalue statistics, which appear in Appendix A, there is clear evidence of the presence of one cointegrating vector with the variables GDP ratio of machinery and equipment imports from the EU, the skills ratio and capital-output ratio (and TFP as dependent variable). The ARDL model can thus be estimated for this, the "base" specification, and the results appear in the first column of Table 1. The lag structure of the ARDL is based on the Akaike Information criterion, as it is for all the regressions.

Table 1
Regressions with imports of machinery and equipment from the European Union, 1976 -2001

Dependent variable: Log of Total Factor Productivity			
	ARDL Lag Structure:		
Long-Run Coefficients:	(1,1,2,1)	(1,1,2,1,1)	(1,0,1,1,0)
CONSTANT	3.8186 [0.000]	4.3226 [0.000]	1.0460 [0.718]
M	4.1917 [0.000]	-6.272 [0.322]	2.5635 [0.056]
K	-0.278 [0.001]	-0.278 [0.000]	-0.364 [0.039]
SKRAT	-0.018 [0.875]	-0.912 [0.120]	-1.701 [0.332]
*M*SKRAT*		19.841 [0.104]	
NESDEG			0.4164 [0.320]
Error Correction Mechanism			
EC(-1)	-1.085 [0.003]	-1.169 [0.002]	
Adj R^2	0.48	0.55	
Diagnostics			
Serial Correlation [F-test]	0.0447 [0.835]	0.6713 [0.429]	0.28E-3 [0.987]
Heteroskedasticity [F-test]	0.0066 [0.936]	0.1703 [0.684]	0.0060 [0.939]
Normality [χ^2-Test]	2.9748 [0.226]	0.7671 [0.681]	1.4690 [0.480]

Note: Values in square parenthesis are *p*-values. The sample period for regressions with *NESDEG* is 1976 -2000.

The coefficient on the technology transfer variable, *M* is statistically significant and has the expected positive sign. The magnitude of the coefficient is very large and one should be cautious in interpreting the statistical significance as being the same as economic significance, and in doing so, committing McCloskey and Ziliak's (1996) "standard error of regressions." This is, however, as result of a scaling issue. The dependent variable is in natural log form and *M* is not. When the variable elasticity of TFP with respect to *M* is calculated (at the mean of *M*), the results show that a 1 per cent increase in *M* is associated with a 0.17 per cent increase in the TFP of the manufacturing sector.

In regressing TFP growth on trade openness, Jonsson and Subramanian (2000) include a measure of the share of investment in machinery and equipment in total investment as a proxy for local R&D activity. No distinction is, however, made between local and imported machinery and equipment. This variable is also positively (and significantly) related to TFP growth.[9] While Jonsson and Subramanian's (2000) results show that 90% of TFP growth during 1970-1997 is explained by increasing international trade as a share of GDP, Harding and Rattso (2005) find that productivity growth is best explained by reductions in tariffs.[10]

Since *K* enters the regressions in logged from, this coefficient can automatically be interpreted as an elasticity. The coefficient on *K* is also statistically significant and it has a negative sign. This is consistent with Fedderke's (2001) finding, which he interprets as a rejection of a Romer (1986) type spillover for South Africa's manufacturing sector. Thus, a technology spillover attaches to investment in foreign capital goods (*M*), not domestic capital goods (*K*), because of the superior technology embodied in the imported goods.

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[9] When a dummy variable for the sanctions period 1985-1992, and a capacity utilisation variable is included, Jonsson and Subramanian's (2000) machinery and equipment variable becomes insignificant, suggesting (i) that the important component of machinery and equipment investment is very important, as suggested by the present study; and (ii) that firms invest less in machinery during recessions, as can be expected.

[10] Harding and Rattso (2005) view their findings as more robust than that of Jonsson and Subramanian (2000) because of the endogeneity issues involved with used trade outcomes instead of trade policies (the by-now famed Rodriguez-Rodrik critique). Similarly, Ferreira and Rossi (2003) find that more liberal trade policy (reductions in ERP and nominal tariffs) better explains growth in TFP than variables based on trade shares.

Table 2
Regressions with machinery imports from the European Union, 1976-2001

Dependent variable: Log of Total Factor Productivity			
	ARDL Lag Structure:		
Long-Run Coefficients:	(1,0,1,0)	(1,0,1,0,0)	(1,0,1,0,0)
CONSTANT	3.8457 [0.000]	4.2972 [0.000]	2.6541 [0.369]
M	6.0239 [0.007]	-7.416 [0.519]	4.2438 [0.050]
K	-0.315 [0.021]	-0.321 [0.018]	-0.330 [0.093]
SKRAT	-0.072 [0.684]	-0.918 [0.241]	-0.915 [0.607]
*M*SKRAT*		24.780 [0.256]	
NESDEG			0.1943 [0.644]
Error Correction Mechanism			
EC(-1)	-0.684 [0.001]	-0.687 [0.001]	-0.671 [0.009]
Adj R^2	0.42	0.44	0.46
Diagnostics			
Serial Correlation [F-test]	0.837E-4 [0.993]	0.2275 [0.640]	0.0513 [0.824]
Heteroskedasticity [F-test]	0.3028 [0.588]	0.8853 [0.357]	0.0106 [0.919]
Normality [χ^2-Test]	0.1501 [0.928]	0.6925 [0.707]	0.3382 [0.844]

Note: Values in square parenthesis are *p*-values. The sample period for regressions with *NESDEG* is 1976 -2000.

The coefficient on the skills ratio *SKRAT* captures two effects. On the one hand, it is an indication of the level of human capital in the economy and thus of the ability to absorb technological improvements made elsewhere. On the other hand, it is also controls for labour quality. Failure to control for the quality of inputs will cause an upward bias of TFP estimates (Fedderke, 2002). The negative coefficient on the skills ratio is consistent with such an upward bias in TFP. It is also consistent with the finding in Fedderke (2001) who found the skills ratio to be negative (for 28 three digit manufacturing sectors), implying that productivity gains in manufacturing were mostly in unskilled intensive sectors. Given that unskilled manufacturing jobs have fallen strongly (see Figure 6), the productivity gains may simply have been experienced because those sectors have been shedding labour.

The error-correction term is statistically significant and has a negative sign. It is also quite large suggesting a quick convergence to the long-run equilibrium, once the economy is shocked. The diagnostics suggest that the null hypotheses of no autocorrelation, no heteroskedasticity and residual normality cannot be rejected.

For the second specification, in column two of Table 1, an interaction term is added to the above model. There is also evidence of a unique cointegrating vector based on the maximal eigenvalue statistic. The lag structure is rather parsimonious and due to the fact that a higher order ARDL gave rise to autocorrelation (this was also the case in many of the other estimations that follow below). The coefficient on *M* is now negative, but the interaction term is positive. This mirrors the result in Mayer (2001) and suggests that the combination of technology imports with skilled labour is very important. Mayer (2001) strongly argues that the role of human capital (or skilled labour) in developing countries lies in facilitating the adoption of technology from abroad rather than as a separate factor of production. While this interpretation is valid for South Africa, it is only so to an extent. Fedderke (2001) has shown that human capital does have a direct impact on growth, along the lines of Mankiw *et al* (1992), provided that the quality dimension is taken into account. The error correction term is negative and significant and the model passes the diagnostic tests.

In the third specification *NESDEG*, the number of natural and engineering science degrees, is added as a human capital variable. It is positively signed, but does not

Table 3
Regressions with imports of machinery and equipment from industrialised countries, 1976-2001

Dependent variable: Log of Total Factor Productivity			
	ARDL Lag Structure:		
Long-Run Coefficients:	(1,0,1,0)	(2,2,2,1,2)	(1,0,1,0,0)
CONSTANT	3.8793 [0.000]	4.4100 [0.000]	4.0392 [0.063]
M	2.2342 [0.006]	-5.215 [0.168]	1.8455 [0.084]
K	-0.223 [0.010]	-0.217 [0.001]	-0.193 [0.080]
SKRAT	0.1101 [0.426]	-0.896 [0.114]	0.1052 [0.937]
*M*SKRAT*		14.564 [0.063]	
NESDEG			-0.007 [0.980]
Error Correction Mechanism			
EC(-1)	-0.752 [0.001]	-1.403 [0.002]	-0.779 [0.004]
Adj R^2	0.44	0.55	0.40
Diagnostics			
Serial Correlation [F-test]	0.4516 [0.511]	0.6482 [0.442]	0.6242 [0.442]
Heteroskedasticity [F-test]	0.0726 [0.790]	0.3425 [0.564]	0.1806 [0.675]
Normality [χ^2-Test]	6.1792 [0.046]	2.1704 [0.338]	6.3422 [0.042]

Note: Values in square parenthesis are *p*-values. The sample period for regressions with *NESDEG* is 1976 -2000.

have a statistically significant impact on productivity growth. An interpretation of this finding is, as said above, that human capital does not have a direct impact on productivity growth through local innovative activity. Productivity growth is improved by technology imports (*M* is significant) and not domestic innovation. In Fedderke (2001), *NESDEG* also proved not to be significant while the proportion of science and engineering degrees to general degrees did prove to have a statistically significant effect on TFP growth.

The implication is again that the production of human capital can directly influence productivity growth – and that it can be a proxy for innovative activity – if it is of sufficiently high quality. Since the production of human capital in South Africa has been inefficient and wasteful (Fedderke *et al*, 2003), it should perhaps not come as a surprise that significant evidence of human capital spillovers can not be found in the present case. The effect of small-sample bias is also a possible factor here.

The next set of estimations, reported in Table 2, uses a narrower category of technology imports, namely machinery imports from the EU. In the base specification, the *M* variable is significant and positive and has a larger coefficient than the corresponding variable in Table 1. Mayer (2001) similarly found that narrowing the technology transfer term down from total machinery and equipment imports to imports of just machinery, the point estimate rises on that variable. The variable elasticity, again taken at the mean, however, is 0.17 and is thus the same. Productivity growth in South Africa's manufacturing sector thus responds equally well to spillovers from imports of the broader category machinery and equipment (the Coe *et al* measure) than to the narrower category of machinery (Mayer's measure).

The coefficients on other variables are broadly similar to those in Table 1. The skills ratio has a negative sign in all three specifications. Adding the interaction term *M*SKRAT* again causes the coefficient on *M* to become negative and not significant. The interaction term itself, as well as *NESDEG,* have a positive coefficient but are not statistically significant. In all three specifications, the error correction term is negative and significant, confirming the existence of a long run relationship between the variables.

Table 4
Regressions with machinery imports from industrialised countries, 1976-2001

Dependent variable: Log of Total Factor Productivity			
	ARDL Lag Structure:		
Long-Run Coefficients:	(2,1,1,1)	(1,0,1,0,0)	(1,0,1,0,0)
CONSTANT	3.8450 [0.000]	4.2523 [0.000]	4.7103 [0.015]
M	3.5125 [0.098]	-5.697 [0.514]	3.3530 [0.013]
K	-0.267 [0.089]	-0.314 [0.021]	-0.226 [0.084]
SKRAT	0.0609 [0.734]	-0.921 [0.286]	0.4457 [0.690]
*M*SKRAT*		19.263 [0.265]	
NESDEG			-0.112 [0.661]
Error Correction Mechanism			
EC(-1)	-0.773 [0.018]	-0.679 [0.003]	-0.813 [0.002]
Adj R^2	0.20	0.40	0.42
Diagnostics			
Serial Correlation [F-test]	0.2332 [0.637]	0.206E-4 [0.996]	0.4848 [0.497]
Heteroskedasticity [F-test]	0.3580 [0.556]	1.3590 [0.256]	0.1247 [0.727]
Normality [χ^2-Test]	0.7387 [0.691]	1.4433 [0.486]	1.0100 [0.603]

Note: Values in square parenthesis are *p*-values. The sample period for regressions with *NESDEG* is 1976 -2000.

Tables 3 and 4 show the results when machinery imports from an expanded sample of countries, namely all industrialised countries, are used in the regressions. For the base specification in tables 3 and 4, the coefficients on *M* show a similar relationship regarding the category of capital imports as above, namely that the coefficients are higher when the category of imports is narrower. They are, however, smaller than the corresponding coefficients (using imports from the EU), possibly suggesting that technology transfer is stronger from the EU, which is South Africa's major trading partner.

In table 5 the sample of countries from which machinery and equipment are sourced is again expanded. The *M* variable now indicates the GDP ratio machinery and equipment imports from the industrialised countries well as developing countries with significant R&D expenditure. As in Mayer (2001), these are termed 'advanced' developing countries. However, Mayer (2001) found that the coefficients on his *M* variables changed little when they included imports from these advanced developing countries, despite the fact that the GDP ratio of these imports rose strongly for his set of 80 countries since the late 1980s. In the present study the size of the coefficients are actually smaller. Importing technology from other developing countries appears not to have a significant impact on manufacturing productivity in South Africa. This should perhaps not come as a surprise. As Figures 1 and 2 show, machinery and equipment imports form advanced developing countries have only really started to pick up during the course of the 1990s. The effect of these imports on productivity and growth is, however, something to keep an eye on for the future as South Africa's trade relations with the developing world normalises and grows.

Table 5
Regressions with machinery and equipment imports from advanced developing and industrialised countries, 1976-2001

Dependent variable: Log of Total Factor Productivity			
	ARDL Lag Structure:		
Long-Run Coefficients:	(1,0,1,0)	(1,1,1,0,1)	(1,1,2,1,1)
CONSTANT	4.0794 [0.000]	4.9787 [0.000]	2.5095 [0.564]
M	1.3622 [0.076]	-9.813 [0.260]	0.5137 [0.784]
K	-0.214 [0.033]	-0.217 [0.051]	-0.277 [0.132]
SKRAT	-0.146 [0.440]	-1.799 [0.189]	-1.120 [0.674]
*M*SKRAT*		20.813 [0.207]	
NESDEG			0.2312 [0.721]
Error Correction Mechanism			
EC(-1)	-0.694 [0.003]	-0.598 [0.008]	-0.723 [0.062]
Adj R^2	0.38	0.45	0.30
Diagnostics			
Serial Correlation [F-test]	0.1544 [0.700]	2.6876 [0.125]	0.0588 [0.813]
Heteroskedasticity [F-test]	0.0312 [0.861]	0.0135 [0.908]	0.0845 [0.774]
Normality [χ^2-Test]	5.2514 [0.072]	2.0633 [0.356]	1.7472 [0.417]

Note: Values in square parenthesis are *p*-values. The sample period for regressions with *NESDEG* is 1976 -2000.

Table 6 provides a summary of the elasticities of TFP in the manufacturing sector with respect to the different configurations of the technology transfer term, *M*, and the different model specifications. Growth in productivity responds equally well as a result of increasing imports of the broader category machinery and equipment than to the narrower category of machinery. This is true both when the origin of the imports is the EU (elasticity of about 0.17) and all industrialised countries (about 0.14). When the variable *NESDEG* is included, this elasticity falls in all cases. The inclusion of the interaction variable (*M*SKRAT*) causes the coefficient (and elasticity) *M* to turn negative. The elasticity on this interaction term is larger than that of *M* across all cases. The implication is again the importance of the interaction of imported technology with human capital.

7. Conclusion

This paper investigated the role of foreign technology on productivity growth in a middle-income country context. Total factor productivity growth has increased in importance in the South African economy and indeed in the economies of most other countries and understanding its sources is important. It is particularly important in South Africa's manufacturing sector, which has exhibited signs of being in decline over the last decade, not least in terms of its international competitiveness. The findings presented show that the diffusion of foreign technology, measured as imports of machinery and equipment, has had a positive impact on TFP growth in South Africa's manufacturing sector between 1976 and 2001. This finding is consistent with the theory and empirics of a growing literature on the subject. The literature also emphasises the role of human capital in combination with technology imports on growth. This hypothesis was tested in the present study and, while not very robust, evidence is presented on this important interaction. Thus, there remains scope for further research. Another area for future research is to examine technology transfer at the level of the three digit economic sectors, thus capturing the effect of sectoral heterogeneity.

Table 6
Variable Elasticity Coefficients of M

Machinery and Equipment imports from the EU			
M1	M2	M3	M*SKRAT
0.1726	-0.2584	0.1056	0.4410
Machinery Imports from the EU			
M1	M2	M3	M*SKRAT
0.1704	-0.2098	0.1201	0.3801
Machinery and Equipment imports from Industrialised Countries			
M1	M2	M3	M*SKRAT
0.1479	-0.3452	0.1221	0.5169
Machinery imports from Industrialised Countries			
M1	M2	M3	M*SKRAT
0.1475	-0.2385	0.1408	0.4287
Machinery and Equipment imports from All			
M1	M2	M3	M*SKRAT
0.0961	-0.6968	0.0364	0.7990

Note: M1, M2, M3 refer to the *M* variables in the three different specifications as used in Tables 1-5. All elasticities are measured at the mean value of *M*. The dependent variable is log of TFP of South African Manufacturing.

What policy implications do these findings present? The most obvious one is that, if a developing country such as South Africa benefits from importing machinery and equipment (and technology broadly defined), its trade regime should facilitate such imports. It would also be worthwhile to consider the impact of the recent fluctuations in South Africa's exchange rate on such imports in future studies. The other factors discussed in section 2 - property rights, regulatory environment, infrastructure, etc. - that serve to incentivise firms to adopt foreign technology are also clearly important. It is safe to say, though, that South Africa meets most of those requirements, or is at least heading in the right direction. What is more questionable, though, is the government's attitude towards technology diffusion versus local innovation.

Government's stance on technology and R&D should ideally reflect the importance of adopting foreign technology. However, Kaplan (2004) argues that the NDRS has "underestimated the importance of technology acquired from abroad" and that it is an area that requires "a great deal more attention." This is not to say that local innovation is unimportant. Fedderke (2001) has shown that domestic R&D spending has a positive impact on growth, as posited by Shumpeterian theory. Kaplan (2004) also argues that there is no "iron wall" between local innovation and foreign technology transfer. Indeed, the greater the ability to innovate locally, the greater the ability to identify appropriate foreign technology and to assimilate it.[11] Or in the words of Keller (2004), "international diffusion of technology is neither inevitable nor automatic. Domestic technology investments are necessary." In a seminal paper, Cohen and Levinthal (1990) made a similar argument: it prior knowledge that allows a firm to acquire new knowledge. Firms that conduct R&D are firms that can assimilate information from the external environment and improved absorptive capacity is thus a by-product of R&D.[12]

The dti's IMS also states that South Africa can become marginalised if it is "left out of the technology transfer loop" (dti, 2002). However, while the proposed microeconomic reforms will play an important role, the strategy does not provide for

[11] This is supported by the findings of Schiff *et al* (2002), that, in a panel of 25 countries and 16 industries, R&D-intensive industries (i.e. industries that perform significant amounts of R&D) benefited more from technology diffusion than R&D non-intesive industries. See also Keller (2004).
[12] That R&D creates greater absorptive capacity helps to explain why firms conduct R&D even when knowledge thus garnered spills out into the public domain.

mechanisms that specifically target the effective identification, acquisition and assimilation of foreign technology. The IMS emphasises local innovation and even contains a brief warning against dependency on external knowledge. It may be that we know too little about such mechanisms to begin with. Kaplan (1999) has argued that the literature on the economics of technological change, while it emphasises innovation, does not provide enough guidance on concrete policies that facilitate diffusion, nor on identifying the socially optimal rate of diffusion. Nevertheless, other countries, notably in east and south - east Asia, have 'got it right' (Coe *et al*, 1997; Mayer, 2001) Clearly, this is another area where more research regarding the South African situation would be helpful.

Finally, there is the need for improvements in the stock of human capital. While the empirics of this paper has emphasised the vital role of imported technology, the availability of quality human capital is nonetheless important, not least because of the importance of local R&D in technology diffusion as discussed above. It is crucially important that efforts to increase technology transfer be coordinated with human capital formation. As Mayer (2001) argues, if the focus is only on investment in human capital, diminishing returns to skill accumulation will result. Technology transfer by itself is not likely to be enduring and could have detrimental effects on development due to greater income inequality. Kaplan (2004) has similarly recommended that South Africa should not simply increase its science and technology programmes without due attention to the supply of scientists and research managers. Doing so would probably raise the returns to the scarce factor (skills) without increasing output. Human capital formation needs to improve not just along the quantity dimension, but critically also in terms of quality. Historically speaking, the quality of inputs into black education was much lower than the quality of inputs into schooling for whites. The institutional environment also constrained the efficient use of the scarce resources available for black schooling. Moreover, the quality (as measured by the proportion of matriculation candidates sitting mathematics) of the more privileged white education has also fallen, particularly during the 1980s(see Fedderke, 2001 and Fedderke *et al*, 2003).

More recently, the focus has been on broadening access to education with seemingly little regard paid to the deepening of quality. All this is reflected in the widely discussed phenomenon that South Africa spends a comparatively large portion of GDP on education while it consistently ranks near the bottom in terms of its educational outcomes (particularly in maths and science). Greater efficiency in human capital investment will allow South Africa to reap the benefits of globalisation, allowing it to access the foreign technology needed to reach higher productivity and thus greater economic growth. Failure to improve educational outcomes might see us fall further and further behind as the global technology frontier shifts inexorably outwards.

Appendix A

Cointegration tests corresponding to Table 1

First Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	67.5180*	31.7900	104.903*	63.0000
$r \leq 1$	$r = 2$	22.6242	25.4200	37.3857	42.3400

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from EU), K, SKRAT; List of Eigenvalues in descending order: 0.93 0.61 0.28 0.24 0.00

Second Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	43.86*	37.86	107.41*	87.17
$r \leq 1$	$R = 2$	26.89	31.79	63.55*	63.00

Note: * Denotes statistical significance; 23 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from EU), K, SKRAT, M*SKRAT; List of Eigenvalues in descending order: 0.85 0.68 0.56 0.35 0.26 0.00

Third Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	68.91*	37.86	130.09*	87.17
$r \leq 1$	$r = 2$	24.95	31.79	61.18	63.00

Note: * Denotes statistical significance; 22 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from EU), K, SKRAT, NESDEG; List of Eigenvalues in descending order: 0.95 0.67 0.62 0.35 0.19 0.00

Cointegration tests corresponding to Table 2

First Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	54.8555*	31.7900	90.5140*	63.0000
$r \leq 1$	$r = 2$	21.1704	25.4200	35.6585	42.3400

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(machinery from EU), K, SKRAT; List of Eigenvalues in descending order: 0.89 0.58 0.29 0.22 0.00

Second Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	71.4667*	37.8600	145.09*	87.1700
$r \leq 1$	$r = 2$	27.5015	31.7900	73.630*	63.0000

Note: * Denotes statistical significance; 24 annual observations ; List of variables included in cointegrating vector: TFP, M(machinery from EU), K, SKRAT, M*SKRAT; List of Eigenvalues in descending order: 0.94 0.68 0.60 0.48 0.27 0.00

Third Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	68.91*	37.86	130.09*	87.17
$r \leq 1$	$r = 2$	24.95	31.79	61.18	63.00

Note: * Denotes statistical significance; 22 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from EU), K, SKRAT, NESDEG; List of Eigenvalues in descending order: 0.95 0.67 0.62 0.35 0.19 0.00

Cointegration tests corresponding to Table 3

First Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	48.1755*	31.7900	87.2623*	63.0000
$r \leq 1$	$r = 2$	24.3809	25.4200	39.0868	42.3400

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from IND), K, SKRAT; List of Eigenvalues in descending order: 0.86 0.63 0.27 0.25 0.00

Second Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	78.1688	37.8600	145.179*	87.1700
$r \leq 1$	$r = 2$	27.5433	31.7900	67.010*	63.0000

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from IND), K, SKRAT, M*SKRAT; List of Eigenvalues in descending order: 0.96 0.68 0.55 0.39 0.27 0.00

Third Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	43.07*	37.86	108.63*	87.17
$r \leq 1$	$r = 2$	31.75	31.79	65.55*	63.00

Note: * Denotes statistical significance; 22 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from IND), K, SKRAT, NESDEG; List of Eigenvalues in descending order: 0.85 0.76 0.60 0.33 0.19 0.00

Cointegration tests corresponding to Table 4

First Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	50.7375*	31.7900	85.1165*	63.0000
$r \leq 1$	$r = 2$	19.6776	25.4200	34.3791	42.3400

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(machinery from IND), K, SKRAT; List of Eigenvalues in descending order: 0.87 0.55 0.28 0.24 0.00

Second Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	69.4634*	37.8600	135.915*	87.1700
$r \leq 1$	$r = 2$	27.1559	31.7900	66.4522*	63.0000

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(machinery from IND), K, SKRAT, M*SKRAT; List of Eigenvalues in descending order: 0.94 0.67 0.50 0.46 0.26 0.00

Third Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	52.00*	37.86	110.71*	87.17
$r \leq 1$	$r = 2$	25.36	31.79	58.71	63.00

Note: * Denotes statistical significance; 23 annual observations; List of variables included in cointegrating vector: TFP, M(machinery from IND), K, SKRAT, NESDEG; List of Eigenvalues in descending order: 0.90 0.68 0.58 0.31 0.21 0.00

Cointegration tests corresponding to Table 5

First Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	30.01*	29.13	60.97*	59.16
$r \leq 1$	$r = 2$	20.00	25.42	30.96	42.34

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from ALL), K, SKRAT; List of Eigenvalues in descending order:

Second Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	61.26*	37.86	126.47*	87.17
$r \leq 1$	$r = 2$	27.20	31.79	65.21*	63.00

Note: * Denotes statistical significance; 24 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from ALL), K, SKRAT, M*SKRAT; List of Eigenvalues in descending order:

Third Specification

Null	*Alternative*	*Eigenvalue Statistic*	*95%Critical Value*	*Trace Statistic*	*95%Critical Value*
$r = 0$	$r = 1$	46.68*	37.86	107.06*	87.17
$r \leq 1$	$r = 2$	26.19	31.79	60.37	63.00

Note: * Denotes statistical significance; 22 annual observations; List of variables included in cointegrating vector: TFP, M(m&e from ALL), K, SKRAT, NESDEG; List of Eigenvalues in descending order: 0.88 0.69 0.62 0.31 0.16 0.00

Appendix B
Stationarity Tests

Series	Model	τ	95% Critical Value
*M*1	Constant	-1.3594	-2.9907
	C&T	-0.9416	-3.6119
*M*2	Constant	-1.7083	-2.9907
	C&T	-1.5408	-3.6119
*M*3	Constant	-1.6056	-2.9907
	C&T	-1.2331	-3.6119
*M*4	Constant	-1.8836	-2.9907
	C&T	-1.6869	-3.6119
*M*5	Constant	-1.3248	-2.9907
	C&T	-1.1956	-3.6119
*K*1	Constant	-0.7266	-2.9907
	C&T	-2.3171	-3.6119
*K*2	Constant	-0.7065	-2.9907
	C&T	-2.2307	-3.6119
*K*3	Constant	-0.7268	-2.9907
	C&T	-2.3141	-3.6119
*K*4	Constant	-0.9837	-2.9907
	C&T	-3.6119	-2.1766
*K*5	Constant	-0.26098	-2.9907
	C&T	-2.6378	-3.6119
SKRAT	Constant	-1.5170	-2.9907
	C&T	-1.3377	-3.6119
NESDEG	Constant	-1.9715	-3.6331
	C&T	-1.5770	-2.9970
TFP	Constant	-1.5698	-2.9970
	C&T	-2.5269	-3.6219

Note: *M*1-5 corresponds to the different *M* variables in each of Tables 1 to 5. Ditto for *K*1-5. *K* variables, *TFP* and *NESDEG* are in natural log form. C&T means a constant and a trend are included. τ refers to the Augmented Dickey-Fuller test statistic.

Series	Model	τ	95% Critical Value
$\Delta M1$	Constant	-3.7190*	-2.9970
	C&T	-3.9558*	-3.6219
$\Delta M2$	Constant	-3.0524*	-2.9970
	C&T	-3.1581	-3.6219
$\Delta M3$	Constant	-3.7176*	-2.9970
	C&T	-3.7790*	-3.6219
$\Delta M4$	Constant	-3.5658*	-2.9970
	C&T	-3.4980	-3.6219
$\Delta M5$	Constant	-3.8569*	-2.9850
	C&T	-3.7184	-3.6027
$\Delta K1$	Constant	-3.1817*	-2.9970
	C&T	-3.1023	-3.6219
$\Delta K2$	Constant	-3.4143*	-2.9970
	C&T	-3.3530	-3.6219
$\Delta K3$	Constant	-3.2373*	-2.9970
	C&T	-3.1785	-3.6219
$\Delta K4$	Constant	-3.5250*	-2.9970
	C&T	-3.5257	-3.6219
$\Delta K5$	Constant	-3.2099*	-2.9970
	C&T	-3.1249	-3.6219
$\Delta SKRAT$	Constant	-2.9067	-2.9907
	C&T	-3.1692	-3.6119
$\Delta NESDEG$	Constant	-2.2212	-3.0039
	C&T	-2.3699	-3.6331
ΔTFP	Constant	-3.1863*	-3.0039
	C&T	-3.6556*	-3.6331

Note: *M*1-5 corresponds to the different *M* variables in each of Tables 1 to 5. Ditto for *K*1-5. *K* variables, *TFP* and *NESDEG* are in natural log form. All variables are in first differenced form, as indicated by Δ. C&T means a constant and a trend are included. τ refers to the Augmented Dickey-Fuller test statistic. * Indicates significance.

According to the above, *SKRAT* and *NESDEG* are non-stationary in first difference form. However, after visual inspection of the graphical representation of the series, and following Fedderke (2001) and Du Toit et al (2004), these series were treated as *I*(1). All the other series are also *I*(1).

References

Arora, V. and A. Bhundia (2003) 'Potential Output and Total Factor Productivity in Post-Apartheid South Africa.' IMF Working Paper WP/03/178

Coe, D. and E. Helpman (1995) 'International R&D Spillovers.' *European Economic Review*, 39, 859-887

Coe, D., Helpman, E. and A. Hoffmaister (1997) 'North-South R&D Spillovers.' *Economic Journal*, 107, 135-149

Cohen, W. and M. Levinthal (1990) 'Absorptive Capacity: A New Perspective on Learning and Innovation.' *Administrative Science Quarterly*, 35, 128-152

De Long, J. and L. Summers (1993) 'How strongly do developing countries benefit from equipment investment?' *Journal of Monetary Economics*, 32, 395 – 415

Department of Trade and Industry (2002) *Accelerating Growth and Development: The Contribution of an Integrated Manufacturing Strategy*. Available at www.thedti.gov.za/downloads/ims.pdf

Du Toit, C., Koekemoer, R. and M. Ground (2004) 'Estimating Technical Progress for South Africa.' Delivered at the Ninth Annual Conference on Econometric Modelling for Africa, available at www.commerce.uct.ac.za/economics/

Easterly, W. and R. Levine (2000) 'It's not Factor Accumulation: Stylized Facts and Growth Models.' Mimeo. World Bank, Washington

Edwards, L. and S. Golub (2003) 'South African Productivity and Capital Accumulation in Manufacturing: an International Comparative Analysis.' *South African Journal of Economics*, 71(4), 659 - 678

Fedderke, J. and P. Vaze (2001) 'The Nature of South Africa's Trade Patterns by Economic Sector, and the Extent of Trade Liberalization during the Course of the 1990's.' *South African Journal of Economics*, 69(3), 436-473

Fedderke, J. (2001) 'Technology, Human Capital and Growth: evidence from a middle income country case study applying dynamic heterogeneous panel analysis.'

Econometric Research Southern Africa Working Paper No. 23, University of the Witwatersrand.

Fedderke, J. (2002) 'The Structure of Growth in the South African Economy: Factor Accumulation and Total Factor Productivity Growth 1970 –1997.' *South African Journal of Economics*, 70(4), 611 - 646

Fedderke, J., de Kadt, R. and J. Luiz (2003) 'A Capstone Tertiary Educational system: Inefficiency, Duplication and Inequity in South Africa's Tertiary Education System, 1910-93.' *Cambridge Journal of Economics*, 27(3), 377 - 400

Ferreira, P and J. Rossi (2003) 'New Evidence from Brazil on Trade Liberalization and Productivity Growth.' *International Economic Review*, 44(1), 1383-1405

Grossman, G. and E. Helpman (1991) *Innovation and Growth in the Global Economy*. Cambridge, Ma. and London: MIT Press

Harberger, A. (1998) 'A Vision of the Growth Process.' *American Economic Review*, 88(1), 1 - 32

Harding, T. and J. Rattso (2005) 'The Barrier Model of Productivity Growth: South Africa.' TIPS Working Paper 4-2005

Jonsson, G. and Subramanian, A. (2000) 'Dynamic Gains from Trade: Evidence from South Africa.' IMF Working Paper WP/00/45

Kaplan, D (1999) 'On the Literature of the Economics of Technological Change. Science and Technological Policy in South Africa.' *South African Journal of Economics*, 67(4), 473-490

Kaplan, D. (2003) 'Manufacturing Performance and Policy in South Africa – A Review.' Paper prepared for TIPS/DPRU Forum, September 2003.

Kaplan, D. (2004) 'South Africa's National Research and Development Strategy: A Review.' *Science, Technology and Society*, 9(2)

Keller, W. (1998) 'Are International R&D Spillovers Trade-Related? Analyzing Spillovers among randomly matched trade Partners.' *European Economic Review*, 42, 1469-1481

Keller, W. (2004) 'International Technology Diffusion.' *Journal of Economic Literature*, XLII, 752 - 782

Mankiw, N., Romer, D and D. Weil (1992) 'A Contribution to the Empirics of Growth.' *Quarterly Journal of Economics*, 107(2), 407-37
Mayer, J. (2001) 'Technology Diffusion, Human Capital and Economic growth in Developing Countries.' UNCTAD Discussion Paper No.154

Mayer, J. (2000) 'Globalization, Technology Transfer and Skill Accumulation in Low-Income Countries.' UNCTAD Discussion Paper No.150

McCloskey, D. and S. Ziliak (1996) 'The standard error of regressions.' *Journal of Economic Literature*, XXXIV, 97-114.

National Advisory Council on Innovation (2003) *A National Advanced Technology Strategy for South Africa*. Available at www.naci.org.za/pdfs/amts

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

Pesaran, H. and Y. Shin (1995) 'An autoregressive distributed lag modelling approach to cointegration analysis.' Department of Applied Economics Working Paper no. 9514, University of Cambridge

Pesaran, H., Shin, Y., and R. Smith (1996) 'Testing for the existence of a long run relationship.' Department of Applied Economics Working Paper no. 9622, University of Cambridge

Pesaran, H. and B. Pesaran (1997) *Working with Microfit 4.0*. Oxford University Press

Rogers, M. (2004) 'Absorptive Capability and Economic Growth.' *Cambridge Journal of Economics*, 28(4), 577 -596

Romer, P. (1986) 'Increasing Returns and Long-Run Growth.' *Journal of Political Economy*, 95(4), 1002 -37

Schiff, M. and Y. Wang (2003) 'Regional Integration and Technology Diffusion: The Case of the North American Free Trade Agreement.' World Bank Policy Research Working Paper 3132

Schiff, M., Wang, Y., and M. Olarreaga (2002) 'Trade-Related Technology Diffusion and the Dynamics of North-South and South-South Integration.' World Bank Policy Research Working Paper 2861

Van Dijk, M. (2003) 'South African Manufacturing Performance in International Perspective 1970 – 1999.' *South African Journal of Economics*, 71(1), 119 - 142