Looking abroad to understand productivity growth: the world technology frontier and industrial sector productivity in South Africa

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Abstract: Individual country industrial sector productivity growth must be understood in the context of the world technology frontier. Industrial sector productivities are to a large extent driven by the international development of similar sectors. This is the basis of this analysis of productivity growth in South African manufacturing sectors and represents an alternative to conventional analysis of domestic determinants of productivity. Productivities in U.S. manufacturing sectors serve as the world technology frontier and allow identification of causal effects of South African productivities. The results show the importance of the world technology frontier and we argue that existing studies overlooking the world frontier may have serious omitted variable bias. In an extension using a quality measure of human capital as barrier to technology adoption we find that observed reduction in quality of human capital has held back productivity growth. Interaction effects imply that the world frontier is more important for productivity the higher the quality of human capital.

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1. Introduction

Lucas (2007) argues that the world growth pattern must be understood as cross-country flows of production-related knowledge from the successful economies to the less successful ones. Klenow and Rodriguez-Clare (2005) offer an overview of the growth-literature based on international spillovers. Cross-country evidence about the importance of the world technology frontier is supplied by Benhabib and Spiegel (1994, 2005), Bernard and Jones (1996), Caselli and Coleman (2006), Comin and Hobijn (2004), and Griffith et al. (2004). Catching up productivity growth to close the technology gap is called the Veblen-Gerschenkron-effect in the development literature. This growth model was first formalized by Nelson and Phelps (1966), and modern restatements include Aghion and Howitt (2005), Ngai (2004), and Parente and Prescott (1994, 2004).

All countries can take benefit of the growth of the world technology frontier, albeit in different degrees and speeds, and depending on their economic conditions. We suggest taking benefit of the role of the world technology frontier in the analysis of industrial sector productivity growth in an individual country, South Africa. A few studies link industrial sector productivity growth to the industrial sector world technology frontier, notably Cameron et al. (2005) analyzing UK industries and Cameron (2005) on Japan. We extend the evidence for the middle income country South Africa and suggest an econometric approach with clear identification of the role of the world technology frontier. The analysis is based on the TIPS (Trade and Industry Policy Strategies) panel data set of manufacturing industries during 1970-1995 (TIPS, 2004) and industrial sector data for the U.S. as world frontier (NBER, 2000).

Our results show that the industrial sector world technology frontier represented by the US industries serve as the driving force of industrial sector productivity growth in South Africa. It follows that productivity studies excluding the world frontier have serious omitted variable problems. Individual country industrial sector growth cannot be understood independent of the industrial sector development at the world market. The whole field of country oriented industrial productivity analysis have had the focus on country determinants, but our study shows that these studies miss out that industries are part of a global industrial development.

The main argument for our approach is to get around the serious problem of endogeneity in productivity analysis. Individual country productivity analysis typically concentrates on domestic determinants, possibly including foreign trade or foreign investment as explanatory factors.

Recent prominent examples include Ferreira and Rossi (2003) and Alcala and Ciccone (2004). The determinants of industrial sector productivity often describe production conditions that themselves respond to productivity. The strength of the world frontier model in econometric terms is that individual country productivity growth is driven by international factors beyond the country level. The world frontier clearly is exogenous for middle income countries like South Africa. The industrial sector world frontier represents a large amount of data that can help explain industrial productivity growth in individual countries. This exogenous determinant allows for identification of the causality behind industrial sector productivity. The identification is independent of a possible battery of other variables representing domestic determinants. In the analysis below unobservable factors potentially important for productivity developments are accounted for by sector and year fixed effects.

The 'barrier model' of economic growth addresses factors that influence the capacity to adopt technologies from the world frontier. The focus in the literature has been set to human capital and trade openness, but in principle an array of domestic economic conditions affect technology adoption (such as infrastructure, barriers to entry, market structure and competition, regulatory environment). Some of the literature has concentrated more on vehicles actually carrying technology and know how from the world frontier, notably foreign direct investment. As with other determinants of productivity growth, the main challenge to identification of barrier effects and vehicles again is endogeneity. We suggest an analysis concentrating on human capital as barrier, since we have available an aggregate measure of quality of human capital based on university student specialization relevant for manufacturing industries (Fedderke, 2002). The share of students in sciences and mathematics has been declining over time and has been interpreted as a decline in the quality of human capital. A sector specific measure of quality of human capital is achieved by interacting the aggregate variable with sector specific skill intensity. The results show that reduced quality of human capital has held back productivity growth and that the world frontier is more important for productivity the higher the quality of human capital.

The challenges related to modeling and econometric analysis of the world technology frontier effect for individual country industrial productivity are discussed in section 2. Data and empirical specification are presented in section 3. Section 4 presents the dependent variable, the calculation of industrial sector TFP development. The estimated effects of the world technology frontier are shown in section 5. The barrier model including quality of human capital is estimated in section 6. Concluding remarks are offered in section 7.

2. Data and TFP estimation

The TIPS (Trade and Industry Policy Strategies) panel data set of 28 South African manufacturing sectors during 1970-1995 (TIPS, 2004) provides us with gross output (X), value added (Y), materials (M), capital (K), labor (L) and income shares. Capital is broken down into structures, machinery and transportation equipment, while labor is classified as highly skilled, skilled and unskilled. All these variables are yearly and sector specific. We use the series up to 1995. Data for years post 1996 are of questionable quality as the last manufacturing survey was undertaken in 1996 . As explained below, the production functions are estimated in several ways to construct sectoral TFPs, A_{it} (sector i, year t). These are all set to 100 in 1970.

In the literature on cross country differences in TFP, the U.S. TFP is widely used as a representation of the world technology frontier. Hsieh and Klenow (2007) is a recent example. We therefore employ the 4-factor U.S. manufacturing TFPs provided by NBER (2000) as the world technology frontier at the sector level, A^*_{it}. NBER presents this measure for 459 4-digit SIC 87-sectors over the period 1958-1996.[1] The concordance between sectors was done by manually attaching each 4-digit SIC87 sector to the corresponding sector in the TIPS data on South Africa. The matching of sectors is presented in Appendix table 3. We use an unweighted average across all 4-digit SIC 87 sectors corresponding to the South African sector i as A^*_{it}. We normalize A^*_{it} to 100 in t=1970. We study 1, 2 and 3 lags to investigate possible delays in the technology diffusion.

TFP is typically backed out as a residual in production functions. When estimating the production functions, we follow the standard procedure of using gross output as dependent variable and materials, real capital and labor as explanatory variables. Like Ferreira and Rossi (2003), the data are pooled assuming equal marginal products of the inputs across sectors. Although debatable, as we include sector fixed effects and (sometimes also) time dummies, we feel more comfortable with this approach than estimating factor shares individually per sector. The latter would imply rather few observations to determine the parameters as well as considerable time series challenges.

[1] An earlier version of the data and calculations are documented in Bartelsman and Gray (1996). We chose to use the 4-factor TFP-measure because this measure is closest to what we do for South Africa (3 factor). We get, however, identical results when we use the 5 factor measure. According to Bartelsman and Gray (1996), the five factor measure is calculated using observed expenditure shares as factor shares. The capital share is calculated as a residual under the assumption that the shares add to 1. We assume the same method was used when constructing the 4-factor TFP measure.

To allow for more heterogeneity across sectors, we also estimate the production functions with three different types of capital. Maximal heterogeneity is allowed in two TFP-measures calculated using (average or time varying) income shares of capital and labor as factor shares and value added as left hand side variable. These factor shares imply constant return to scale, are sector specific, and also year-specific in the latter case. Our results are robust also when using these measures and we are not concerned about the assumed common marginal effect of inputs across sectors. Inspired by the plant level literature on TFP-estimations, we present results using a productivity measure corrected for potential endogeneity of factor inputs by the method of Olley and Pakes (1996). In our setting the concern would be that inputs flow to sectors with the highest unobserved productivity, biasing the estimates of marginal factor products. [2] The correction does not affect our main results, as shown below. Except for the alternative with heterogeneous capital, the production factors are assumed homogenous in all our TFP specifications. Hence, changes in input quality are not corrected for and quality improvements are picked up by the estimated TFP-growth.

We assume the following standard Cobb-Douglas production technology, transforming inputs M, Capital K and labor L into output X in sector i at time t:

$$X_{it} = A_{it} M_{it}^{\gamma} K_{it}^{\alpha} L_{it}^{\beta} \tag{1}$$

A_{it} is the total factor productivity level in sector i at time t. Taking logs, we can estimate (1) with linear OLS. We favor estimating the factor shares after taking the first differences of the logs. All the variables included are typically assumed to be non-stationary, creating scope for spurious correlations. TFP levels typically trend over time and it is more than likely that the OLS assumption of zero serial correlation could be violated if we estimated in log levels. We also include sector fixed effects and a common intercept in the estimations:

[2] A challenge in estimating the production function is the endogeneity of factor inputs. The estimation requires that the residuals, interpreted as growth in TFP, are orthogonal to the factor inputs. However, productivity improvements clearly influence the profitability of sectors and thereby the flow of factor inputs. In some studies, factor rewards are used as instruments for factor inputs, but factor rewards are equally endogenous. Instruments are hard to find since we need a full time series that is important for factor input, but not for production. We chose the widely used Olley-Pakes method, which employ investment data to proxy unobserved productivity shocks. Another econometric challenge is the structural change within sectors that may lead to changing factor shares over time. The data period covers a turbulent period of the economy and the relative importance of the production factors may have changed, as discussed by Fedderke (2001). As our results hold time series of the factor shares are used, this is not a big worry for the results in this paper Measurement errors always are a source of potential inconsistent parameter estimates. Fedderke (2001) discusses mismeasurement of capital growth and the potential underestimation of the capital share. Ferreira and Rossi (2003) discusses the problem of bias towards decreasing returns to scale under fixed effects estimation due to bad measurement of within sector fluctuations.

$$d\ln X_{it} = \gamma d\ln M_{it} + \alpha d\ln K_{it} + \beta d\ln L_{it} + const + e_i + u_{it}, \qquad (2)$$

The estimated TFP log growth for sector i in period t becomes:

$$d\ln A_{it} = const + e_i + u_{it} \qquad (3)$$

The general intercept represents a common trend in the TFP-levels across sectors, while the sector fixed effects, e_i, capture sector specific trends. The OLS residual, u_{it}, then represents the variation of TFP log growth around its trend in sector i at time t. For normal growth rates we can interpret first differenced log levels as growth rates, and the residual in the regression is interpreted as TFP growth:

$$A_{it} = A_{it-1}(1 + d\ln A_{it}) \qquad (4)$$

The factor share estimates from the estimation of equation (2) are presented in column 1 in Table 1. The sum of the estimated factor shares is 0.954 and close to constant returns to scale. The factor share estimate of materials of 0.575 seems reasonable and consistent with the rule of thumb of around 0.5. Capital and labor shares of 1/3 and 2/3 respectively are standard for the remaining of the sum of the factor shares. Our estimate of the capital share of 0.054 is small, while the labor share of 0.325 seems more reasonable. When endogeneity of inputs is not accounted for the factor share of capital is typically 'too low'. Using the Olley-Pakes method to account for such endogeneity raises the estimate of the capital share. Column 2 in Table 1 reports estimates where year fixed effects are included in equation (2), marked as A_T. The most interesting change is that the effect of capital gets insignificant. Given that capital stock figures typically move slowly over time, it is not surprising that year fixed effects account for large parts of the movements in the capital. Column 3 reports a specification as equation (2), but where the capital is split into three sub-categories, A_{3K}. The estimates on the material share and labor share are like in column 1, while capital is non-significant. Column 4 presents estimate of equation (2) where the Olley-Pakes method is used to account for endogenity of factor inputs, $A_{OPD.}$[3] The estimates of the

[3] Olley-Pakes estimate TFP in levels: $\ln X_t = \ln A_t + \gamma \ln M_t + \alpha \ln K_t + \beta \ln L_t$. The residual is interpreted as the logarithm of TFP, implying: $A_t = e^{\ln A_t}$. We do the Olley-Pakes correction both when estimating in levels and on first differences. We include sector fixed effects in both stages for both.

factor shares of materials and labor stay as in column 1, while the factor share of capital is estimated to 0.142. The economy of scale therefore gets a little higher than in column 1, but is still roughly equal to one. Column 5 repeats the Olley-Pakes estimation on levels, as this is the most common way to employ the Olley-Pakes method, A_{OP}. Finally, columns 6 and 7 show observed factor shares as found in the TIPS dataset, which are calculated from the national accounts. We here assume the TFP-log growth to be given as the difference between log change in value added and the sum of the change in the log of the factors, weighted by their sector specific factor shares.[4] In Column 6 the factor shares are an average across our period, 1970-95, A_{is7095}, while they are a yearly time series in column 7 (presented as an average in the table), A_{is}. These factor shares are close to the standard factor shares of 1/3 to capital and 2/3 to labor.

The data are documented in Appendix table 1. As presented in Table 2 and Appendix table 2, the unweighted average sectoral log growth of TFP in South Africa in our period is varying across the different TFP measures. Most measures suggest an annual growth rate of about 0.3-0.4 percent. An interesting exception is A_T, for which time fixed effects are included in the production function estimation. The intuition for the high growth in A_T is that the time fixed effects take out the common downswing in productivity which was observed during the period of international sanctions in the 1980s. Our estimates are in broad accordance with TFP calculations of South Africa by Fedderke (2001, table 8-10) and Edwards (2004, table 3). There is no serious controversy over the description of the productivity development in South African manufacturing industries presented here. The log TFP growth for the U.S. is 0.3 percent on average, close to the observation for South Africa. While there are large differences across industries, the growth pattern for each sector is quite similar in South Africa and the U.S.. This is illustrated for selected industries in Figure 1. Dijk (2002) shows that the labor productivity relative to the U.S. has declined from 32% in 1970 to 20% in 1999. Our TFP numbers are fairly consistent with his labor productivity measure. South Africa has not been catching up to the world technology frontier.

Figure 1 about here.

In an extension we introduce a quality measure of human capital combined with the skill intensities of sectors to represent the human capital barrier faced at the sector level. Fedderke (2003) and Fedderke et al. (2003) apply the ratio of mathematical, natural and engineering

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4 $d \ln A_{it} = d \ln Y_{it} - \alpha_i d \ln K_{it} - \beta_i d \ln L_{it}$, where α_i and β_i are sector specific factor shares.

science (NES) degrees to the total number of degrees issued by the university system in South Africa as the best available measure of education quality in South Africa. In our context this is a measure of human capital relevant for technology adoption in manufacturing industries and name this variable H. South Africa has experienced a remarkably fall in H (see Figure 2). From the manufacturing sectors' point of view, this fall can be interpreted as a fall in the human quality of available highly skilled and skilled workers coming out from the education system. We agree with Vandenbusche, Aghion and Meghir (2004) that labor skills are relevant for technology adoption. The quality of highly skilled and skilled workers may matter more in sectors relatively intensive in their use of highly skilled and skilled workers. We calculate S as the sum of highly skilled and skilled workers as share of total labor use in each sector over 1970-1995. S_i is the average share (taking values between 0 and 1) of skilled and highly skilled workers in sector i across the years 1970-1995. Using the average rather than the time series makes S a sector fixed effect and represents the time invariant role of human capital in a sector. An interaction term between H and S is going to be the representation of the barrier at the sector level. Econometrically this formulation offers variation across sectors in the barrier variable, allowing us to include year dummies to adjust for aggregate shocks. As the variation over time is the same for all sectors, we always cluster standard errors on year.

H exists only until 1992 (although it starts way before 1970). As it takes some time before the students described by H flow into the industries and are influential, we focus on 2, 3 and 4 period lagged H x S in our analysis. Using 0 and 1 period lags make the results less robust, as expected. Human capital quality, H, is measured by the share of students in natural sciences, and this share is 16.5 percent on average, while the share of skilled and high skilled, S, is on average 32 percent. In combination with the lagged U.S. TFPs, H does not restrict our sample when using 3 and 4 lags. The dataset ends up covering 28 industrial sectors focusing on 1970-1995, with the lagged H and A* going back into the 1960s. We apply about 600 observations (see details in the tables).

3. Empirical strategy

The basic assumption of this analysis is that individual country industrial sector productivity growth cannot be understood in isolation, but should be related to the world technology frontier. Industrial sector productivities are to a large extent driven by the international development of similar sectors, and in particular the industrial sector world frontier. The basic linkage goes from the world industrial sector technology frontier, A^*_{it}, to the domestic industrial sector productivity,

A_{it}, (sector i, year t). The relative technology gap is the main determinant of the growth of productivity in the sector concerned. Industrial productivity growth in middle-income countries such as South Africa is first and for all about technology adoption and diffusion from the world market.

In the most general formulation the world frontier is estimated as the only determinant of domestic industrial sector productivity, given sector and time fixed effects. The econometric formulation goes as follows:

$$\ln A_{it} = \alpha_i + \alpha_t + \beta \ln A^*_{it-1} \tag{5}$$

This benchmark model tests the importance of the world technology for the domestic industrial TFP-development. Sector fixed effects take into account time-invariant unobserved factors affecting the variation in TFP across sectors. Year fixed effects take out all time variation common to the sectors. South Africa went through considerable macro shocks in this period, for instance international sanctions due to the Apartheid regime, which are taken into account by the year fixed effects. $\beta = 1$ implies that the South-African manufacturing sectors on average fully manage to take advantage of the growth in the international technology level. $\beta < 1$ implies that innovations at the international level are not completely exhausted in the South African industries.

Model (5) estimates an average relationship between the world frontier and domestic productivity. To investigate the dynamics between the two TFP-indexes further we estimate an error correction model where short run effects are separated out. The dependent variable is the growth rate of sectoral TFP, and the full model is:

$$\mathrm{d} \ln \mathrm{A}_{\mathrm{it}} = \alpha_{\mathrm{i}} + \beta \ln \mathrm{A}_{\mathrm{it}-1} + \gamma \ln \mathrm{A}^*_{\mathrm{it}-2} + \varepsilon \mathrm{d} \ln \mathrm{A}^*_{\mathrm{it}-1} \tag{6}$$

A significant, negative β indicates cointegration between the two series.

Cameron (2005), Cameron et al. (2005) and Griffith et al. (2004) innovated the econometric analysis of the world technology frontier at the industrial sector level. They suggest an error correction model separating between short run and long run effects and apply the technology gap, the ratio between frontier and domestic productivity, as independent variable. They show how this can be derived from the more general ADL-model. Their specification offer some problem in interpretation, however, since the gap term includes the lagged endogenous variable and consequently speed of adjustment. We prefer a specification where the world technology frontier is a separate independent variable. Another challenge in their specifications is that they take into account the level of TFP across the countries studied. Although interesting in the light of theory, it poses an empirical challenge of valuing goods across countries at the sector level. Some of the within sector developments in the TFP-gap could then be driven by different price and sector weighted exchange rate developments – on inputs or outputs - in the two countries. As sector specific ppp-adjusted price indices are hard to come by, we suggest a cleaner approach. We set the TFP-level in each sector in each country to 100 in 1970 and employ the TFP-growth to create technology indexes within sectors across time. Our analysis focus on whether changes in the international technology frontier induces any changes in the South African TFP. The cost of our approach is a lack of ability to analyze effects of the gap size and whether there are non-linearities according to the size of the gap.

The barrier model first formalized by Nelson and Phelps (1966) and implemented by Benhabib and Spiegel (1994, 2004) assumes that human capital is the main determinant of the barrier affecting the linkage to the world technology frontier. Human capital influences the capacity for technology adoption. Human capital stimulates catching up to the frontier. Human capital also may stimulate domestic innovations, but they are expected to be of limited importance in middle-income countries. In a multi-country setting the model has a stationary cross-country distribution where the productivity growth in all countries is equal to the world frontier growth rate. The level of human capital explains the productivity level relative to the world frontier. Higher human capital level increases the technology adoption and can directly contribute to higher productivity. A positive shift in the human capital level generates transitional higher productivity growth in the country and a new long run equilibrium with productivity level closer to the world frontier.

As explained above, a sector specific, time-varying measure of human capital quality is constructed by interacting an aggregate measure of human capital relevant for manufacturing industries, H_t, with sector-specific skill intensity, S_i (sector i). The assumption is that human capital quality is more important in high skill intensive industries. The interaction term is specified as $(\ln H_t) S_i$. The main hypothesis to be investigated is whether the down slide in our human capital quality measure was acting as an increased barrier to technology adoption. It follows that the interaction between the human capital quality measure and the international technology frontier is in question. The model allows for effect of the industrial sector world frontier and interaction between the frontier and the human capital quality measure:

$$\ln A_{it} = \alpha_i + \alpha_t + \beta \ln A^*_{it-1} + \gamma(\ln H_{t-2}) S_i \ln A^*_{it-1} \qquad (7)$$

The human capital measure is essentially a product of a variable varying only over time and a sector fixed effect, which constrains the specification. It follows that we have used the human capital as an interaction term with the world frontier only. We show that including the human capital measure separately instead of in interaction with the frontier produces basically the same results.

As explained above, we are in model (6) incapable to take into account the level of the technology gap and do only focus on the relation between changes in South African and U.S. TFP. The interaction term in model (7) includes a representation of the U.S. TFP-level. A positive γ indicates that human capital is more important the higher the U.S. TFP-level is. For given South African TFP, this is consistent with a decrease in the barrier leading to faster catch-up the higher the gap is. Strictly interpreted, it is nothing in our model ensuring that this effect is present only if the TFP-level in the U.S. is higher than in South Africa.

An alternative to the model of equation (7) focuses directly on the catching up towards the world frontier. The effect of human capital on the productivity gap A_{it}/ A^*_{it} is investigated directly:

$$\ln(A_{it} / A^*_{it}) = \alpha_i + \alpha_t + \beta(\ln H_{t-2}) S_i \qquad (8)$$

This specification is used as a robustness check of the role of human capital as barrier.

We present estimations of our two main models, equation (5) and (6), across a wide range of alternative TFP-specifications to show that our results are not dependent on the particular TFP-measurement employed. In equation (5) to (8) the domestic TFP-level is calculated from estimated production functions as explained in section 2.2. As a final robustness check we estimate the effects of our variable of interest, A* and H, in a one-step procedure often used (see for instance Javorcik, 2004):

$$\ln X_{it} = \gamma \ln M_{it} + \alpha \ln K_{it} + \beta \ln L_{it} + \kappa \ln A^*_{it-1} + \gamma(\ln H_{t-2}) S_i \ln A^*_{it-1} + e_i + e_t + u_{it} \quad (9)$$

In all models we have investigated various lags for the effects of the world frontier and the sector-specific human capital. The results are robust to alternative specification of lags. Some alternatives are reported below. In all estimations capacity utilization U is included as a variable to take into account short run shocks.

It can be argued that the analysis suffers from bias due to omitted variables at the sector-year level. Most of the empirical literature on industrial productivity growth focus on a series of domestic determinants, and we accept that there may be many other time varying characteristics at the sector level that are important for productivity. Our contribution, however, is not a full model including all determinants of productivity. Most domestic candidate variables are part of a nexus together with productivity. They are therefore notoriously endogenous and it is not clear how the estimated coefficients should be interpreted. Our contribution is to identify the effects of two key determinants of technology adoption. The estimates should not suffer from omitted variable bias if our variables are truly exogenous to South African sector productivity. A series of papers have focused on vehicles carrying the technology or know how from the world frontier (in the line of Coe et al. (1997) and following literature). Analyses focusing on foreign trade and foreign direct investment face the same endogeneity challenge as domestic determinants. In a companion paper (Harding and Rattsø, 2007) we investigate the effects of trade tariffs as barriers to productivity spillovers addressing this endogeneity (using industrial sector tariff development in other world regions as instruments).

4. Results: The world technology frontier

The basic model formulation relating industrial sector productivity to the industrial sector world technology frontier is shown in Table 3. Capacity utilization is always included as control variable to account for short term shocks. The first panel describes the relationship across seven measures of TFP and with one year lag. The second and third panels show the estimates with two and three year lag respectively. The estimates are based on data covering 28 sectors over 25 years, both for South Africa and the U.S. The effect of the world technology frontier is convincing. The coefficient in all 21 models shown is positive and statistically significant at the 1 % level.

The size of the coefficient linking South African industries to the world frontier depends on the methodology chosen to derive TFP. The three first TFP-measures, in columns 1-3, are based on estimating factor shares based on first differences of the logs; in column 2 with fixed effects and in column 3 with disaggregation of capital. The estimated coefficient is about 0.3-0.4 and not sensitive to length of lag. South Africa is not able to keep up with the development of the frontier according to these results. To account for endogeneity of factor inputs we apply the Olley-Pakes method in columns 4 and 5. When the Olley-Pakes adjustment is made on difference form, the coefficient increases to about 0.5, while the adjustment on level form reduces the coefficient to about 0.2. When TFP is estimated on levels, we assign neither a common nor a sector specific trend to the South African TFPs. As is seen in Table 2, the TFP-growth under this method is on the lower side compared to our other estimations. Since the TFP growth is lower, the coefficient measuring the link to the world frontier is lower. Finally, in columns 6 and 7 we apply the TFP-measures based on observed income shares, with average shares of the period in column 6 and with yearly time series in column 7. In contrast to the estimated production functions, now value added is employed on the left hand side and only capital and labor as input factors. This specification is often found in the literature, but is not our preferred alternative. The value added formulation only gives room for a restricted role of materials.[5] The coefficient linking to the world technology frontier increases to about 0.9 when we use the observed income shares and value added.

Table 3 about here

The main conclusion that stands out from Table 3 is that the industrial sector productivity growth in South Africa must be understood in the context of the industrial sector development abroad. Any attempt at explaining the industrial sector productivity growth in South Africa without taking into account the performance of the same industrial sectors abroad is misplaced. Industrial productivity growth must be explained in the context of industrial development elsewhere. Estimated coefficients at around 0.3-0.4 in our preferred specifications imply that a 1 percent growth in the frontier results in a 0.3-0.4 percent growth in the South African TFP. Ceteris paribus this implies that the South African TFP-level has been lagging behind the frontier in the period studied.

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[5] Implying a production function like: $X = M + Y = M + AK^{\alpha}L^{\beta}$

The dynamics of the link to the world technology frontier are investigated in an error correction formulation separating between short term and long term effects in Table 4. The South African TFP-indexes and the indexes of the world technology frontier are cointegrated, as the lagged frontier variables are negative and statistically significant at the 1 % level. The long run coefficients, found by setting all difference terms to zero and order South African TFP on the left hand side, vary between 0.5 and 0.9 across the various lags. These coefficients are larger than the earlier estimated coefficients for this productivity measure. Since year fixed effects are excluded to focus on the actual dynamics of the variables, the world frontier in this model may represent more of the general movement of South African industrial TFPs. In addition, this formulation is assumed to better identify the long run relationship as short term dynamics are explicitly accounted for. The error correction model confirms the strong effect of the world technology frontier and that South Africa has been lagging behind the world frontier.

The importance of the world technology frontier is in line with the few cross country analyses and industrial sector analyses addressing this relationship. The cross country studies, notably Caselli and Coleman (2006), Comin and Hobjin (2005) and Bernard and Jones (1996), indicate that technology diffusion from the most advanced economies is important to understand individual country productivity growth. Cameron et al. (2005) show the importance of the world technology frontier (measured by the U.S.) for productivity growth in UK manufacturing industries, but their estimates do not allow for a comparison of the degree of catching up. We have shown a middle income country that takes benefit of the world technology frontier, but that is lagging behind the frontier.

5. Results: Human capital as barrier

It is certainly of interest to expand the analysis of the world technology frontier to identify the channels and investigate the barriers of technology diffusion. Unfortunately most candidate variables to represent channels and barriers are endogenous. The key variable addressed in the barrier models of the Nelson-Phelps (1966) tradition is human capital. As explained above we have established an industrial sector specific measure of the quality of human capital of particular relevance for manufacturing industries. In this section we look at the combined effect of the world technology frontier and the quality measure of human capital.

We start out in Table 5, which is an extension of Table 3, by presenting the estimates of equation (7) across the seven different TFP-measures and with different lags on human capital quality. The total effect of the international frontier is now found as:

$$d\ln A_{it} / d\ln A^*_{it} = \beta + \delta(\ln H_{t-2})S_i \quad (10)$$

The direct effect of the international barrier, β, is estimated to be roughly 0.3 in Table 5 (except for the observed income share measures). The coefficients on the interaction terms are around 0.1 and the average value of the human capital term in our data is 0.878 (Appendix table 1). The total frontier effect is then found to be around 0.4 (0.3+0.1*0.878). Including the barrier gives about the same effect of the international frontier as previously found, but we now show that a part of the technology spillovers depend on human capital quality. As the total effect of the international frontier is about the same, this illustrates that out estimations in Table 3 do not suffer from omitted variable bias due to human capital. As equation (10) illustrates, a positive and significant δ implies that the frontier is more important the higher the human capital quality level.

Table 5 about here

Benhabib and Spiegel (1994, 2005) analyze two roles of human capital; in innovation and absorption. We believe the innovation channel to be of little importance in a middle income country like South Africa. Specifying the model with both an interaction term and human capital alone is too demanding for our dataset. The human capital quality measure is a product of sector and year fixed effects, which are already included in the model. For completeness we show in Table 6 estimates for a model where the human capital is included alone. The coefficients on the frontier are found to be around 0.3 as before, and the coefficients on the human capital are around 0.3-04. They are all significant at the 1 percent level.

The only difference between model 1 of Table 5 and model 1 of Table 6 is the functional form. The frontier effect of model 1, Table 5, is estimated to 0.29 (0.228+0.076*0.878). Similar to equation (10), the human capital effect is found to be about 0.35 (0.076*4.645). In model 1, Table 6, the estimates are 0.29 and 0.34, respectively. In other words, the estimates are basically the same, indicating that this variation in functional form is not important for the estimates.

Table 6 about here

The effect of human capital on the "productivity gap" A/ A* is investigated directly in Table 7. The estimates show a consistent positive effect of sector-specific human capital on the productivity gap, but the coefficients are less significant when the gap is measured with contemporary A* in the denominator. 1 and 2 period lagged frontier gives robust results for 3 and 4 period lagged human capital quality. A one percent increase in the human capital quality reduces the distance to the world technology frontier by about 0.3 percent. During the period studied the reduction in human capital has increased the distance to the world frontier. South Africa has been lagging behind because of decline in human capital quality important for manufacturing industries.

Table 7 about here

As a final robustness check we estimate the effects of the frontier and human capital in a one step procedure (Table 8 and Table 9). The effects are found to be quite robust, although the size of the coefficients is smaller and the frontier works only through the interaction term in some specifications. As already mentioned, the smaller coefficients compared to most of the earlier presented estimations could be due to inappropriate handling of general and sector specific trends when estimating in levels.

Table 8 and Table 9 about her

We conclude that the world technology frontier and human capital quality affect South African TFP in our period. This conclusion seems to be robust across a wide range of TFP measurements and functional forms and is consistent with the theoretical barrier model of productivity growth. Our results are broadly in accordance with the cross country evidence of Benhabib and Spiegel (2005). Caselli and Coleman (2006) emphasize the role of skills for technology diffusion. We have the importance of human capital quality in skill intensive sectors.

6. Concluding remarks

We offer a test of the importance of the industrial sector world technology frontier for the industrial sector productivity growth in South Africa. The world technology frontier is represented by productivity in the U.S. manufacturing sectors. The world technology frontier works as an exogenous driver of individual country industrial sector productivity. Industrial sector productivity development in South Africa cannot be understood without this linkage to the world frontier. We argue that existing productivity studies overlooking the world frontier may have serious omitted variable bias. In an extension using a quality measure of human capital as barrier we find that observed reduction in quality of human capital has held back technology adoption.

Given the importance of the world technology frontier for individual country productivity growth, the next step is to investigate channels of technology diffusion and further barriers to technology adoption. The main channels of diffusion discussed in the literature are foreign trade and foreign direct investment. Additional barriers to human capital discussed are openness of the economy and policy conditions for investment. The main challenge for this empirical research is the endogeneity of channels and barriers.

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Tables

Table 1: Factor shares in the different production functions

	1	2	3	4	5	6	7
Corresponding TFP-measure	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
Dependent variable	dln X	dln X	dln X	dln X	ln X	dln Y	dln Y
dln M	0.575***	0.547***	0.574***				
	[0.011]	[0.012]	[0.011]				
dln K	0.054**	0.035				0.353	0.353
	[0.025]	[0.027]				(0.180)	(0.180)
dln L	0.325***	0.265***	0.323***			0.647	0.647
	[0.030]	[0.032]	[0.030]			(0.180)	(0.180)
D. ln K structures			0.02				
			[0.026]				
D. ln K machinery			0.011				
			[0.013]				
D. ln K transp. eq.			0.018				
			[0.015]				
Beta_dM				0.572***			
				[0.011]			
Beta_dK				0.142***			
				[0.041]			
Beta_dL				0.328***			
				[0.030]			
Beta_M					0.614***		
					[0.011]		
Beta_K					0.047		
					[0.034]		
Beta_L					0.371***		
					[0.020]		
Observations	700	700	700	700	728	728	728
R-squared	0.83	0.86	0.83	0.83¤	0.93¤¤		

Note: Standard errors in brackets. Standard deviation of income shares across sectors in column 3 and across sectors and years in column 4 in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. ¤ corresponds to the first stage R-squared. ¤¤ corresponds to the first stage overall R-squared. Column 1 - 4 are from estimations of a first differenced Cobb-Douglas production function, with first differenced log gross output on the left hand side and first differenced log materials, capital and labor on the right hand side in addition to a general intercept and sector fixed effects. The estimation reported in column 2 contains in addition year fixed effects. Olley-Pakes' method to adjust for endogeneity of factor inputs is employed in column 4. Column 5 reports the coefficients from Olley-Pakes estimation in log levels. Sector fixed effects and a general intercept are included. Column 6 and 7 report average observed income shares of capital and labor over the period 1970-1995.

Table 2: average TFP log growth across time and sectors

Variable	No. of obs.	Mean	Std. Dev.	Min	Max
dln A	643	0.004	0.038	-0.148	0.293
dln A_T	643	0.020	0.035	-0.123	0.269
dln A_3K	643	0.004	0.038	-0.151	0.295
dln A_OPD	643	0.007	0.039	-0.144	0.292
dln A_OP	643	0.003	0.039	-0.152	0.365
dln A_is7095	643	0.003	0.078	-0.266	0.321
dln A_ists	643	0.003	0.078	-0.261	0.322
dln A*	643	0.003	0.028	-0.104	0.098

Note: table presents first differenced log TFP. Mean=0.004 means 0.4 percent average yearly growth in the level of TFP.

Table 3: International frontier

	1	2	3	4	5	6	7
	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
Ln A*-1	0.346***	0.423***	0.338***	0.539***	0.179**	0.966***	0.966***
	[0.087]	[0.099]	[0.089]	[0.116]	[0.083]	[0.129]	[0.128]
Ln U	-0.018	0.018	-0.028	0.110	-0.039	0.009	-0.003
	[0.058]	[0.063]	[0.059]	[0.067]	[0.061]	[0.114]	[0.110]
Observations	643	643	643	643	643	643	643
Number of sectors	28	28	28	28	28	28	28
R-squared within	0.21	0.80	0.21	0.31	0.15	0.19	0.20
R-squared overall	0.15	0.64	0.15	0.18	0.08	0.15	0.16

	8	9	10	11	12	13	14
	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
Ln A*-2	0.347***	0.419***	0.341***	0.513***	0.185**	0.930***	0.937***
	[0.076]	[0.086]	[0.077]	[0.102]	[0.070]	[0.120]	[0.122]
Ln U	-0.015	0.021	-0.025	0.110*	-0.037	0.011	0.000
	[0.054]	[0.059]	[0.055]	[0.062]	[0.059]	[0.109]	[0.105]
Observations	643	643	643	643	643	643	643
Number of sectors	28	28	28	28	28	28	28
R-squared within	0.21	0.80	0.21	0.31	0.15	0.18	0.19
R-squared overall	0.15	0.64	0.15	0.18	0.08	0.15	0.15

	15	16	17	18	19	20	21
	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
Ln A*-3	0.326***	0.399***	0.321***	0.473***	0.169***	0.844***	0.856***
	[0.063]	[0.072]	[0.063]	[0.089]	[0.057]	[0.117]	[0.122]
Ln U	-0.017	0.019	-0.027	0.105*	-0.039	0.000	-0.010
	[0.050]	[0.055]	[0.051]	[0.058]	[0.056]	[0.105]	[0.100]
Observations	643	643	643	643	643	643	643
Number of sectors	28	28	28	28	28	28	28
R-squared within	0.21	0.79	0.21	0.30	0.15	0.17	0.18
R-squared overall	0.15	0.64	0.15	0.17	0.08	0.15	0.15

Note: Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%.. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variables: TFP measures based on the production functions presented in Table 1.

Table 4: Error correction formulation of catch up: A and A* are cointegrated

	1	2	3
	dln A	dln A	dln A
ln A-1	-0.143***	-0.141***	-0.137***
	[0.040]	[0.040]	[0.041]
dln A*-1	0.092		
	[0.061]		
ln A*-2	0.131***		
	[0.046]		
dln A*-2		0.157	
		[0.103]	
ln A*-3		0.108***	
		[0.036]	
dln A*-3			0.138**
			[0.057]
ln A*-4			0.074*
			[0.036]
dln U	0.070	0.075	0.073
	[0.053]	[0.053]	[0.052]
ln U-1	0.073*	0.068	0.064
	[0.040]	[0.039]	[0.038]
	615	615	615
	27	27	27
	0.23	0.23	0.22
	0.15	0.15	0.14

Note: Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variable: log growth of TFP-level A. A is based on the estimates on factor shares reported in column 1, Table 1. The TFP-level A is calculated by setting the level to 100 in 1970 and employing the growth rate.

Table 5: Human capital

	1	2	3	4	5	6	7
	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
ln A*-1	0.228***	0.330***	0.226**	0.264**	0.066	0.824***	0.818***
	[0.080]	[0.094]	[0.081]	[0.100]	[0.072]	[0.109]	[0.110]
ln H-2 x S x ln A*-1	0.076***	0.036	0.068***	0.233***	0.074**	0.077	0.088
	[0.023]	[0.021]	[0.024]	[0.028]	[0.027]	[0.064]	[0.065]
ln U	-0.027	0.008	-0.039	0.113	-0.052	0.010	-0.001
	[0.060]	[0.066]	[0.061]	[0.069]	[0.062]	[0.118]	[0.115]
Observations	615	615	615	615	615	615	615
Number of sectors	27	27	27	27	27	27	27
R-squared within	0.20	0.79	0.20	0.31	0.14	0.18	0.19
R-squared overall	0.00	0.54	0.00	0.01	0.00	0.02	0.01

	8	9	10	11	12	13	14
	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
ln A*-1	0.271***	0.381***	0.268***	0.330***	0.106	0.862***	0.855***
	[0.079]	[0.094]	[0.080]	[0.100]	[0.072]	[0.107]	[0.107]
ln H-3 x S x ln A*-1	0.088***	0.049***	0.081***	0.244***	0.084***	0.121**	0.129**
	[0.018]	[0.016]	[0.019]	[0.025]	[0.021]	[0.057]	[0.058]
ln U	-0.019	0.018	-0.029	0.107	-0.041	0.008	-0.004
	[0.057]	[0.063]	[0.058]	[0.066]	[0.060]	[0.112]	[0.109]
Observations	643	643	643	643	643	643	643
Number of sectors	28	28	28	28	28	28	28
R-squared within	0.22	0.80	0.22	0.33	0.15	0.19	0.20
R-squared overall	0.00	0.50	0.00	0.01	0.00	0.01	0.00

	15	16	17	18	19	20	21
	ln A	ln A_T	ln A_3K	ln A_OPD	ln A_OP	ln A_is7095	ln A_ists
ln A*-1	0.262***	0.373***	0.261***	0.320***	0.100	0.848***	0.840***
	[0.080]	[0.095]	[0.081]	[0.100]	[0.073]	[0.109]	[0.109]
ln H-4 x S x ln A*-1	0.094***	0.056***	0.087***	0.248***	0.089***	0.134**	0.142***
	[0.015]	[0.013]	[0.015]	[0.025]	[0.017]	[0.050]	[0.051]
ln U	-0.021	0.016	-0.031	0.100	-0.043	0.004	-0.009
	[0.058]	[0.063]	[0.058]	[0.068]	[0.061]	[0.112]	[0.109]
Observations	643	643	643	643	643	643	643
Number of sectors	28	28	28	28	28	28	28
R-squared within	0.22	0.80	0.22	0.33	0.15	0.19	0.20
R-squared overall	0.00	0.47	0.00	0.01	0.01	0.00	0.00

Note: Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%.. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variables: TFP measures based on the production functions presented in Table 1.

Table 6: Single human capital

	1	2	3	4	5	6
	ln A	ln A	ln A	ln A	ln A	ln A
ln A*-1	0.289***	0.341***	0.339***			
	[0.085]	[0.085]	[0.085]			
ln A*-2				0.296***	0.343***	0.344***
				[0.073]	[0.074]	[0.074]
ln H-2 x S	0.335***			0.324***		
	[0.103]			[0.114]		
ln H-3 x S		0.360***			0.367***	
		[0.079]			[0.092]	
ln H-4 x S			0.384***			0.414***
			[0.065]			[0.075]
ln U	-0.029	-0.021	-0.023	-0.025	-0.018	-0.020
	[0.060]	[0.057]	[0.058]	[0.057]	[0.054]	[0.054]
Observations	615	643	643	615	643	643
Number of sectors	27	28	28	27	28	28
R-squared within	0.20	0.22	0.22	0.21	0.22	0.22
R-squared overall	0.00	0.00	0.00	0.00	0.00	0.00

Note: Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%.. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variable: TFP log growth is calculated as the sum of the residual, the general intercept and the sector specific fixed effect from an estimation of a first differenced Cobb-Douglas production function, with first differenced log gross output on the left hand side, and first differenced log materials, capital and labor on the right hand side in addition to a general intercept and sector fixed effects. The estimates on factor shares are reported in column 1, Table 1. The TFP-level is calculated by setting the level to 100 in 1970 and employing the growth rate.

Table 7: Catch up directly

	1	2	3	4	5	6	7	8	9
	ln (A/A*)	ln (A/A*)	ln (A/A*)	ln (A/A*-1)	ln (A/A*-1)	ln (A/A*-1)	ln (A/A*-2)	ln (A/A*-2)	ln (A/A*-2)
Ln H-2 x S	0.179			0.248			0.212		
	[0.111]			[0.151]			[0.164]		
Ln H-3 x S		0.196*			0.286**			0.308**	
		[0.097]			[0.120]			[0.133]	
Ln H-4 x S			0.179*			0.284**			0.373***
			[0.091]			[0.112]			[0.122]
Ln U	0.106	0.107	0.106	0.074	0.074	0.072	0.083	0.081	0.079
	[0.074]	[0.069]	[0.069]	[0.085]	[0.079]	[0.079]	[0.076]	[0.071]	[0.071]
Observations	615	643	643	615	643	643	615	643	643
Number of sectors	27	28	28	27	28	28	27	28	28
R-squared within	0.17	0.16	0.16	0.14	0.14	0.14	0.14	0.14	0.14
R-squared overall	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01

Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%.. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variable: log of the ratio between A and A*. A is based on the estimates on factor shares reported in column 1, Table 1 The TFP-level A is calculated by setting the level to 100 in 1970 and employing the growth rate. A* is the TFP-level of the corresponding US manufacturing sector, as calculated by NBER (2000)

Table 8: One step

	1	2	3	4	5	6	7	8
	ln X	ln X	ln X	ln X	ln X	ln X	ln X	ln X
ln M	0.587***	0.579***	0.584***	0.583***	0.588***	0.579***	0.585***	0.584***
	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]
ln K	0.143***	0.135***	0.150***	0.150***	0.143***	0.136***	0.150***	0.151***
	[0.019]	[0.022]	[0.021]	[0.021]	[0.020]	[0.023]	[0.021]	[0.021]
ln L	0.357***	0.379***	0.363***	0.364***	0.355***	0.376***	0.361***	0.362***
	[0.031]	[0.030]	[0.031]	[0.031]	[0.031]	[0.030]	[0.031]	[0.031]
ln A*-1	0.158**	0.021	0.048	0.039				
	[0.063]	[0.045]	[0.047]	[0.049]				
ln A*-2					0.169***	0.043	0.063	0.056
					[0.054]	[0.038]	[0.042]	[0.043]
ln H-2 x S x ln A*-1		0.110***						
		[0.030]						
ln H-3 x S x ln A*-1			0.124***					
			[0.025]					
ln H-4 x S x ln A*-1				0.132***				
				[0.021]				
ln H-2 x S x ln A*-2						0.102***		
						[0.030]		
ln H-3 x S x ln A*-2							0.120***	
							[0.026]	
ln H-4 x S x ln A*-2								0.130***
								[0.022]
ln U	-0.021	-0.034	-0.022	-0.026	-0.018	-0.031	-0.019	-0.022
	[0.059]	[0.060]	[0.059]	[0.059]	[0.057]	[0.059]	[0.057]	[0.057]
Observations	643	615	643	643	643	615	643	643
Number of sectors	28	27	28	28	28	27	28	28
R-squared within	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
R-squared overall	0.93	0.95	0.95	0.95	0.93	0.95	0.95	0.95

Note: Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%.. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variable: log gross output.

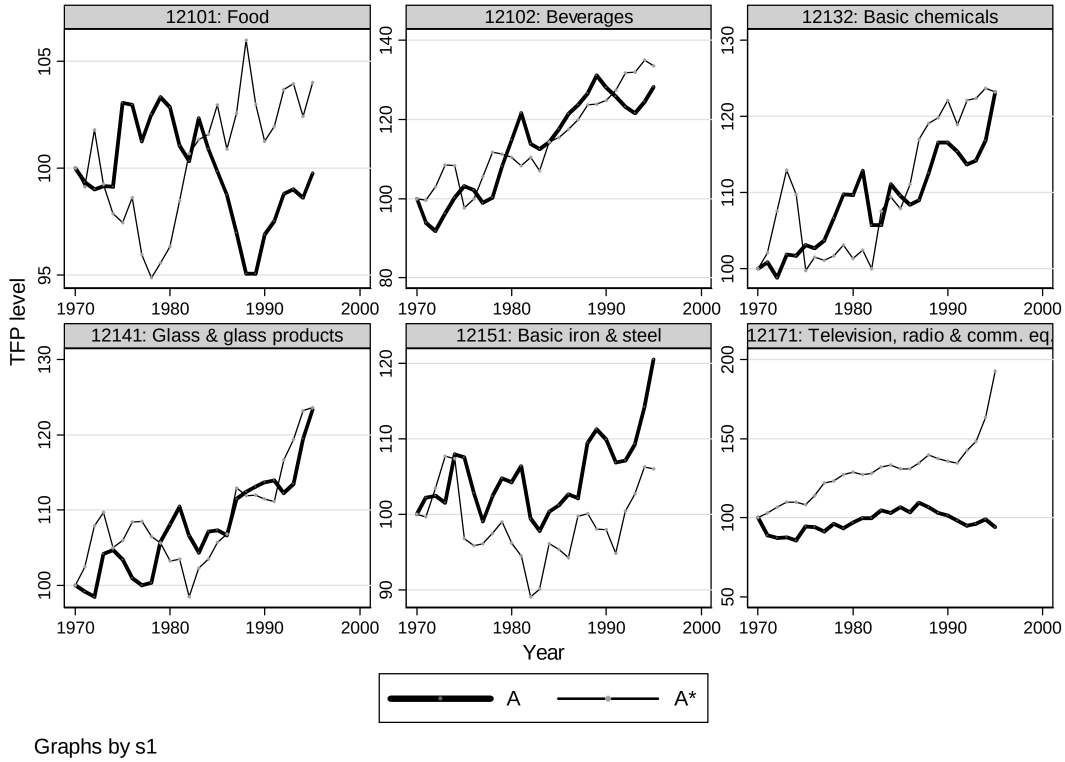
Table 9: One step, heterogeneous capital

	1	2	3	4	5	6	7	8
	ln X	ln X	ln X	ln X	ln X	Ln X	ln X	ln X
ln M	0.598***	0.589***	0.596***	0.595***	0.599***	0.589***	0.597***	0.595***
	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]
ln L	0.342***	0.364***	0.346***	0.347***	0.339***	0.361***	0.344***	0.344***
	[0.033]	[0.032]	[0.034]	[0.034]	[0.033]	[0.032]	[0.034]	[0.034]
ln K structures	0.121***	0.115***	0.129***	0.129***	0.122***	0.116***	0.130***	0.130***
	[0.020]	[0.021]	[0.021]	[0.021]	[0.020]	[0.022]	[0.022]	[0.021]
ln K machinery	0.035***	0.035***	0.031***	0.032***	0.035***	0.037***	0.032***	0.032***
	[0.007]	[0.007]	[0.007]	[0.007]	[0.008]	[0.007]	[0.008]	[0.008]
ln K transp. eq.	-0.029**	-0.035**	-0.027*	-0.026*	-0.029*	-0.036**	-0.027*	-0.027*
	[0.014]	[0.015]	[0.015]	[0.015]	[0.014]	[0.015]	[0.015]	[0.015]
ln A*-1	0.170***	0.050	0.061	0.052				
	[0.051]	[0.042]	[0.041]	[0.043]				
ln A*-2					0.187***	0.079**	0.081*	0.075*
					[0.043]	[0.037]	[0.041]	[0.042]
ln H-2 x S x ln A*-1		0.105***						
		[0.032]						
ln H-3 x S x ln A*-1			0.118***					
			[0.027]					
ln H-4 x S x ln A*-1				0.124***				
				[0.022]				
ln H-2 x S x ln A*-2						0.098***		
						[0.032]		
ln H-3 x S x ln A*-2							0.115***	
							[0.027]	
ln H-4 x S x ln A*-2								0.124***
								[0.023]
ln U	0.029	0.020	0.033	0.030	0.033	0.025	0.037	0.035
	[0.064]	[0.067]	[0.064]	[0.064]	[0.062]	[0.066]	[0.063]	[0.063]
Observations	643	615	643	643	643	615	643	643
Number of sectors	28	27	28	28	28	27	28	28
R-squared within	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
R-squared overall	0.93	0.95	0.95	0.95	0.93	0.95	0.95	0.95

Note: Robust standard errors in brackets (clustered on year). * significant at 10%; ** significant at 5%; *** significant at 1%.. Sector and year fixed effects included. Years in database: 1965-1995. Left hand side variable: log gross output.

Figures

Figure 1: TFP level in South Africa and U.S.(*)



Note: A corresponds to the TFP calculated from the estimates reported in column 1,Table 1. The TFP-level is calculated by setting the level to 100 in 1970 and employing the growth rate. A* is the TFP-level of the corresponding US manufacturing sector, as calculated by NBER (2000)

Figure 2: Human capital quality, H

Note: H is the percent mathematical, natural and engineering science (NES) degrees of the total number of degrees issued by the university system in South Africa

Appendix

Appendix table 1: Descriptive statistics

Variable	No. of observations	Mean	Std. Dev.	Min	Max
X	615	9790.373	8824.333	513.519	47649.890
M	615	6348.181	6568.813	168.741	37033.530
K	615	3912.233	5713.863	87.376	49995.030
L	615	53541.280	44335.180	3121.000	207068.100
A	615	105.612	9.937	79.324	143.746
A _T	615	131.528	24.290	93.023	216.705
A _3K	615	105.743	9.977	80.504	145.241
A _OPD	615	109.697	17.620	67.107	182.797
A _OP	615	104.475	9.268	80.534	156.946
A _is7095	615	106.598	24.096	16.997	185.431
A _ists	615	107.116	24.191	18.510	186.969
H-2	615	16.510	1.951	13.811	21.309
S	615	0.315	0.121	0.098	0.728
A*	615	104.355	8.083	74.227	132.004
U	615	82.917	6.456	58.173	94.829
Year	615			1971	1994
ln X	615	8.789	0.950	6.241	10.772
ln M	615	8.278	1.026	5.128	10.520
ln K	615	7.530	1.304	4.470	10.820
ln L	615	10.500	0.963	8.046	12.241
ln A	615	4.655	0.093	4.374	4.968
ln A _T	615	4.863	0.177	4.533	5.379
ln A _3K	615	4.657	0.092	4.388	4.978
ln A _OPD	615	4.686	0.155	4.206	5.208
ln A _OP	615	4.645	0.087	4.389	5.056
ln A _is7095	615	4.639	0.266	2.833	5.223
ln A _ists	615	4.644	0.263	2.918	5.231
ln H-2	615	2.797	0.116	2.625	3.059
S	615	0.315	0.121	0.098	0.728
ln H-2 x S	615	0.878	0.328	0.260	1.911
ln H-2 x S x ln A*-1	615	4.080	1.459	1.264	8.909
ln A*	615	4.645	0.079	4.307	4.883
ln U	615	4.415	0.081	4.063	4.552

Note: the sample of 615 observations corresponds to the sample of the upper panel of Table 5.

Appendix table 2: TFP log growth across time by sector

Sector	No. of obs.	dln A	dln A_T	dln A_3K	dln A_OPD	dln A_OP	dln A_is7095	dln A_ists	dln A*
12101: Food	25	0.000	0.000	0.000	0.010	0.005	0.007	0.006	0.000
12102: Beverages	25	0.010	0.028	0.011	0.016	0.008	0.006	0.005	0.013
12103: Tobacco	25	-0.005	0.011	0.000	-0.001	0.000	-0.009	-0.008	-0.008
12111: Textiles	25	0.005	0.020	0.006	0.012	0.006	0.010	0.010	0.009
12112: Wearing apparel	25	0.005	0.022	0.005	0.011	0.002	0.011	0.011	0.005
12113: Leather & leather products	25	0.006	0.022	0.006	0.011	0.005	0.006	0.004	0.000
12114: Footwear	25	-0.001	0.015	0.000	-0.002	-0.002	-0.002	-0.002	-0.003
12121: Wood & wood products	25	0.003	0.020	0.004	0.007	0.002	0.006	0.007	0.004
12122: Paper & paper products	25	0.006	0.024	0.006	0.010	0.004	0.007	0.004	0.002
12123: Printing, pub. & rec. media	25	-0.006	0.012	-0.005	-0.012	-0.008	-0.012	-0.012	0.001
12131: Coke & refined petroleum prod.	7	0.002	0.023	0.006	0.008	0.001	-0.053	-0.055	-0.001
12132: Basic chemicals	25	0.008	0.027	0.009	0.014	0.006	0.012	0.013	0.007
12133: Other chem. & man-made fib.	10	0.019	0.038	0.019	0.036	0.018	0.051	0.050	0.000
12134: Rubber products	25	0.004	0.020	0.005	0.008	0.003	0.006	0.005	0.008
12135: Plastic products	25	0.011	0.030	0.011	0.021	0.007	0.028	0.029	0.008
12141: Glass & glass products	25	0.008	0.025	0.009	0.014	0.008	0.016	0.018	0.007
12142: Non-metallic minerals	25	0.003	0.019	0.004	0.006	0.003	0.003	0.003	0.004
12151: Basic iron & steel	25	0.007	0.023	0.008	0.013	0.007	0.011	0.010	0.000
12152: Basic non-ferrous metals	25	0.016	0.034	0.018	0.026	0.015	0.029	0.024	-0.001
12153: Metal prod. excl. mach.	25	-0.002	0.014	-0.001	-0.006	-0.002	-0.008	-0.008	0.001
12154: Machinery & equipment	25	0.000	0.016	0.001	0.000	0.000	-0.001	-0.001	0.003
12160: Electrical machinery	25	0.007	0.024	0.008	0.012	0.005	0.017	0.017	0.003
12171: Television, radio & comm. eq.	1	-0.052	-0.057	-0.050	-0.060	-0.042	-0.137	-0.133	0.098
12172: Professional & scientific eq.	25	-0.004	0.014	-0.003	-0.008	-0.007	0.002	0.003	0.006
12181: Motor vehicles, parts & acc.	25	0.005	0.023	0.006	0.010	0.005	0.009	0.008	0.007
12182: Other transport equipment	25	-0.009	0.005	-0.007	-0.015	-0.005	-0.025	-0.025	-0.002
12191: Furniture	25	0.006	0.023	0.006	0.012	0.004	0.013	0.013	0.002
12193: Other industries	25	0.010	0.027	0.012	0.022	0.010	0.019	0.016	0.004
Sum or Average	643	0.002	0.018	0.003	0.006	0.002	0.001	0.000	0.006

Note: table presents first differenced log TFP. Mean=0.004 means 0.4 percent average yearly growth in the level of TFP.

Appendix table 3: concordance TIPS data and SIC 87

Code SA	Name South Africa	Code SIC 87	Name SIC 87, NBER
12101	Food [301-304]	20	Food and kindred products
12102	Beverages [305]	20	Food and kindred products
12103	Tobacco [306]	21	Tobacco products
12111	Textiles [311-312]	22	Textile mill products
12112	Wearing apparel [313-315]	23	Apparel and other textile products
12113	Leather & leather products [316]	31	Leather and leather products
12114	Footwear [317]	31	Leather and leather products
12121	Wood & wood products [321-322]	24	Lumber and wood products
12122	Paper & paper products [323]	26	Paper and allied products
12123	Printing, publishing & recorded media [324-326]	27	Printing and publishing
12131	Coke & refined petroleum products [331-333]	29	Petroleum and coal products
12132	Basic chemicals [334]	28	Chemicals and allied products
12133	Other chemicals & man-made fibers [335-336]	28	Chemicals and allied products
12134	Rubber products [337]	30	Rubber and miscellaneous plastics products
12135	Plastic products [338]	30	Rubber and miscellaneous plastics products
12141	Glass & glass products [341]	32	Stone, clay, and glass products
12142	Non-metallic minerals [342]	32	Stone, clay, and glass products
12151	Basic iron & steel [351]	33	Primary metal industries
12152	Basic non-ferrous metals [352]	33	Primary metal industries
12153	Metal products excluding machinery [353-355]	34	Fabricated metal products
12154	Machinery & equipment [356-359]	35	Machinery, except electrical
12160	Electrical machinery [361-366]	36	Electric and electronic equipment
12171	Television, radio & communication equipment [371-373]	36	Electric and electronic equipment
12172	Professional & scientific equipment [374-376]	38	Instruments and related products
12181	Motor vehicles, parts & accessories [381-383]	37	Transportation equipment
12182	Other transport equipment [384-387]	37	Transportation equipment
12191	Furniture [391]	25	Furniture and fixtures
12193	Other industries [392]	39	Miscellaneous manufacturing industries

Note: The NBER data set used to construct the international frontier, A*, includes 459 4-digits SIC sectors. Each was matched to the corresponding 3-digit sector in South Africa. This table gives the rough picture of the concordance. The detailed concordance is available upon request from the authors.