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LOOKING ABROAD, BUT LAGGING BEHIND: HOW THE WORLD TECHNOLOGY FRONTIER AFFECTS SOUTH AFRICA

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Looking Abroad, but Lagging Behind: How the World Technology Frontier Affects South Africa

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Abstract: Industrial sector technology growth must be understood in the context of the international technology development. We study South African manufacturing industries and let the US represent the world technology frontier. The industrial sector linkages between domestic and frontier technology shocks are estimated using panel-data for the period 1970 – 1995. The results show that industrial performance in South Africa is related to the world technology frontier and consequently existing studies of technology overlooking the international context have omitted variable bias. We find that South Africa industries respond to the technology gap to the US, but that the industries are lagging behind. The analysis explains prolonged stagnation in this middle income country and rejects catching up to the frontier.

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JEL – codes: F13, F43, O11, O33, O55, Key words – World technology frontier, barriers to growth, technology adoption, international technology spillover, South Africa, total factor productivity, technology shock.

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1. Introduction

The recent literature on technology growth has set the focus towards international technology spillovers. 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. We contribute to the empirical literature of technology growth by analyzing how the industry specific technological shocks in South Africa (SA) are correlated with technological shocks in the corresponding industries at the world technology frontier, here the US.

The analysis of the industrial sector technology spillover shocks is related to recent analyses of spillovers and border effects. A few studies link industrial sector productivity growth to the world technology frontier, notably Cameron et al. (2005) for UK industries and Cameron (2005) for Japan. We suggest a more general error correction model to identify the effect of the frontier and apply the measurement of technology shocks analyzed by Basu et al. (2006, from now on called BFK). The analysis of a middle income country, South Africa, allows for an investigation of the industrial development far from the technology frontier. Vigfusson (2008) analyzes how productivity fluctuations are industry specific versus how much are country specific using data on manufacturing industries in Canada and the United States. He shows that cross-border pairings of the same industries are often highly correlated. As will come clear, we apply his method of identification of scale effects in the measurement of technology shocks.

Our representation of the world technology frontier is the technology indexes estimated by BFK for US industries. On the South African side we use the TIPS (Trade and Industry Policy Strategies) panel data set of manufacturing industries during 1970-1995 (TIPS, 2004). We follow the approach of BFK and estimate the growth in the technology indexes from a production function allowing for imperfect competition, non-constant returns to scale and changes in capacity utilization. We show that our estimations are robust to the alternative standard multi factor productivity measures for South Africa and the US. Aghion et al. (2008) use similar industrial sector data for South Africa in a broader analysis of the determinants of a more conventional measure of total factor productivity. Their contribution is an investigation of hypotheses from new trade and growth theory. We have a more narrow focus in the identification of the role of the world frontier and avoid including other factors that have potential endogeneity problems.

Our main result is that industry sector technology shocks in SA are influenced by technology shocks in corresponding US industries, but that the SA industries are not catching up to the US. It follows that productivity studies excluding the world technology frontier have an omitted variable problem. Individual country industrial sector growth cannot be understood independent of the technological frontier. The whole field of country oriented industrial productivity analysis has had the focus on country determinants, but our study shows that these studies miss out that industries are part of a global industrial development. You have to look abroad to understand industrial productivity growth.

South Africa is taking benefit of the world technology frontier, but is also lagging behind. When we estimate the relationship between technology shocks and the technology gap in line with Cameron et al. (2005) and Cameron (2005), we find slow adjustment response to the gap. Long run equilibrium with equal growth rates between industries in SA and the US is rejected. The results indicate that about 25 % of frontier growth is absorbed in South Africa. This rejection of an equilibrium gap implies technology growth divergence. South African industries experience prolonged stagnation instead of catching up.

The result is inconsistent with the more optimistic literature on international spillovers (see overview article by Klenow and Rodriguez-Clare, 2005). The broader understanding of catching up often is called the Veblen-Gerschenkron-effect, with more rapid technological growth in the follower to close the technology gap to the leader. [1]

[1] 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). 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).

According to this literature divergence and lagging behind can be understood as movement to a low-equilibrium growth or as the result of worsening barriers to technology adoption. Benhabib and Spiegel (2004) show the dynamics of divergence, but this low-equilibrium story looks less realistic for South Africa. It seems reasonable to assume that lagging behind is the result of shifting barriers affected by trade protection, limited human capital and/or domestic market conditions. Harding and Rattsø (2009) investigate the trade policy effect in SA using identification based on multilateral reform and find that protection may explain some of the productivity stagnation. Aghion et al. (2008) investigate broader mechanisms of trade and growth in SA based on recent theoretical innovations. Their results indicate that competition may be important for the foreign channel, which is consistent with the analysis of domestic competition conditions in SA by Aghion et al. (2006).

Individual country productivity analysis typically concentrates on domestic determinants, possibly including foreign trade and 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. Our analysis of correlation of technology shocks across borders represents an answer to the econometric challenges of the existing literature. The world technology frontier can plausibly be treated as exogenous for middle income countries like South Africa. In the analysis below, unobservable factors potentially important for productivity developments are accounted for by sector and year fixed effects. We do not claim that the correlation of technology shocks necessarily is a causal effect of the technology frontier. It can be argued that the US and South Africa have experienced common technology shocks that explain the correlation. This interpretation does not threaten our conclusion that the productivity development must be understood in the international context.

Section 2 presents data, methodology and estimates of technology shocks, and econometric approach. The estimated effects of the world technology frontier are shown in section 3. Concluding remarks are offered in section 4.

2. Data and estimation of technology shocks

The analysis relates measures of industrial productivity in South Africa and the world technology frontier represented by the US manufacturing sectors. Our starting point is the BFK estimation of technological change for 21 US manufacturing sectors for the period 1949-1996. Their estimation of technology shocks goes beyond the crude Solow residual as they also take into account sector specific returns to scale, imperfect competition and capacity utilization. They find that their measure has about half the variation of the plain Solow residual. We let the technology growth series provided by BFK represent technology shocks on the frontier.

We establish a similar South African industrial panel of manufacturing sectors covered by the TIPS (Trade and Industry Policy Strategies, 2004).[2] The South African data contain yearly gross output (X), value added (Y), materials (M), capital (K), labor (L), labor and capital compensation, energy usage (E) and a measure of capacity utilization (U) for the period. To measure technology shocks in the South African manufacturing sectors we estimate a production function similar to BFK and Vigfusson (2008). We focus on the period 1971-1995, as data for years after 1996 are of questionable quality since the last manufacturing survey was undertaken in 1996 BFK estimate over 47 years, while Vigfusson estimates over 36 and we estimate over 25 years.[3]

The variables used in the analysis are documented in appendix Table 1. Growth rates are reported for output (dy), capital input (dk), labor input (dl) and materials input (dm). Aggregate input growth is measured by dx. Output and aggregate input have average annual growth over the 480 observations of about 2.7 %. The capacity utilization U is reported from the TIPS dataset with percentage point change dU.

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[2] The 28 manufacturing sectors in the TIPS dataset is aggregated to the same 21 sectors as used by BFK. The petroleum sector is excluded due to lack of data for many years and we end up with 20 sectors.

[3] Given the last manufacturing survey of 1996 we have prolonged the data series to 2003 and have extended the US dataset accordingly. The estimates using this longer dataset are similar to the results reported below.

In the estimation of the production functions we use three factors (K, L, and M) as BFK. The BFK method addresses two important challenges. The first is to take into account the effect of changing capacity utilization. While BFK make use of hours worked by employees, we employ a direct measure of capacity utilization provided in the TIPS-dataset. In a robustness check we use growth in electricity consumption as suggested by Vigfusson (data on hours worked are missing in our dataset).

The other challenge is the handling of scale. Whereas BFK estimate sector specific returns to scale parameters, Vigfusson restricts his scale parameters to vary only between durable and non-durable sectors. Both BFK and Vigfusson let the capacity utilization coefficient vary only between durable and non-durable sectors. We choose to follow Vigfusson and consequently estimate only four parameters (capacity utilization and scale across the two types of sectors). Although the results of BFK (see their table 1) point to relatively large differences between sectors regarding the scale parameters, we see our simplified representation as an improvement compared to the standard procedure. Ferreira and Rossi (2003), for instance, assume equal marginal products of the inputs across all sectors. As we include sector fixed effects in the estimations, 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.

Following BFK, the production function of gross output Y_{it} in sector i in year t can be specified as:

$$Y_{it} = F(U_{it}^{K} K_{it}, U_{it}^{L} L_{it}, M_{it}, Z_{it}) \qquad (1)$$

M is intermediate inputs, K is capital, L is labor, U^K and U^L indicates capacity utilization for capital and labor, respectively, and Z is a technology index. BFK show that the growth in the technology index, dz, can be estimated by:[4]

[4] Output growth can be expressed as: $dy_{it} = \gamma_j (dx_{it} + du_{it}) + dz_{it}$, where dx is defined as in (4) and $du_{it} = s_{K,it} du_{it}^{K} + s_{L,it} du_{it}^{L}$. For constant returns to scale/perf. comp. and no utilization changes, dz equals the standard Solow residual, i.e. growth in multifactor productivity: $dz_{it} = dmfp_{it} = dy_{it} - dx_{it}$

$$dy_{it} = \gamma_i dx_{it} + \beta_i du_{it} + c_i + dz_{it}\,, \qquad (2)$$

Where dy and dx is growth in output and input, respectively. du is growth in capacity utilization, capturing the capacity utilization of both capital and labor. c is a sector-specific constant capturing a sector specific trend. As Vigfusson we specify the relationship on first differenced log form and estimate

$$dy_{it} = \gamma_j dx_{it} + \beta_j du_{it} + c_i + dz_{it}\,, \qquad (3)$$

Where j indicates durables versus non-durables, and

$$dx_{it} = s_{K,it} dk_{it} + s_{L,it} dl_{it} + s_{M,it} dm_{it}\,, \qquad (4)$$

The shares s_K, s_L, s_M are the value weights of capital, labor and intermediates in gross output.[5]

Input growth, dx, may be correlated with the technology growth and estimating (3) with OLS could give biased estimates of the scale parameter. We therefore instrument dx in equation (3). We directly employ BFK’s instruments, which are lagged oil price shocks, lagged US monetary shock and lagged US military spending (see BFK for explanation and data). Especially oil price shocks are found to be a good predictor in the South African case as well. To reduce potential problems of weak instruments we also add current gold price, measured in USD as an instrument in our main specification. In alternative formulations we use current platinum price as an additional instrument. The intuition behind the BFK instruments are that these are important business cycle characteristics affecting inputs, but not technology. The same argument goes for the

[5] For South Africa we do only have the manufacturing panel in 1995-prices. Theory suggests that the value shares should be measured in current prices. Our wage bill and capital compensation bill is now deflated with output prices, and only if wage and capital compensation inflation differ from output price inflation our wages would be different from the ones calculated with current prices. BFK use average factor shares over their whole period, we chose a time series of factor shares. We believe that none of these two differences affect our results as the results are robust to technology measures from production functions with estimated factor shares,

prices of gold and platinum. These are arguably determined at the world market, but are correlated with input use in South Africa as these are important metals for South Africa. For all of these instruments, it seems reasonable, for given capacity utilization, that they affect gross output only through inputs and not directly or through technology. The exclusion restriction therefore seems to be plausibly satisfied. In contrast to BFK and Vigfusson, we prefer to use the cleaner 2SLS approach rather than the less transparent GMM-procedures they are using. The instruments data are documented in Appendix Table 1.

Our estimated growth in the technology index is calculated as $c_i + dz_{it}$ (the sector fixed effects, c_i, capture sector specific trends, and the residual, dz_{it}, variation of technology growth around its trend) and the technology index is calculated as:

$$Z_{it} = Z_{it-1}(1 + c_i + dz_{it}) \qquad (5)$$

We use the same approach when constructing technology indexes for the US. The growth rates are then taken to be BFKs estimated technology shocks, included their estimated constants. For both countries we set the indexes to 100 in 1971. A concern can be raised about the long run implications of imposing such sector specific trends. Given that such trends are not exactly the same across countries, in the long run there will be divergence rather than convergence. Our estimates are describing the developments within sample, and we do not claim that these necessarily can be extrapolated into infinity. For a given time period, industry-specific trends seems to be a reasonable assumption. By definition, estimation of (3) assumes that dz_{it} has a mean equal to zero. As technology growth on average is likely to be different than zero, inclusion of the industry specific constant c_i seems reasonable.

The econometric analysis concentrates on the relationship between the domestic technology shocks dz and the US technology shocks dz*. The natural starting point is the econometric gap formulation of Cameron et al. (2005) and Cameron (2005) which assumes equal growth rates in the long run:

$$dz_{it} = a_i + b_t + cdz^*_{it} + d(z_{it-1} - z^*_{it-1}) \qquad (6)$$

The dependent variable is specified as the growth rate dz, and it is related to the growth rate dz* and the lagged technology gap (z-z*). The coefficients a and b represent sector and year fixed effects. The estimated coefficient d measures the adjustment response to the gap and a negative coefficient is consistent with an equilibrium mechanism. We prefer the more general error correction framework:

$$dz_{it} = a_i + b_t + cdz^*_{it} + ez_{it-1} + fz^*_{it-1} \qquad (7)$$

This is the standard approach to identify cointegration between the technology shocks and the long run relationship comes out with the coefficient –f/e. The restricted formulation of Cameron et al. (2005) and Cameron (2005) can be tested by adding the lagged foreign technology shock on level form as a separate variable compared to equation (6):

$$dz_{it} = a_i + b_t + cdz^*_{it} + d(z_{it-1} - z^*_{it-1}) + gz^*_{it-1} \qquad (8)$$

A statistically significant coefficient g implies that the technology gap does not ensure a long run equilibrium with the same growth rates dz = dz*. A negative value of the coefficient g implies that that the growth rates in the long run obey dz < dz*. South Africa is lagging behind.

The background theory models of this relationship follow the literature after Nelson and Phelps (1966) referred to in footnote 1 and emphasizing international technology spillovers, catching up, and the world technology frontier. In the case of catching up industrial productivity growth in South Africa is above the productivity growth in US industries. In the Nelson-Phelps models the long run equilibrium implies a constant technology gap. But the dynamics towards the long run equilibrium can be complicated (see in particular Benhabib and Spiegel, 2005). The dynamic path is determined by the initial gap, the catching up process, and shifts in barriers to international spillovers (such as trade policy, taxation policy and human capital).

In the extension of the analysis we include the world frontier technology shocks in one-step estimation of the production function with capital, labor, materials and capacity utilization. Alternative specifications are estimated on growth rate form, with and without the frontier technology shocks, and with added interaction between technology shocks and the three input variables. The interaction terms allow for an investigation of possible input transmission channels of technology shocks.

The dominating measure of productivity in the literature is multifactor productivity. Its growth rate is defined as (see Vigfusson 2008, p. 50):

$$dmfp_{it} = dy_{it} - dx_{it} \tag{9}$$

We calculate multifactor productivity for SA and US and use them as alternative measures of technology.

3. The relationship between technology shocks in the US and South Africa

The technology shocks for South Africa are calculated based on the estimated sectoral production functions explained above. Four parameters are estimated representing scale and capacity utilization for durables and nondurables sectors. Our preferred estimates of the scale parameter and capacity utilization coefficient are shown in column (1) in Table 1, and the instrumentation is reported in the footnote. The scale parameters are around 1 and not statistically significant different from 1. The 95% confidence intervals cover 1 for both durables and nondurables. The capacity utilization variables are not quantitatively important and only statistically significant at 5% level in durables. The result does not change when platinum price is added as instrument in column (2). When the TIPS measure of capacity utilization is replaced by the energy input in column (3) and (4), capacity utilization has no effect on output. The scale parameters are still around 1. The growth shock dz is estimated as explained above, and the technology index is calculated using the sector fixed effects as explained in equation (4). The development of the measured technology shocks are documented in Appendix Table 1 and Figure 1. The numbers in the table and the analysis below is based on column (1) in Table 1.

The development of the industrial sector technology indexes for South Africa and the US are shown in Figure 1. The upper panel shows durables sectors and the lower panel covers nondurables. The durables sectors on average have a better technology development in both countries. The technology growth in the US is clearly above that in South Africa for sectors such as furniture, machinery, instruments, food, textiles, apparel, printing and rubber. But there are also industrial sectors where the technology growth is higher in South Africa, such as primary metal, motor vehicles, chemicals and leather. The figure shows large variation across sectors and over time.

On average the technology shock in the US industries is about 0.6% while the technology shock in SA is about 0.2 %. Interestingly, studies measuring the technology gap based on different methodology and aggregation finds that South Africa productivity is about 30 % of the world frontier, notably Dijk (2002). Our estimated technology shocks are in broad accordance with TFP calculations of South Africa by Fedderke (2001, table 8-10) and Edwards (2004, table 3).

Table 1 about here.
Figure 1 about here.

We start the investigation of the dynamics of the relationship between the US and South Africa technology shocks by looking at growth rates and with various distributed lags. Only estimates with industry fixed effects are reported. The upper panel in Table 2 shows the immediate effect of the US technology shock and one year lag, the lower panel shows the one year lag effect of the shock and two years lag. The estimates imply that shocks in the US are significantly and positively correlated with technology shocks in South Africa with one year lag. The estimated coefficients are stable with and without year fixed effects and with inclusions of different lags. One percentage point technology shock in the US leads to about 0.15 percentage point technology shock in South Africa in the following year.

The correlation of growth rates means that innovations in US industries have consequences for South Africa industries. The technology shocks are related to the world technology development in the same industrial sector as represented by the US industries. South African industries benefit from spillovers from the world frontier. The growth effect is limited in size, however, and the short run spillover coefficient is well below 1.

Table 2 about here.

The long run relationship is investigated using the error correction framework as stated in equation (7). The estimates of a general dynamic model with one and two lags are reported in Table 3. The coefficient of the lagged dependent variable shows slow adjustment mechanisms. The short run transmission of technology shocks with one year lag is consistent with the growth rate model of Table 2. There is no strong statistical significance of the long run relationship between the technology index series. The long run elasticity implied by the one year lag specification of column 1 is (0.012/0.056) about 0.25. The long run relationship is weak and indicates divergence. The result motivates further investigation of the dynamics below.

Table 3 about here.

The analysis of the importance of the technology gap for industrial sector productivity growth by Cameron et al. (2005) and Cameron (2005) includes the gap as a separate explanatory variable. We reach their model specification by restricting the model above by assuming that the lagged technology shocks in South Africa and the US have equal coefficients, as in equation (6). The resulting ‘gap model’ in Table 4 shows statistically significant gap effect with one year lag (columns 1 and 2) and for two years lag with both industry and year effects. The coefficient implies slow response to the gap, about 3% per year. For comparison, Cameron et al. (2005) find an adjustment effect of about 10% for UK industries, and Cameron (2005) about 6-7% for Japanese industries. Our results also are in line with the effect of the distance to the international technology frontier estimated by Aghion et al. (2008) using South African data. They find that distance to the frontier has a positive, but weak effect on productivity growth. Distance to the frontier is shown to be important for total factor productivity in a panel of OECD countries by Vandenbussche et al. (2004).

Table 4 about here.

The equilibrium formulation used in the above studies of the UK and Japan can be tested by the more general formulation in equation (8). The results are reported in Table 5. As shown, the separate entry of lagged z* is statistically significant in all specification (at 10% level). It follows that the technology gap term (z-z*) is not a valid formulation for the long run, the domestic and foreign technology shocks have not equal growth rate. This must be interpreted as a rejection of catching up and constant gap and indicates divergence. South Africa industries are lagging behind the US industries.

Table 5 about here.

Lagging behind can be understood as the result of divergence towards a low-income equilibrium as suggested by Benhabib and Spiegel (2004). Papageorgiou (2002) and Stokke (2008) elaborate possible adjustment mechanisms. We see such a poverty trap as unrealistic in the case of South Africa. Lagging behind is better understood as the result of negative shifts in barriers to technology adoption. Worsening of barriers can lead to slow productivity growth away from the frontier. In the literature on barriers Benhabib and Spiegel (2005) emphasize human capital, Parente and Prescott (1994) propose policy determined investment costs, and Rattsø and Stokke (2008) analyze trade policy barriers in a growth model of South Africa, Our results are consistent with a dynamic path away from a relatively low technology gap due to worsening of possibly several barriers to international spillovers. South Africa moves from relative high productivity in the late 1960s and is now lagging behind and on the way to lower long run equilibrium.

A one-step approach to estimating the role of the technology frontier is reported in Table 6. The dependent variable is log growth in gross output and, as always, we include industry fixed effects to allow for industry-specific trends. The model formulations approximate error correction forms with lagged endogenous variable and interaction terms with the lagged frontier level are investigated. In lack of good input-specific instruments we use OLS. All models include as independent variables log growth rates and lagged log levels of capital, labour, and materials, and percentage point change and lagged level of capacity utilization. Column (1) presents the estimates of this basic one-step model. The capital, labour and material coefficients are estimated to be around 0.1, 0.3 and 0.5, respectively, suggesting a return to scale coefficient in terms of these factors of about 0.9, which is consistent with the scale parameter estimates obtained in Table 1. These estimates are not sensitive to the inclusion of the international productivity frontier.

The lagged level effect of the frontier technology shock is added in column (2). The effect is consistent with the two-step procedure discussed above. The estimated long run elasticity between y and z* is (0.014/0.113) about 0.09, but not statistically significant.
Columns (3)-(5) interact the lagged frontier technology shock with growth in the three different factors respectively. Statistically significant interaction between change in factor input and lagged frontier technology shock is estimated for materials in column (5). The long run elasticity between y and z* implied by this interaction is about 0.05. The positive interaction between frontier shock and material input indicates that the international spillover effect is materials saving.

Table 6 about here.

In Table 7 we investigate the robustness of our results by employing multifactor productivity mfp as dependent variable. We use the same error correction formulation as presented for the technology shocks in Tables 3-5, and the results are consistent with the estimates using technology shocks. We comment the estimates using both industry and year fixed effects, but also report the results without year effects. The simplest form of the error correction model of domestic versus foreign mfp in column (1) shows a long run elasticity of (0.013/0.077) about 0.2, but it is not statistically significant. When we reformulate the model to identify the adjustment to the technology gap (mfp-mfp*) in column (3), the adjustment coefficient is statistically significant and represents an adjustment of 4.8% per year. The effect is comparable to the results of Cameron et al. (2005) for the UK and Cameron (2005) for Japan. In column (5) the technology gap adjustment is tested by introducing a separate effect of the lagged frontier technology shock. The lagged technology shock is statistically significant and implies that the data are not consistent with an adjustment to a long run equal growth rate between the technology shocks of the US and South Africa. South Africa industries are lagging behind also as measured by multifactor productivity.

Table 7 about here.

The relationship between multifactor productivity and technology indexes across industrial sectors is shown in Appendix Figure 1. Broadly the development of technology shocks and multifactor productivity are fairly consistent.

All in all the analysis shows that the industrial sector technology development is related to the technology development of the world frontier here measured by US industrial sectors. The industrial development cannot be understood as the result of domestic factors only. Analyses of changes in the coefficients over time (not reported) confirm the stability of the relationships estimated here.

Further robustness of the parameters of scale and capacity utilization is investigated in various model formulations in Appendix Table 2. Column (1) presents OLS-estimations of our base line production function. Column (2) shows the OLS-estimates when energy consumption is used to represent capacity utilization and column (3) splits up dx and allows for estimated coefficients on materials, capital and labor. The scale effects in columns (1) and (2) are fairly stable for both durables and nondurables sectors. The factor shares estimated in column (3) are realistic, although the capital share is a bit low, a result that often appears in estimation of production functions.

The scale effects in production are an important aspect of our methodology and the robustness of the results is investigated. Appendix Table 3 reports industry specific scale parameters. The 95 % confidence intervals of the scale parameter cover 1 for all industrial sectors except two. Tobacco and transportation equipment have scale parameters statistically significant below 1. Broadly the industrial sectors conform to the common models analyzed here.

4. Concluding remarks

Industrial sector development must be understood in an international context. This proposition is analyzed using panel data for manufacturing industries in SA and the US. The analysis of industrial sector linkages between domestic and frontier technology shocks assumes that the US industries represent the world technology frontier. The results show that industrial performance in South Africa is related to the world technology frontier and consequently existing studies of technology overlooking the international context have omitted variable bias. We find that South Africa industries respond to the technology gap to the US, but that the industries are lagging behind. The analysis explains prolonged stagnation in this middle income country and rejects catching up to the frontier.

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. Aghion et al. (2008) offer an interesting analysis of economic mechanisms important for the relationship between trade and growth. The main challenge for further research is the handling of endogeneity of mechanisms, channels and barriers.

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Table 1: Estimated scale and capacity utilization parameters

	(1) dy	95% Confidence Interval	(2) dy	(3) dy	(4) dy
dx durables	0.757***	[0.327,1.186]	0.693***	0.566*	0.900***
	(0.219)		(0.221)	(0.315)	(0.221)
dx non-durables	1.099**	[0.210,1.987]	1.257***	1.314***	1.147***
	(0.453)		(0.434)	(0.465)	(0.379)
dU durables	0.004*	[-0.000,0.009]	0.005**		
	(0.002)		(0.002)		
dU non-durables	0.001	[-0.005,0.008]	0.000		
	(0.003)		(0.003)		
de durables				0.168	0.028
				(0.133)	(0.093)
de non-durables				-0.162	-0.108
				(0.150)	(0.123)
Observations	480		480	480	480
R-sq	0.87		0.84	0.85	0.90
Sargan-p	0.21		0.40	0.93	0.11

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. dy is growth in gross output, dx is a weighted sum of growth in capital, labor and material inputs where the respective factors' value shares in gross output are used as weights. dU is change in capacity utilization as measured by TIPS. de is growth in electricity consumption, representing an alternative capacity utilization measure. Model (1) and (3) are estimated with 2SLS with the instruments: oildummy, govtdefence, moneyshock and goldprice in USD. In model (2) and (4), platinum price in USD are used as an additional instrument. Sectors that are included and which that are defined as durable producing and non-durable producing, can be seen from Figure 1. All models include industry and year fixed effects.

Table 2: The relationship between z and z*, growth rate form

	(1)	(2)	(3)	(4)
	dz	dz	dz	dz
dz*	0.078	0.038	0.094*	0.056
	(0.048)	(0.046)	(0.048)	(0.046)
dz*(-1)			0.151***	0.162***
			(0.051)	(0.048)
Industry FE	Yes	Yes	Yes	Yes
Year	Yes	No	Yes	No
Observations	480	480	480	480
Industries	20	20	20	20
R-sq within	0.09	0.00	0.10	0.03
R-sq overall	0.08	0.00	0.10	0.03

	(9)	(10)	(13)	(14)
	dz	dz	dz	dz
dz*(-1)	0.140***	0.155***	0.139***	0.156***
	(0.051)	(0.048)	(0.051)	(0.048)
dz*(-2)			-0.009	0.002
			(0.051)	(0.048)
Industry FE	Yes	Yes	Yes	Yes
Year	Yes	No	Yes	No
Observations	480	480	480	480
Industries	20	20	20	20
R-sq within	0.10	0.02	0.10	0.02
R-sq overall	0.09	0.02	0.09	0.02

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Dependent variable, dz, is technology growth including sector specific trend in South Africa backed out from the production function estimate presented in column (1), Table 1. dz* is technology growth in the corresponding industry in the US, estimated by Basu et al. (2006).

Table 3: Error correction model of the relationship between z and z*

	(1) dz	(2) dz	(3) dz	(4) dz
dz*	0.070	0.025		
	(0.049)	(0.047)		
dz*(-1)			0.125**	0.133***
			(0.052)	(0.049)
z(-1)	-0.056***	-0.061***	-0.052***	-0.056***
	(0.019)	(0.019)	(0.019)	(0.019)
z*(-1)	0.012	0.002		
	(0.020)	(0.019)		
z*(-2)			-0.001	-0.008
			(0.019)	(0.018)
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No
Observations	480	480	480	480
Industries	20	20	20	20
R-sq within	0.10	0.03	0.11	0.04
R-sq overall	0.04	0.00	0.05	0.00

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Dependent variable, dz, is technology growth including sector specific trend in South Africa backed out from the production function estimate presented in column (1), Table 1. dz* is technology growth in the corresponding industry in the US, estimated by Basu et al. (2006). z and z* refers to log of technology indexes corresponding to the growth rates. The indexes are set to 100 in 1971.

Table 4: Restricted model, the effect of the gap between z and z*

	(1) dz	(2) dz	(3) dz	(4) dz
dz*	0.084*	0.044		
	(0.048)	(0.046)		
z(-1)-z*(-1)	-0.035**	-0.031**		
	(0.015)	(0.015)		
dz*(-1)			0.145***	0.159***
			(0.051)	(0.049)
z(-1)-z*(-2)			-0.027*	-0.023
			(0.015)	(0.015)
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No
Observations	480	480	480	480
Industries	20	20	20	20
R-sq within	0.10	0.01	0.10	0.02
R-sq overall	0.05	0.00	0.07	0.01

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. The coefficient between z and z* is here assumed to be one in the long run. For more details, see note Table 3.

Table 5: Testing the restriction of long run unit elasticity

	(1) dz	(2) dz	(3) dz	(4) dz
dz*	0.070	0.025		
	(0.049)	(0.047)		
dz*(-1)			0.125**	0.133***
			(0.052)	(0.049)
z*(-1)	-0.044*	-0.059***		
	(0.023)	(0.022)		
z(-1)-z*(-1)	-0.056***	-0.061***		
	(0.019)	(0.019)		
z*(-2)			-0.052**	-0.064***
			(0.023)	(0.022)
z(-1)-z*(-2)			-0.052***	-0.056***
			(0.019)	(0.019)
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No
Observations	480	480	480	480
Industries	20	20	20	20
R-sq within	0.10	0.03	0.11	0.04
R-sq overall	0.04	0.00	0.05	0.00

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. The restriction of setting the coefficient between z and z* equal to one is tested by including z* independently. Significant coefficient on independent z* indicates non-valid restriction. For more details, see note Table 3.

Table 6: One-step estimating using capital, labor and intermediates

	(1)	(2)	(3)	(4)	(5)
	dy	dy	dy	dy	dy
y(-1)	-0.111***	-0.113***	-0.116***	-0.113***	-0.111***
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
dk	0.106***	0.109***	-1.233	0.107***	0.108***
	(0.040)	(0.041)	(1.106)	(0.041)	(0.040)
dl	0.294***	0.292***	0.292***	1.434*	0.294***
	(0.040)	(0.040)	(0.040)	(0.805)	(0.040)
dm	0.512***	0.512***	0.512***	0.512***	-0.705
	(0.015)	(0.015)	(0.015)	(0.015)	(0.533)
dU	0.002**	0.002**	0.002**	0.002**	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
k(-1)	0.007	0.008	0.007	0.008	0.006
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
l(-1)	0.039**	0.040**	0.041**	0.040**	0.039**
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
m(-1)	0.074***	0.075***	0.077***	0.075***	0.074***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
U(-1)	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
z*(-1)		0.014	0.014	0.013	0.007
		(0.020)	(0.020)	(0.020)	(0.020)
dk x z*(-1)			0.288		
			(0.237)		
dl x z*(-1)				-0.242	
				(0.170)	
dm x z*(-1)					0.259**
					(0.113)
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	480	480	480	480	480
Ind	20	20	20	20	20
R-sq within	0.86	0.86	0.86	0.86	0.86
R-sq overall	0.76	0.75	0.75	0.75	0.76

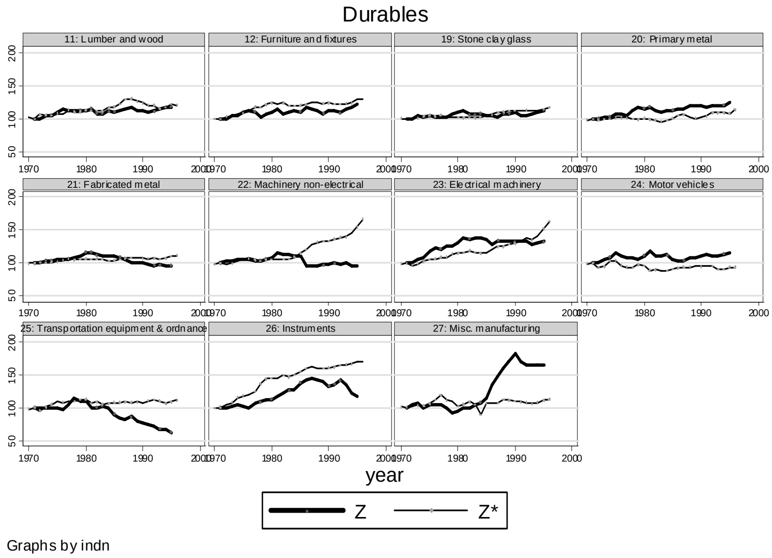
Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Dependent variable, dy, is growth in gross output, dk, dl and dm are growth in capital, labor and material inputs, respectively. y, k, l, m are log levels of gross output, capital, labor and material inputs. U is capacity utilization in percent as measured by TIPS. dU is change in capacity utilization in percentage points. z* log of a technology index in the corresponding industry in the US, constructed by setting the 1971 value to 100 and applying technology growth as estimated by Basu et al. (2006). All models include industry and year fixed effects.

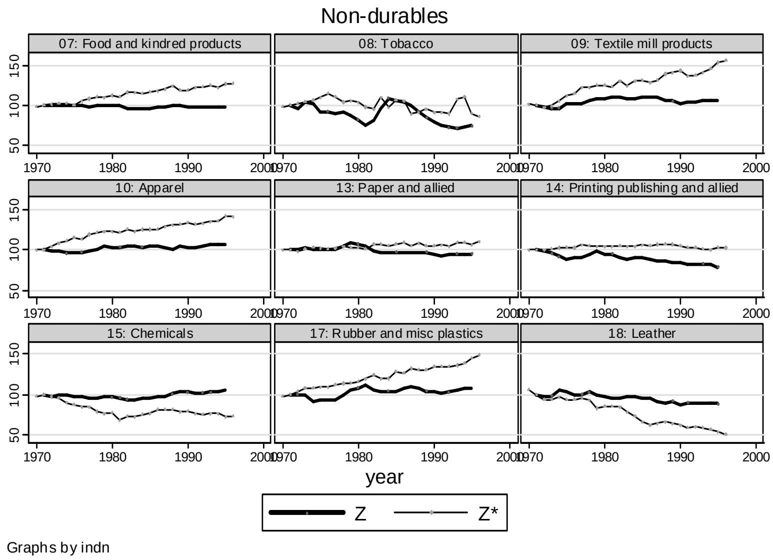
Table 7: Multifactor productivity

	(1) dmfp	(2) dmfp	(3) dmfp	(4) dmfp	(5) dmfp	(6) dmfp
mfp(-1)	-0.077***	-0.084***				
	(0.021)	(0.021)				
dmfp*	0.133***	0.154***	0.151***	0.178***	0.133***	0.154***
	(0.046)	(0.045)	(0.046)	(0.044)	(0.046)	(0.045)
mfp*(-1)	0.013	0.013			-0.064**	-0.070***
	(0.023)	(0.019)			(0.028)	(0.026)
mfp(-1)-mfp*(-1)			-0.048***	-0.043***	-0.077***	-0.084***
			(0.017)	(0.015)	(0.021)	(0.021)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No	Yes	No
Observations	480	480	480	480	480	480
Industries	20	20	20	20	20	20
R-sq within	0.18	0.06	0.17	0.04	0.18	0.06
R-sq overall	0.11	0.01	0.11	0.01	0.11	0.01

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Dependent variable, dmfp, is growth in multifactor productivity, dmfp=dy-dx, where dy is growth in gross output and dx is weighted sum of growth in capital, labor and material inputs. I.e., dmfp equals the standard Solow residual. dmfp* is growth in US multifactor productivity defined the same way as for South Africa, using dy* and dx* as provided by Basu et al. (2006). mfp and mfp* are log of indexes constructed by setting 1971 value to 100 and applying the growth rates dmfp and dmfp*.

Figure 1: Technology SA and US





Note: Figures show indexes of technology for the US (Z*; constructed by setting 1971 value to 100 and applying technology growth as estimated by Basu et al. 2006) and for South Africa (Z; constructed in same way as Z* employing growth rates estimated in production function presented in Table 1). The upper panel shows industries defined to produce durable goods, the lower panel industries defined to produce non-durable goods. Sector aggregation and definitions of durable versus non-durable producing sectors are identical to Basu et al. (2006).

Appendix Table 1: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
dy	480	0.0275	0.0905	-0.3530	0.3605
dk	480	0.0224	0.0571	-0.1360	0.2573
dl	480	0.0090	0.0525	-0.2314	0.2209
dm	480	0.0323	0.1411	-0.6396	0.7585
dx	480	0.0271	0.0860	-0.2873	0.3588
U	480	82.5253	6.5607	58.1730	94.8290
dU	480	-0.0409	2.9613	-9.4798	12.3000
Oildummy	480	12.0509	18.7350	0.0000	67.6612
Govtdefence	480	0.0023	0.0513	-0.1153	0.0875
Moneyshock	480	-0.1768	1.0150	-1.9934	2.3291
Gold price (usd)	480	249488	96080	60974	441663
Platinum price (usd)	480	358	145	124	677
Z	480	105.3072	14.7444	62.6658	180.7402
Z_ind	480	105.4197	15.0205	63.2350	175.2799
MFP	480	101.1867	9.6337	66.7329	148.3160
Z*	480	109.7895	18.2692	53.0803	169.2653
MFP*	480	112.6830	15.1257	87.5729	174.1080
dz	480	0.0022	0.0347	-0.1345	0.1775
dz_ind	480	0.0026	0.0301	-0.0958	0.1469
dmfp	480	0.0004	0.0313	-0.1350	0.1656
dz*	480	0.0063	0.0356	-0.1864	0.1974
dmfp*	480	0.0080	0.0329	-0.1864	0.1636
Year	480	1983.5	6.9294	1972	1995

dy is gross production, dx is aggregate of input growth, U is capacity utilization in percent, Z is a productivity index given the technology growth from the estimation of column 1 in Table 1. Z* is a productivity index given the technology shocks estimated by Basu et al. (2006). d in front mean first difference, small letters mean logs and _ind means industry-specific parameters.

Appendix Table 2: Robustness checks scale and capacity utilization estimations

	(1)	(2)	(3)
	dy	dy	dy
dx durables	0.958***	1.006***	
	(0.020)	(0.030)	
dx non-durables	0.948***	1.143***	
	(0.035)	(0.047)	
dU durables	0.002***		0.003***
	(0.001)		(0.001)
dU non-durables	0.002***		0.003***
	(0.001)		(0.001)
de durables		-0.016	
		(0.016)	
de non-durables		-0.107***	
		(0.021)	
dm durables			0.531***
			(0.015)
dm non-durables			0.460***
			(0.023)
dk durables			0.158***
			(0.044)
dk non-durables			0.056
			(0.047)
dl durables			0.289***
			(0.044)
dl non-durables			0.328***
			(0.063)
Observations	480	480	480
R-sq	0.90	0.90	0.86

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. See note Table 1 for more details.

Appendix Table 3: Industry specific scale parameters

	(1) dy	95% Confidence Interval
dx 07: Food and kindred products	0.992***	[0.598,1.385]
	(0.201)	
dx 08: Tobacco	0.387***	[0.120,0.655]
	(0.137)	
dx 09: Textile mill products	1.394***	[0.977,1.810]
	(0.213)	
dx 10: Apparel	1.067***	[0.726,1.408]
	(0.174)	
dx 11: Lumber and wood	0.847***	[0.535,1.158]
	(0.159)	
dx 12: Furniture and fixtures	0.805***	[0.585,1.025]
	(0.112)	
dx 13: Paper and allied	0.497	[-0.252,1.247]
	(0.382)	
dx 14: Printing, publishing and allied	0.839***	[0.476,1.202]
	(0.185)	
dx 15: Chemicals	0.885***	[0.357,1.413]
	(0.269)	
dx 17: Rubber and misc plastics	1.102***	[0.753,1.452]
	(0.178)	
dx 18: Leather	1.183***	[0.817,1.549]
	(0.187)	
dx 19: Stone, clay, glass	0.986***	[0.583,1.390]
	(0.206)	
dx 20: Primary metal	1.088***	[0.568,1.609]
	(0.266)	
dx 21: Fabricated metal	1.116***	[0.787,1.446]
	(0.168)	
dx 22: Machinery, non-electrical	1.008***	[0.817,1.200]
	(0.098)	
dx 23: Electrical machinery	1.058***	[0.896,1.221]
	(0.083)	
dx 24: Motor vehicles	1.077***	[0.911,1.242]
	(0.084)	
dx 25: Transportation equipment & ordnance	0.772***	[0.602,0.943]
	(0.087)	
dx 26: Instruments	0.809***	[0.616,1.002]
	(0.099)	
dx 27: Misc. manufacturing	0.782***	[0.526,1.037]
	(0.130)	
dU durables	0.002**	[0.000,0.003]
	(0.001)	
dU non-durables	0.002	[-0.000,0.004]
	(0.001)	
Observations	480	
R-sq	0.91	
Sargan-p	0.47	

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Scale parameters estimated freely for each sector. Capacity utilization parameter vary only between durable and non-durables producing sectors. See note Table 1 for more details.

Appendix Figure 1: Technology shocks and multifactor productivity SA