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The Barrier Model of Productivity Growth: South Africa

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Acronyms

ADF	Augmented Dickey Fuller
GDP	Gross Domestic Product
IMF	International Monetary Fund
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
R&D	Research and Development
SA	South Africa
TFP	Total Factor Productivity
TIPS	Trade and Industrial Policy Strategies

1. Abstract

The barrier model of productivity growth suggests that individual country productivity is related to the world technology frontier disturbed by national barriers. We[1] offer a country study of the barrier model, exploiting the dramatic changes in the linkages to the world economy in South Africa (SA).

The productivity growth in the manufacturing sector panel for 1970-2003 covers a period of political and economic turbulence and international sanctions. The econometric analysis uses tariffs as a measure of barrier and fixed effects estimation to concentrate inference to time-series properties. The model shows how productivity growth can be understood as a combination of world frontier growth and the tariff barrier to international spill-overs. The estimates establish a long-run relationship where domestic productivity follows the world frontier, with change of barrier affecting transitional growth.

[1] We appreciate discussions at the TIPS/NTNU workshop in Cape Town on 'Growth, Openness and Poverty in SA and Thailand' and at staff seminars at the University of Oslo and NTNU, and comments in particular from Alice Amsden, Ådne Cappelen, Rob Davies, Xinshen Diao, Lawrence Edwards, Johannes Fedderke, Stephen Gelb, Steinar Holden, Ravi Kanbur, Terry Roe, Dirk van Seventer, Terje Skjerpen, Hildegunn Stokke and Kjetil Storesletten. The project is financed by the Norwegian Research Council. Authors' contact details: Torfinn Harding, Statistics Norway and Norwegian University of Science and Technology, torfinn.harding@ssb.no and Jørn Rattsø, Norwegian University of Science and Technology, jorn.rattso @svt.ntnu.no.

2. Introduction

The world income distribution among countries is stable over time. Differences in income levels are permanent, while differences in growth rates are transitory. There seems to be agreement about this description (see Acemoglu and Ventura, 2002, Klenow and Rodriguez-Clare, 2004, Parente and Prescott, 2004). The key to understanding this pattern is the role of externalities. Klenow and Rodriguez-Clare (2005) argue that all countries grow at the same rate due to international spill-overs. Differences in policies explain differences in total factor productivity (TFP) levels. Parente and Prescott (2004) and Ngai (2004) present models where barriers to technology adoption determine timing and pace of modern economic growth. The emphasis on catching-up productivity growth, called the Veblen-Gerschenkron effect, is established in development literature and was first formalised by Nelson and Phelps (1966). All countries can benefit from the growth of the world technology frontier, albeit to different degrees and at various speeds, and depending on the initial conditions. We present empirical evidence for SA backing up the barrier model of productivity growth

The importance of international technology spill-overs for economic growth is addressed in a comprehensive literature of cross-country regressions. The dominant study of foreign spill-overs to developing countries is Coe, Helpman and Hoffmeister (1997), which analyses how developing countries get access to the stock of knowledge of their trading partners in the Organisation for Economic Co-operation and Development (OECD) countries. They construct an import-weighted measure of industrial countries' knowledge stock that developing countries can benefit from. This measure interacted with the openness of the economy has a statistically significant effect on the growth in TFP in developing countries. While these results are not unchallenged, most observers agree that international productivity spill-overs are important. The serious concern with the many studies of openness and growth is the identification problem due to endogeneity of the explanatory factors. We attempt to get around this problem by using trade policy as a barrier to productivity spill-over.

We offer evidence based on individual country growth experience over time. SA is an interesting case study because of changes in the trade regime and international sanctions. While the scope of the direct effects of sanctions is questionable, according to Levy (1999), they certainly influenced the country's relation with the rest of the world. The economic and political experiences and good data have drawn many researchers to the analysis of productivity growth in SA. The most enthusiastic argument for the importance of openness is presented in the International Monetary Fund (IMF) study of Jonsson and Subramanian (2001). Fedderke (2003) finds more support for the importance of domestic factors. We suggest an alternative approach which emphasises the gap in the world technology frontier, with trade policy as a barrier to international spill-over. The analysis is based on Trade and Industry Policy Strategies (TIPS) panel data set of manufacturing industries during 1970-2003 (TIPS, 2004).

SA achieved annual economic growth of about 6% from 1960 to the mid-1970s. The white minority enjoyed living standards at the level of the richest countries of the world, while the black majority lived in poverty. Economic growth shifted down in the mid-1970s due to internal political struggle and international isolation. The sanctions period forced domestic industries to change their investment and marketing strategies. Changing external conditions represent an interesting experiment of protectionism and offer a unique opportunity of identifying the effects of openness. In the post-sanctions period, economic performance has been erratic, but with a low average. Fedderke (2001) and Lewis (2001) draw on broad lessons from the recent economic growth history. Van Dijk (2002) shows that the labour productivity relative to the US has declined from 32% in 1970 to 20% in 1999.

In the next section we present our modelling strategy and summarise relevant studies of productivity growth. Section 4 looks at the TFP measurement and the associated methodological challenges. Section 5 reports the econometric specification of the barrier model of productivity. The first analyses in section 6 apply standard openness measures of actual trade. The effect of trade policy as barrier is estimated in section 7, while section 8 investigates the heterogeneity of the panel. Concluding remarks are offered in section 9.

3. Modelling Productivity Dynamics

A stylised fact of economic growth is that countries have permanent differences in productivity (Hall and Jones, 1999). Countries tend to grow at world normal growth rates, and changes in the world income distribution are limited to transitions. Country-specific policies can influence the ability to take advantage of international spill-overs and thus generate transitional growth. This is the main channel of extraordinary growth in the developing country context with little domestic research effort. Barriers to technology adoption are the key concern of growth policy.

The understanding of barriers in the tradition of Nelson and Phelps (1966) and Parente and Prescott (1994, 2004) combines two elements – the distance to the world technology frontier defining the potential productivity level and the role of the barrier. The barrier may be in the form of human capital (Nelson and Phelps) or investment regulations (Parente and Prescott). In the formulation below, we assume that the world technology frontier A^* is advancing at a constant growth rate g. The relative technology gap and the barrier to technology adoption B determine the growth of productivity A in the country concerned. The model is a modification of Nelson and Phelps (1966) and consistent with recent formulations of Klenow and Rodriguez-Clare (2004) and Howitt (2000). The growth rate of the aggregate productivity level A is written as (t is time period):

$$\frac{dA_t}{A_t} = \phi(B_t)\frac{(A^*_t - A_t)}{A_t} \qquad (1)$$

The barrier B enters as a ϕ-function multiplied by the technology gap. The derivative of ϕ with respect to the barrier is assumed negative since the barrier limits the catch-up to the world technology frontier. The productivity growth is higher the further the country is from the frontier. In a multi-country setting, the model has a stationary cross-country distribution where the productivity growth in all countries is equal to the frontier rate g. The long-run relationship between the individual country and the frontier on level form is easily derived from (1):

$$A_t = \frac{\phi(B_t)}{g + \phi(B_t)} A^*_t \qquad (2)$$

The barrier explains the productivity level relative to the world frontier. High barriers reduce the absorption of technology from the world frontier and consequently hold down the productivity level and income level. A reduction of the barrier generates transitional higher productivity growth in the country and a new long-run equilibrium, with a productivity level closer to the world frontier. Our econometric analysis attempts to identify this long-run level relationship by estimating a linearisation of (2).

Industrial level analyses offer considerably more data to sort out the dynamics of productivity. The study of the aggregate Solow residual soon moved to a disaggregated approach estimating industry-level production functions. The methodology is presented by Griffith, Redding and Van Reenen (2004) in an analysis of innovation and adoption in OECD countries. A recent contribution relevant to SA is provided by Ferreira and Rossi (2003) on Brazil.

The relationship between openness and TFP in SA has been analysed by Jonsson and Subramanian (2001). They calculate TFP growth for 24 sectors and investigate cross-section relationships for the

1990s and time-series relationships in aggregate TFP growth in private non-agricultural gross domestic product (GDP) for 1971-1997. Openness is measured by sectoral export shares, import shares and tariffs in the cross-section, and by the trade share of GDP in the time series. The authors conclude that strong trade liberalisation effects are identified. They find that tariff reductions of 14% during the 1990s are translated to annual TFP growth of 3%. The time-series analysis is interpreted as evidence that a 3.2% annual increase in openness generates 1.6% annual growth in TFP. The aggregate analysis is updated by Arora and Bhundia (2003). They find that TFP growth has increased substantially after 1994 and that openness and private investment have been driving forces.

Fedderke (2002) gives more documentation of aggregate and disaggregated TFP calculations during 1970-1997. TFP is measured by growth accounting given factor shares. The analysis of 28 manufacturing sectors covers three separate decades and shows strong heterogeneity between sectors. While more than half of the manufacturing sectors show positive TFP growth during the 1970s and 1980s, and the best of them are above annual growth of 10%, the majority of sectors have negative TFP growth during the 1990s, with the highest growth rate being 3%.

At the aggregate level, he finds TFP growth of about 1% during the 1990s. Fedderke (2003) extends the analysis to the determinants of TFP using pooled mean group estimator methodology for heterogeneous panels. This is clearly the most comprehensive and competent analysis available. Fedderke concludes that the TFP growth process has benefited from knowledge spill-overs to human capital and innovations driven by domestic research and development (R&D).

We conclude that the analyses of Jonsson and Subramanian (2001) and Fedderke (2003) present conflicting evidence on the sources of productivity growth in SA. While openness explains most of the productivity growth according to Jonsson and Subramanian, foreign trade as a channel of technology spill-overs do not appear in the final specifications of Fedderke. We suggest investigating barriers to foreign spill-overs more directly, with an emphasis on trade policy as the barrier. Future research should include domestic market barriers to productivity growth.

4. Estimating TFP Growth

TFP is typically backed out as a residual in production functions. Hulten (2000) gives a good overview and Prescott (1998) discusses shortcomings. Given output growth, the handling of factor inputs is consequently essential. We follow the standard procedure of taking into account the use of labour and real capital. The production factors are assumed homogenous and changes of input quality is not corrected for. Hence quality improvements are picked up by TFP growth. We have manufacturing-level panel data for the period 1970-2003 and for 28 sectors. In the main approach explained below, we estimate sectoral factor shares based on this time series. As a robustness check we calculate TFP using the development of actual factor income shares.

We are aware of serious shortcomings of this standard approach. The main challenge is the endogeneity of factor inputs. The estimation requires that the residuals, interpreted as growth in TFP, are orthogonal to 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. 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). However, the comparison of our estimated results with actual factor shares calculation indicates that these problems are limited. Measurement errors are always a source of potential inconsistent parameter estimates.[2]

The standard method of estimating TFP was documented recently by Ferreira and Rossi (2003). We have data about intermediate inputs and need not apply gross production output as proxy for value added. Instead of their assumption of equal factor shares across sectors, we estimate factor shares for each sector. A standard Cobb-Douglas production function is assumed for each sector i:

$$Y_{it} = A_{it} K^{\alpha_i} L_{it}^{\beta_i} \quad (i = 1, ..., N;\ t = 1, ..., T) \qquad (3)$$

Here *Y* is value added, *K* is fixed capital stock, *L* is number of employed and *A* is total factor productivity. The subscripts *i* and *t* represent sector and time respectively. Taking logs and differentiating give the linear equation estimated for each sector:

$$dy_{it} = da_{it} + \alpha_i dk_{it} + \beta_i dl_{it} \qquad (4)$$

Small letters indicate logs. The differential of the log of total factor productivity, da_{it}, is the residual in the regression. These residuals form the basis of the sources of growth analysis below.

The database is documented in Appendix Table 1, while the manufacturing TFP growth rates by sector are shown in Appendix Table 2. The productivity growth is quite heterogeneous across sectors. The average annual TFP growth over the full period is 1.1%. Interestingly, the overall TFP was stagnant during the sanctions period (1985-1992), but was growing on average before sanctions and after sanctions. The high TFP growth sectors include basic non-ferrous metals,

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[2] Fedderke (2001) discusses mismeasurement of capital growth and the potential underestimation of the capital share. Ferreira and Rossi (2003) discuss the problem of bias towards decreasing returns to scale under fixed-effects estimation due to bad measurement within sector fluctuations.

chemicals, beverages, plastic products and glass products. On the other hand, some sectors had negative average TFP growth during the period studied, such as professional and scientific equipment, other transport equipment, metal production excluding machinery, and printing. Our TFP estimates are in broad accordance with TFP calculations of SA by Fedderke (2001, table 8-10) and Edwards (2004, table 3). In addition, the alternative TFP calculations using time series of actual sectoral factor shares also produce very similar results. It seems to us that there is no serious controversy over the description of productivity development in SA manufacturing industries presented here.

5. Econometric Approach to the Barrier Model

The barrier model is a way of understanding the link between the world market and domestic productivity growth. The relationship between openness and growth has been addressed in comprehensive cross-country literature. Our study is motivated by the need for a deeper understanding of the growth process at the country level. The endogeneity of the openness is a problem for the interpretation of cross-country results. Rodriguez and Rodrik (2001) summarise the econometric concerns involved. Macro variables are notoriously interdependent, and certainly productivity improvements may influence trade, both via structural and cyclical channels. Frankel and Romer (1999) introduce a gravity equation of bilateral trade shares that uses countries' geographic characteristics and size to predict trade. Frankel and Rose (2002) extend the evidence to currency unions. Recent contributions to sort out the endogeneity problem include Dollar and Kray (2003) estimating in first-differences, Irwin and Trevio (2002) using alternative instruments for openness, and Alcala and Ciccone (2004) discussing concerns of weak instruments and measures of openness. Lee, *et al.* (2004) offer a new method with identification through heteroskedasticity. Their results indicate a positive, but small, effect from openness to growth. Generally, taking into account the endogeneity problem reduces the effect of openness on growth compared to earlier studies with a simultaneity problem.

Many industry-level studies of productivity effects of R&D input and openness are available. The possibility of reverse causation is raised too as an issue in this literature, in particular regarding the relationship between exports and productivity. Bernard and Jensen (1999) discuss whether highly productive firms become exporters or whether exporting improves firm performance. The endogeneity problem of openness in the industry-level studies is basically the same as in aggregate studies. Productivity influences the profitability of imports and exports, and trade variables may reflect the influence of productivity rather than the opposite. It is a serious challenge to establish causality from adoption to productivity.[3]

Our main strategy to identify barriers to technology adoption is to look at trade policy and not foreign trade. While foreign trade endogenously responds to the development of productivity, trade policy is determined by political institutions. The political institutions may respond to the economic development, and trade policy may be endogenous to the economic performance in this sense. But this effect will be much more indirect and the development of tariffs seems to reflect broader political responses to openness, with reduced tariffs before and after the high-tariff sanctions period.

We see trade policy variables as a significant step forward compared to the estimation of the effects of trade variables. We exclude domestic factors that have been included in recent studies of TFP growth in SA (share of machinery and equipment in domestic investment and the ratio of skilled to unskilled labour) since they are endogenous. It is of interest in future research to test for exogenous factors potentially important for domestic barriers to productivity growth in SA. Cole, *et al.* (2004) introduce competitive barriers in their analysis of Latin America.

The sectoral TFP series A_{it} is related to the world technology frontier A^*_t and alternative measures of the barrier B. The starting point is the long-run relationship of section 3 between productivity A, barrier B and world frontier A^*, and we estimate a linear approximation. In the formulation below, sectoral productivity measures are related to aggregate measures of barriers and technology gap (to be discussed). The model assumes an error correction formulation allowing for a separation of short-run and long-run effects:

[3] Biesbroeck (2003) investigates the effects of exports on productivity in sub-Saharan manufacturing plants, and finds a positive effect of exports on productivity. This also holds when self-selection into export markets is counted for.

$$\Delta A_{it} = a_0 + a_1 A_{it-1} + a_2 B_{t-1} + a_3 A*_{t-1} + a_4 B_{t-1} A*_{t-1} + a_5 \Delta B_t + a_6 \Delta A_t * + e_i + u_{it} \quad (5)$$

The dynamic econometric specification is similar to Rattsø and Stokke (2003). The level variables and the endogenous variable are lagged one period on the right-hand side and short-run effects are included as first differences. The barrier and the world frontier enter separately and in interaction in this general form. The Ordinary Least Squares (OLS) estimation assumes fixed effects, taken care of by the sectoral constant term e_i. In the estimations, capacity utilisation *U* is included as a variable both in level and first difference form to take shocks into account.

The dynamic properties of the panel and the aggregate data are documented in the appendix. The level variables are non-stationary and support the long-run interpretation of levels. Our understanding is that the period 1970-2003 shows transitional growth, that is, the SA economy was outside a steady-state path. The transition growth is generated by changing barriers. The transition period, when barriers are non-stationary, allows identification of a cointegrating relationship between the level variables and thus the growth effects of changing barriers. During long-run balanced growth, the barriers (trade policy) are stationary and growth is determined by the world frontier. We concentrate on the long-run relationship on level form. Given the estimation of (5), the long-run equation can be deduced as:

$$A_{it-1} = \frac{-a_2}{a_1} B_{t-1} - \frac{a_3}{a_1} A^*_{t-1} - \frac{a_4}{a_1} B_{-1} A*_{t-1} + \frac{e_i}{a_1} \quad (6)$$

The barrier and the world frontier determine the movement of the productivity level over time, and we will report alternative specifications and investigation of heterogeneity. It should be noticed that we apply measures of the barrier and the world frontier productivity as independent variables. This is in line with the long-run relationship shown in section 3. The alternative specification introducing the technology gap as an independent variable faces problems of endogeneity since the productivity level investigated enters this variable. Griffith *et al.* (2004) discuss the conditions needed to estimate the relationship with the technology gap on the right-hand side (in relation to their equation 8).

We will proceed in three steps to investigate the barrier to international technology spill-over. First, we reproduce the overwhelming positive effect of foreign trade on TFP growth identified by Jonsson and Subramanian (2001). It should be noticed that we have serious concerns about the endogeneity of foreign trade in this analysis. But it is of interest to check the results of this influential study.

We use three measures of foreign trade in this attempt: TRADE, TRADEAGG and TRADEINDEX. TRADE is sectoral exports + imports as share of value added in each sector, and offers information of how the sector is integrated into the international economy. The other measures are at the aggregate economy-wide level. TRADEAGG is total exports + imports as share of GDP, and is the economy-wide equivalent of TRADE. TRADEINDEX is an index of openness for SA constructed by Aron and Muellbauer (2002)[4]. The index is based on information on import tariffs and surcharges, as well as an unmeasured component of quotas and effect of sanctions. It is calculated as the residual of an estimated import function, and will therefore also reflect actual trade. The index is fairly consistent with the calibrated tariff equivalent calculated by Rattsø and Stokke (2004). Their

[4] Aron and Muellbauer (2002) describe the construction of the openness index. The unmeasured component of quotas and effect of sanctions are captured by an I(2) stochastic trend. The openness indicator is shown in figure 1 in their paper, and increasing values means increasing openness. The indicator is a quarterly time series. We have only read the annual numbers from the figure.

tariff equivalent is calibrated to reproduce the development of foreign trade in an inter-temporal Ramsey model of SA, and represents an indirect measure of the consequences of sanctions.

In the second step we move to our preferred model with trade policy as barrier to international spill-over. The aggregate import TARIFFS are measured on the basis of import tax revenue and are calculated as a share of import value. Edwards (2004) also applies the tariff data in an analysis of TFP and factor returns. As a third step we investigate the heterogeneity in the productivity development with respect to production sectors and time periods (pre-sanctions, sanctions and post-sanctions).

Before we move to the econometric results, it is worthwhile to have a look at the time variation in the data in Table 1. The average annual growth rate of TFP is about 1% over the 33 years studied, but differs between time periods, with about 1% per year pre-sanctions, about zero growth during sanctions and with 3% post-sanctions. The foreign trade share TRADEAGG was declining in the pre-sanctions period, reached a low 36% average during sanctions and increased again post-sanctions. The trade share was about the same in 2003 as in 1970, with an overall average of 44%. The reduction in the trade share, together with higher productivity pre-sanctions, goes against the hypothesis that aggregate trade can 'explain' much of the productivity growth. The TRADEINDEX also shows reduced openness pre-sanctions. Only TARIFFS have the pattern of reduced barriers pre-sanctions, increased barriers during sanctions and reduced barriers post-sanctions. This is consistent with high productivity growth before and after sanctions and stagnating productivity during sanctions. The world technology frontier *A**, which is measured as the labour productivity in the US manufacturing sector, is steadily increasing over the whole period.

Table 1 Estimated average TFP level across sectors and over time, and average level of barrier variables and world technology frontier 1)

	Pre-sanctions 1970-1984	Sanctions 1985-1992	Post-sanctions 1993-2003	Full period 1970-2003	Std. dev. 1970-2003
A	1.089	1.175	1.240	1.158	0.095
TRADEAGG	0.441	0.367	0.501	0.443	0.068
TRADEINDEX	0.107	0.034	0.310	0.140	0.162
TARIFF	0.038	0.055	0.033	0.041	0.019
A*	0.594	0.803	1.049	0.774	0.208

[1) The productivity level A is an unweigthed average of the sectoral productivity levels. The productivity in the sub-periods is calculated with factor shares estimated for the entire period.]

The three steps add up to seven models of TFP growth. The estimated results are commented upon with emphasis on the long-run results. The short-run effects basically clean out disturbances that help us to identify the long-run relationships. The dynamic adjustment represented by the lagged TFP level A_{t-1} is stable around the value of -0.1 and statistically significant at 1% in all seven models. This, in combination with the fact that the variables seem to be I(1),[5] supports a cointegrating relationship between the level variables (Banerjee, Dolado and Mestre, 1998).

[5] See appendix for an investigation of the time-series properties of the different variables.

6. Openness and TFP Growth

This section investigates the main conclusion in the IMF study of Jonsson and Subramanian (2001), who find that 90% of the TFP growth during 1970-1997 is explained by increasing foreign trade. We basically suggest an alternative understanding of the transmission of international spill-overs. Their result and the methodological concern of endogenous foreign trade motivate our analysis of tariff policy as barrier to growth in the next section. The first results regarding openness and TFP are reported in the three models of Table 2 (excluding interaction effects).

In model 1 we include the foreign trade share of value added in each sector TRADE as the barrier affecting foreign spill-over. But this sectoral measure of trade openness does not matter in terms of productivity. In this specification the SA productivity level basically follows the world frontier. The long-run coefficient is close to 1. This is a fairly good description of the pre-sanctions (1973-1984) and post-sanctions (1993-2001) periods, when SA productivity moved in a similar pattern to the world frontier. But the model does not reproduce the sanctions period well, since productivity in SA was stagnant while the world frontier continued to grow. We do need a barrier to capture the full picture.

The studies referred to above with strong effects of openness all use aggregate measures of openness. The results of model 1 indicate that openness important for foreign spill-over may be external to each production sector. Model 2 includes the aggregate trade share and model 3 the openness index of Aron and Muellbauer. Both the trade share and the index positively and significantly influence the sectoral productivity level. Although the two variables are strongly correlated (0.86), the size of the effect on productivity is very different. The long-run elasticity of the productivity level with respect to TRADEAGG is about 0.5, while the corresponding elasticity with respect to TRADEINDEX is about 0.05. The different elasticities reflect the more dramatic changes in openness represented by the Aron-Muellbauer index.

The results imply that there is a positive association between aggregate measures of openness and TFP in the SA manufacturing in our period. With the foreign trade share of GDP as measure of openness, we broadly reach the same elasticity between TFP and foreign trade as Jonsson and Subramanian (2001) did. But the foreign trade share is U-shaped in our period, with its minimum level around 1985. This U shape implies that foreign trade cannot explain much of the TFP growth over the whole period, even if it is significantly important for TFP growth. In fact, as the aggregate trade share is larger in 1973 than in 2001, the development of the aggregate trade share cannot 'explain' the development of TFP. Only in the post-sanctions period do foreign trade and productivity grow in tandem. The significance of aggregate trade as barrier reduces the role of the world frontier. The long-run coefficient is reduced to about 0.5. But our main conclusion is that this is not a very successful model of the TFP development in SA, both because of the time path of the aggregate trade share and the endogeneity of this share.

The estimated openness index of Aron and Muellbauer has the same development as the aggregate trade share, although with more dramatic changes over time. Consequently it has the same problem 'explaining' the barrier to productivity growth in the pre-sanctions period. The productivity increased while openness was reduced. The index shows a large shift towards more openness in the post-sanctions period while the productivity has only risen gradually. We must move to trade policy to get a better understanding of the growth process.

Table 2 Sources of TFP growth; various measures of openness

	dA, model 1	dA, model 2	dA, model 3
A-1	-0.121*** (0.02)	-0.099*** (0.02)	-0.118*** (0.02)
TRADE-1	-0.008 (0.01)		
TRADEAGG-1		0.146*** (0.05)	
TRADEINDEX-1			0.067*** (0.03)
A*-1	0.113*** (0.03)	0.045* (0.03)	0.075** (0.03)
CAPUTIL-1	0.067 (0.11)	0.036 (0.11)	-0.036 (0.10)
dTRADE	-0.055*** (0.01)		
dTRADEAGG		0.582*** (0.12)	
dTRADEINDEX			0.031 (0.14)
dA*	-0.008*** (0.27)	-0.962*** (0.27)	-1.332*** (0.35)
d CAPUTIL	0.007*** (0.13)	0.555*** (0.13)	0.531*** (0.13)
Constant	0.034 (0.10)	0.021 (0.10)	0.140 (0.10)
R2	0.21	0.18	0.18
N and parameters	783, 35	783, 35	755, 35
Period	1972 - 2001	1972 - 2001	1972 - 2000

*[Fixed effects, no time dummies; * 10% level, ** 5% level, *** 1% level]*

7. Tariffs as Barriers

Since foreign trade is determined simultaneously with productivity, we need to identify background factors determining foreign trade as barriers to foreign spill-over. Table 3 investigates the role of foreign trade policy, the import tax share TARIFFS, together with the world technology frontier *A**. The import tax share calculated on the basis of import tax revenues is the measure of trade policy now used by SA economists.

In model 4, the two variables TARIFFS and *A** are entered separately. The long-run coefficient between productivity and world frontier is about 0.8. Given constant barriers (here tariffs), the productivity in SA basically will follow the world frontier, although somewhat slower. The barrier clearly influences productivity and has been important in the period studied. The long-run elasticity is about -0.3. The reduction of the barrier can explain about a third of the growth of productivity over the entire period. If we separate out the sub-periods, the reduced tariffs in the pre-sanction period explain most of the rise in productivity, and the reduced tariffs of the post-sanction period explain about 70% of the productivity growth. During the sanctions period, tariffs were increased and then reduced, and the average constant tariff level is consistent with the constant productivity level. If we combine the effects of tariffs and the world frontier, the model predicts somewhat higher productivity growth pre-sanctions and during sanctions, and the tariffs seem to underestimate the barrier.

Table 3 Sources of TFP growth, preferred measure of barrier and interaction effects

	dA, model 4	dA, model 5	dA, model 6
A-1	-0.110*** (0.02)	-0.107*** (0.02)	-0.348*** (0.07)
A-1 x A*-1			0.255*** (0.08)
TARIFF-1	-0.849*** (0.16)	3.024* (1.63)	-0.759*** (0.16)
TARIFF-1 x A*-1		-4.806** (2.00)	
A*-1	0.092*** (0.03)	0.252*** (0.07)	-0.194** (0.09)
CAPUTIL-1	0.073 (0.11)	0.101 (0.11)	0.085 (0.11)
dTARIFF	-0.470*** (0.15)	-0.475*** (0.15)	-0.421*** (0.15)
dA*	-1.302*** (0.31)	-1.133*** (0.34)	-1.222*** (0.32)
dCAPUTIL	0.604*** (0.14)	0.595*** (0.14)	0.614*** (0.14)
Constant	0.074 (0.11)	-0.088 (0.14)	0.324*** (0.11)
R2	0.19	0.20	0.21
N and parameters	758, 35	758, 36	758, 36
Period	1973 - 2001	1973 - 2001	1973 - 2001

*[Fixed effects, no time dummies; * 10% level, ** 5% level, *** 1% level]*

The full interaction effect is investigated in model 5, which is our preferred specification consistent with equation (5). In the interaction model the effect of the world frontier depends on the barrier (and *vice versa*). Given average values of the interacting variables, the long-run coefficient between productivity and world frontier is about 0.6 and the elasticity with respect to the tariff barrier is about -0.3. The new insight is that the spill-over from the world frontier to the domestic productivity level can be raised by lowering the tariffs. Reduced barrier can increase the spill-over coefficient from 0.7 towards 1.0, where SA broadly follows the world frontier. On the other hand, the increasing world frontier strengthens the productivity effect of reducing the barrier. The higher the world frontier, the larger is the technology gap. The result can be interpreted as if there is more to gain from reduced tariffs the higher the technology gap to the frontier. The model reproduces the productivity growth pre- and post-sanctions as a result of world improvements together with reduced barrier. The stagnation during sanctions is the result of higher barrier.

Alternative productivity dynamics are investigated in model 6, where the world frontier is assumed to interact with the level of productivity. The formulation highlights the importance of the level of the world frontier technology for the spill-over effect. The higher the world frontier, the more important are barriers.[6] Again the higher world frontier can be interpreted as higher technology gap. It follows that barriers are more important the larger the gap. The results are consistent with those in model 5. The time period is too short and the gap towards the world frontier too large to detect non-linearities in a robust way.

Our broad conclusion is that the TFP development in SA can be understood with a barrier growth model as a combination of world technology frontier and barrier. We have concentrated on the long-run effects, but have also shown that the productivity adjustment is sluggish (low coefficient on the lagged dependent variable). The sluggishness can be interpreted as an ongoing learning-by-doing process. Over time this process needs fuel from international spill-overs. We have investigated alternative specifications not reported and the results seem to be robust. In particular we have checked the results with the alternative measure of TFP based on actual income shares. The main quantitative effects and conclusions regarding the role of the world frontier and barriers hold.

[6] The model formulation now is:

$$dA_{it} = a_0 + a_1 A_{it-1} + a_2 A_{it-1} A*_{t-1} + a_3 TARIFFS_{t-1} + a_4 A*_{t-1} + a_5 dTARIFFS_t + a_6 dA_{t-1}* + e_i + u_{it}$$

The long-run level relationship consequently is:

$$A_{it-1} = \frac{-1}{(a_1 + a_2 A*_{t-1})}(a_3 TARIFFS_{t-1} + a_4 A^*_{t-1} + e_i)$$

8. Heterogeneity Across Sectors and Regime Changes Over Time

Our panel data set consists of 28 sectors, which are different in many aspects. The time period covered was also a turbulent period for SA. Heterogeneity can therefore be significant, and the Appendix Table 2 indicates that the average TFP-growth hides large variation between sectors. We have investigated heterogeneity both with respect to production sectors and time periods. Production sectors have been classified according to openness (their participation in imports and exports), skill levels (high-skill and low-skill intensive), and machinery intensity of investment (different shares of machinery in investment). We have found no systematic differences in productivity dynamics between groups of production sectors. Changing behaviour over time is important, however, and Table 4 reports a separation between pre-sanctions, sanctions and post-sanctions.

Table 4 Sources of TFP growth, heterogeneity over time and across sectors

	dA, model 7
A-1	-0.100*** (0.02)
TARIFF-1	0.486 (0.61)
TARIFF-1 x Sanc	-1.510*** (0.52)
TARIFF-1 x Postsanc	-1.452*** (0.54)
A*-1	-0.066 (0.06)
A*-1 x Sanc	0.109*** (0.02)
A*-1 x Postsanc	0.120*** (0.03)
CAPUTIL-1	0.118 (0.11)
dTARIFF	-0.441** (0.20)
dA*	-1.184*** (0.40)
dCAPUTIL	0.570*** (0.14)
Constant	0.068 (0.12)
R2	0.21
N and parameters	758, 39
Period	1973 - 2001

*[Fixed effects, no time dummies; * 10% level, ** 5% level, *** 1% level]*

Model 7 allows separate long-run effects of the world technology frontier and the tariff barrier for the three sub-periods. The main message is that the two factors were important during sanctions and after sanctions, but not before sanctions. The long-run coefficient between domestic productivity and world frontier is one both during and after sanctions. Tariffs represent important barriers during sanctions and post-sanctions and the quantitative effect is about the same during the two periods. The elasticity of TFP with respect to tariffs is about -0.8, somewhat higher than in the time invariant model. The combination of tariffs and world frontier growth does not contribute much to the understanding of the pre-sanctions period. The turbulence of the late 1970s and early 1980s has not left much of a systematic pattern. With this *caveat*, the barrier growth model looks like a promising approach to understand productivity growth.

9. Concluding Remarks

Recent literature on international income differences suggests a barrier growth model (Klenow and Rodriguez-Clare, 2004, Parente and Prescott, 2004). All countries can benefit from the growth of the world technology frontier, but in different degrees due to barriers to international spill-overs. The model implies a long-run relationship between country productivity and the world technology frontier, and changing barriers can add transitional growth. Our analysis of productivity growth in SA manufacturing industries is consistent with this model. The long-run coefficient between SA TFP and the world technology frontier (measured as US labour productivity) is about one. The relationship is influenced by the level of tariffs serving as a barrier.

SA is an interesting case study, and comes close to a natural experiment regarding openness. The economic and political turbulence including sanctions have generated large variation in the barriers to international spill-overs. Reduced barriers before and after sanctions and the high barrier during sanctions explain the development of productivity. The recent improvement in productivity during late 1990s and early 2000s can be understood as increased spill-over with reduced barrier. Future research may add the role of domestic barriers to this emphasis on international spill-over.

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11. Appendix

Appendix Table 1: Data description

Series	Description	Means	Standard dev.
Y[1]	Value-added sector (RM at 1995 prices)	3513.100	2668.500
K[1]	Fixed capital stock sector (RM at 1995 prices)	4840.600	7807.000
L[1]	Formal sector employment, sector (Number of people)	49854.000	42518.000
A[1]	Total factor productivity, estimated, sector (Index, normalised to 1 in 1970)	1.138	0.276
TRADE[1]	Exports and imports as share of value added, sector	1.201	1.459
TRADEAGG[2]	Exports and imports as share of GDP, aggregate	0.434	0.064
TRADEINDEX[3]	Index of openness	0.131	0.157
TARIFFS[2]	Total import taxes received by government as a share of imports in current RM value, aggregate	0.041	0.019
A*[4]	Output Per Hour All Persons, US manufacturing, Series Id: PU300001 (Index, 1996 = 1)	0.787	0.188
CAPUTIL[1]	Capacity utilisation, sector (share)	0.825	0.063
Ais	Total factor productivity, calculated with time series of sectoral factor shares, sector.	1.087	0.295
TARIFF x A*	Interaction term	0.032	0.016
A x A*	Interaction term	0.904	0.359
Ais x A*	Interaction term	0.842	0.359

1: TIPS, www.tips.org.za
2: World Development Indicators, World Bank, http://publications.worldbank.org/WDI/
3: Aron and Muellbauer (2002)
4: US Department of Labour, Bureau of Labour Statistics, http://www.bls.gov/data/home.htm

Appendix Table 2 Estimated average TFP growth rates by sector

Sector		Pre-sanctions 1970-1984	Sanctions 1985-1992	Post-sanctions 1993-2003	Full period 1970-2003	Std. dev. 1970-2003
Food	1	0.005	0.015	0.016	0.011	0.038
Beverages	2	0.025	0.024	0.019	0.023	0.082
Tobacco	3	0.040	-0.067	0.027	0.010	0.117
Textiles	4	0.020	-0.029	0.013	0.005	0.063
Wearing apparel	5	0.009	0.001	-0.004	0.003	0.064
Leather	6	0.003	-0.014	0.020	0.005	0.098
Footwear	7	0.012	-0.024	0.010	0.002	0.064
Wood/Wood products	8	0.007	0.003	0.034	0.015	0.064
Paper/Paper products	9	0.020	-0.014	0.024	0.013	0.055
Printing, etc.	10	0.018	-0.016	-0.021	-0.003	0.042
Coke/Refined petrol	11	0.076	-0.058	0.007	0.020	0.133
Basic chemicals	12	0.009	0.024	0.030	0.020	0.069
Other chemicals	13	0.010	0.053	0.031	0.027	0.067
Rubber products	14	0.033	-0.007	0.023	0.020	0.074
Plastic products	15	0.038	-0.008	0.022	0.022	0.089
Glass products	16	0.000	0.024	0.048	0.022	0.065
Non-met. minerals	17	0.007	-0.012	0.036	0.012	0.070
Basic iron/steel	18	0.000	0.002	0.055	0.019	0.084
Basic non-ferrous met.	19	0.032	0.009	0.045	0.031	0.100
Met. prod. excl. mach	20	-0.004	-0.037	0.023	-0.003	0.059
Machinery	21	-0.005	-0.007	0.020	0.003	0.055
Electrical machinery	22	0.004	-0.005	0.028	0.010	0.064
Tel./Rad./Com. equip.	23	0.023	0.010	0.025	0.020	0.097
Prof./Scientific equip.	24	0.000	0.004	-0.037	-0.011	0.087
Motor vehicles	25	-0.025	0.015	0.024	0.001	0.096
Other transp. equip.	26	0.012	-0.085	0.024	-0.008	0.110
Furniture	27	0.004	-0.013	0.006	0.001	0.060
Other manufacturing	28	-0.002	0.056	0.004	0.014	0.077
Average		0.013	-0.006	0.020	0.011	0.077

11.1. Testing for unit roots

11.1.1.TFP

We run Augmented Dickey Fuller (ADF) tests with up to five lags and include a constant and a trend. According to Appendix Table 3, the productivity level is non-stationary in all sectors, with the exception of sector 23 (Tel./Rad/Com equip) when one lag is used. Appendix Table 4 shows that the first difference of the productivity level is stationary in 24 of the 28 sectors when the standard Dickey Fuller test (zero lag) is used, and 17 when the ADF test with one lag is used. It is reasonable to take this as support for the productivity level being aI(1) variable in at least those 17 sectors. When five lags are introduced, only two sectors are stationary, suggesting that the productivity level is I(2) or more.[7] However, the last row in Appendix Table 3 and 4, reporting the Im, Pesaran and Shin (2003) statistics, supports that the panel of productivity levels can be seen as I(1).[8]

The aggregate variables TRADEAGG, TRADEINDEX, TARIFFS and A^* seem to be, according to Appendix Table 5, non-stationary. Appendix Table 6 gives a mixed picture of whether the variables are I(1) or integrated of higher order.

[7] The variation in the t-statistics as the lag length varies in the ADF tests reported in Table 1 and 2 shows a clear picture: the more lags, the lower t. In other words, the more lags, the harder it is to reject the hypothesis of non-stationarity.

[8] An alternative for testing for unit roots in panel data is to use the approach developed by Im, Pesaran and Shin (2003). The null hypothesis is that all series in the panel contains a unit root, and the alternative is that at least one of the series in the panel is stationary. Technically it is done by estimating a separate OLS (time series) equation for each of the series in the panel, and the test statistics is an average of the individual Dickey-Fuller "tau" statistics. Im, *et al.* propose standardised statistics for testing the average Dickey-Fuller taus, which converge weakly to a standard normal distribution as N and T goes to infinity (See Marrocu et al., 2000, p. 9).[8] Im, et al. (2003, table 2) gives the critical values, based on Monte Carlo experiments, of average t statistics used in their test. We have in our sample about N=28 and T=30. The t statistics for N=25 and T=30 is t=-1.94 at 1% significance level and t=-1.82 at the 5% significance level, when the regression contains only an intercept. When the regressions contain an intercept and a linear trend, the corresponding t values are t=-2.56 and t=-2.45. The last rows in table 1 and 2 give the average t statistics of the individual regressions, and support that the productivity level is non-stationary, as the average t statistics is in the interval of (-2.12, -1.29). The first difference test indicates that TFP is I(1).

Appendix Table 3 t-statistics ADF test, productivity level, A

		A, t-adf					
	Lags	*0*	*1*	*2*	*3*	*4*	*5*
	Sector						
Food	1	-1.89	-1.68	-0.40	-0.55	-0.65	-1.03
Beverages	2	-2.20	-3.22	-2.82	-2.11	-1.58	-1.54
Tobacco	3	-1.70	-2.76	-2.35	-1.80	-2.16	-2.25
Textiles	4	-1.99	-2.28	-2.31	-2.17	-1.99	-2.39
Wearing apparel	5	-2.33	-1.96	-1.86	-1.14	-0.85	-1.23
Leather	6	-3.01	-2.99	-2.75	-3.20	-2.06	-1.26
Footwear	7	-1.83	-1.01	-1.02	-1.21	-1.50	-1.73
Wood/Wood products	8	-2.00	-1.59	-1.65	-1.56	-0.79	-0.37
Paper/Paper products	9	-1.87	-2.70	-2.56	-2.12	-1.60	-2.21
Printing, etc.	10	-2.08	-2.00	-1.85	-1.83	-1.46	-1.73
Coke/Refined petrol.	11	-1.78	-1.74	-1.56	-1.83	-2.19	-2.14
Basic chemicals	12	-2.59	-3.13	-2.67	-1.87	-1.48	-1.25
Other chemicals	13	-2.77	-2.72	-2.87	-2.75	-1.77	-1.73
Rubber products	14	-3.05	-2.54	-1.88	-2.60	-2.27	-2.00
Plastic products	15	-2.33	-3.29	-3.08	-3.17	-1.70	-1.27
Glass products	16	-0.85	-0.71	-0.35	-0.20	0.86	1.80
Non-met. minerals	17	-1.83	-2.03	-2.21	-1.02	-0.03	-0.15
Basic iron/steel	18	0.11	0.11	0.11	0.28	1.17	0.90
Basic non-ferrous met.	19	-1.60	-2.09	-1.20	-1.85	-2.04	-2.00
Met. prod. excl. mach	20	-0.99	-2.24	-1.35	-0.82	-1.46	-1.15
Machinery	21	-0.93	-0.96	-0.74	0.15	0.33	0.30
Electrical machinery	22	-1.21	-1.37	-1.10	-1.36	-1.07	-1.43
Tel./Rad./Com. equip.	23	-3.39	-4.44	-2.76	-2.62	-1.39	-1.39
Prof./Scientific equip.	24	-1.74	-1.83	-1.74	-1.15	-1.70	-1.38
Motor vehicles	25	-1.81	-1.82	-1.54	-1.20	-1.20	-0.84
Other transp. equip.	26	-1.83	-2.22	-2.33	-1.89	-2.15	-2.48
Furniture	27	-1.96	-2.21	-2.28	-2.13	-2.15	-2.29
Other manufacturing	28	-1.10	-1.94	-2.27	-1.88	-1.66	-1.87
Average		-1.88	-2.12	-1.84	-1.63	-1.30	-1.29

[Critical values on the sectoral level (ADF test with T=27, Constant +Trend): 5%=-3.59 1%=-4.34). Critical values last row (Im, Pesaran and Shin, 2003, table 2, panel B, N=25 and T=30, intercept and linear trend): 1%: t=-2.56; 5 %: t=-2.45.]

Appendix Table 4 t-statistics ADF test, first difference of productivity level, dA

		dA, t-adf											
	D-lag	*0*		*1*		*2*		*3*		*4*		*5*	
	Sector												
Food	1	-5.77	**	-6.03	**	-3.57		-2.95		-2.16		-2.23	
Beverages	2	-3.82	*	-3.79	*	-4.24	*	-4.48	**	-3.31		-2.96	
Tobacco	3	-3.31		-3.45		-3.76	*	-2.49		-2.28		-1.98	
Textiles	4	-4.48	**	-3.34		-3.02		-3.10		-1.83		-1.46	
Wearing apparel	5	-6.13	**	-4.09	*	-4.22	*	-3.63	*	-2.64		-2.31	
Leather	6	-5.71	**	-4.30	*	-3.17		-4.18	*	-4.74	**	-3.68	*
Footwear	7	-7.15	**	-4.11	*	-3.16		-2.64		-2.03		-1.88	
Wood/Wood products	8	-6.20	**	-3.97	*	-3.32		-3.95	*	-3.85	*	-3.42	
Paper/Paper products	9	-3.73	*	-3.41		-3.51		-3.83	*	-2.25		-2.30	
Printing, etc.	10	-5.51	**	-4.11	*	-3.13		-3.34		-2.48		-3.19	
Coke/Refined petrol.	11	-5.21	**	-4.00	*	-2.81		-2.16	-	-2.14		-2.26	
Basic chemicals	12	-3.30		-3.44		-4.24	*	-3.94	*	-3.53		-2.77	
Other chemicals	13	-5.16	**	-3.28		-3.02		-4.17	*	-3.03		-3.58	
Rubber products	14	-5.58	**	-5.01	**	-2.97		-3.07		-3.05		-2.91	
Plastic products	15	-3.91	*	-3.57		-3.11		-5.69	**	-4.56	**	-4.65	**
Glass products	16	-5.29	**	-4.10	*	-3.22		-4.08	*	-4.73	**	-1.76	
Non-met. minerals	17	-5.01	**	-3.68	*	-4.41	**	-4.89	**	-3.08		-3.50	
Basic iron/steel	18	-4.71	**	-2.96		-2.49		-2.87		-1.53		-1.31	
Basic non-ferrous met.	19	-4.53	**	-4.82	**	-2.95		-2.50		-2.38		-2.00	
Met. prod. excl. mach	20	-3.51		-4.15	*	-4.05	*	-2.36		-2.49		-2.43	
Machinery	21	-5.10	**	-4.06	*	-4.70	**	-3.66	*	-2.67		-2.78	
Electrical machinery	22	-4.81	**	-3.95	*	-2.86		-2.85		-2.09		-2.16	
Tel./Rad./Com. equip.	23	-4.63	**	-5.78	**	-4.22	*	-6.97	**	-3.63	*	-2.88	
Prof./Scientific equip.	24	-4.50	**	-3.50	-	-4.09	*	-2.04		-2.25		-2.05	
Motor vehicles	25	-5.27	**	-4.28	*	-3.95	*	-3.00		-3.32		-2.29	
Other transp. equip.	26	-4.23	*	-3.22		-3.44		-1.99		-1.47		-0.79	
Furniture	27	-4.60	**	-3.54		-3.28		-2.92		-2.55		-2.77	
Other manufacturing	28	-3.06		-2.39		-2.65		-2.66		-2.18		-2.19	
Average		-4.79	**	-3.94	**	-3.48	**	-3.44	**	-2.79	**	-2.52	*

*[Critical values on the sectoral level (ADF test with T=27, Constant +Trend) *: 5%, t=-3.59, **: 1%, t=-4.34. Critical values last row (Im, Pesaran and Shin, 2003, table 2, panel B, N=25 and T=30, intercept and linear trend): *: 5 %, t=-2.45, **: 1%, t=-2.56]*

Appendix Table 5 t-statistics ADF test, levels of aggregate explanatory variables

	t-adf					
D-lag	0	1	2	3	4	5
TRADEAGG	-1.43	-1.463	-1.237	-1.217	-1.219	-0.1331
TRADEINDEX	-0.8272	-1.494	-0.9922	-1.105	-0.787	-0.7778
TARIFFS	-3.183	-2.254	-2.334	-1.968	-2.422	-1.814
A*	-0.183	-0.6359	-0.638	0.1897	0.249	0.3557

[ADF tests (T=23, Constant+Trend): 5%=-3.62; 1%=-4.42]

Appendix Table 6 t-statistics ADF test, first difference of aggregate explanatory variables

	t-adf					
D-lag	0	1	2	3	4	5
dTRADEAGG	-3.615	-3.361	-2.365	-1.926	-2.919	-2.185
dTRADEINDEX	-2.678	-2.931	-2.119	-2.275	-2.508	-2.367
dTARIFFS	-6.645**	-3.874**	-3.573	-2.482	-2.907	-2.894
dA*	-3.584	-2.799	-3.512	-2.787	-2.325	-2.325

*[ADF tests (T=22, Constant + Trend): *: 5%, t=-3.63; **: 1%, t=-4.44]*