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Wage inequality, comparative advantage and skill biased technical change in South Africa^{*}

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Abstract

International trade may influence income distribution. This study takes as a starting point the puzzling development of relative wages between skilled and unskilled labor in South Africa. Wage inequality decreased during the sanctions period and increased with trade liberalization post Apartheid, contrary to the standard trade theory prediction for an economy with comparative advantage in unskilled labor. We calibrate a Ramsey growth model for South Africa to clarify and quantify the distributive effects of trade barriers, and offer an understanding of the South African experience based on the interaction between openness and skill biased technical change. The dependence on foreign technology increases with openness and gives higher degree of skill bias, which may explain the observed relative wage path. Our model calibration is an alternative to econometric studies separating between trade and technology effects. A counterfactual analysis shows that without sanctions and protectionism during the 1980s the skilled-unskilled wage gap is about 13% larger on average. The quantitative results imply that an increase in trade as share of GDP of 10% points generates an increase in the wage gap of 6.6%. The analysis reveals a tradeoff between growth and distribution.

JEL: F16, O33, O41, O55.

Keywords: Wage gap; wage inequality; technological change; productivity growth; skill bias; comparative advantage; South Africa.

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1. Introduction

Standard trade theory suggests that the relative wage of unskilled benefits from openness in an economy with comparative advantage in unskilled labor. The development of relative wages in South Africa represents a puzzle in this context.¹ The international isolation during the 1980s is expected to increase the wage gap, while the recent trade liberalization post Apartheid should improve the wage inequality. The opposite has happened. While the wage gap decreased in the 1970s and 1980s, there was a distributional break in the mid 1990s with increased inequality post Apartheid (Fedderke et al., 2003, Leibbrandt et al., 2006). We offer an understanding of the South African experience based on the interaction between openness and skill biased technical change.

The relationship between trade openness and wage inequality has been addressed in a large literature. The increased wage inequality in industrialized countries has been understood as the result of comparative advantage or worldwide skill-biased technological change. Hanson and Harrison (1999) turned the attention towards developing countries, in particular Mexico, where they expected to find the opposite development of wages if the comparative advantage story was true. Mexico experienced a dramatic increase in the skilled-unskilled wage gap during a period of trade liberalization. Hanson and Harrison (1999) tend to conclude that Mexico has a comparative advantage in skilled labor. The more recent literature offers closer examination of the technology channel. Esquivel and Rodriguez-Lopez (2003) argue that trade liberalization should have led to a reduction of the wage gap in Mexico, and conclude that a large negative impact of technological progress has reduced the real wage of unskilled workers. Verhoogen (2008) develops the understanding of the technological channel in an analysis of quality upgrading in Mexican industries. This econometric approach attempts at separating the trade and the technology effects, but does not take into account that trade affects the technology channel. Underestimation of the trade effect then is likely. We suggest calibration of a growth model to include the interaction between trade and technological change.

¹ Edwards (2006) shows that the manufacturing sector in South Africa has a comparative advantage in unskilled labor when trading with developed economies and Asia (excluding China and India), while it has a comparative advantage in skilled labor when trading with Africa, South America, China and India. But since 80% of total trade is with developed and Asian (excluding China and India) countries, he finds that in total South Africa has a comparative advantage in unskilled labor.

Our starting point is a more conventional model of technology adoption and innovation to quantify the importance of trade openness for wage inequality. New technology innovated in skill-intensive developed countries is likely to be skill biased following from directed technical change (Acemoglu, 1998). Adoption of foreign technology is therefore expected to generate productivity growth biased towards skilled workers. Local improvement of technology can be directed based on given factor endowments, which in an unskilled-intensive economy implies technical change biased towards unskilled workers. The more dependent the economy is on adoption of foreign technology, the higher is the degree of skill bias in technical change. Empirical support is offered by Acemoglu (2003) and Zhu and Trefler (2005).

We apply a Ramsey growth model to clarify and quantify the effects of trade barriers for wage inequality. The model specification separates between a traditional unskilled-intensive sector, a modern skill-intensive sector, and a non-traded service sector. The traditional sector covers a large part of exports and confirms the comparative advantage of unskilled labor. We calibrate a reference path that captures the main elements of the South African experience during 1960-2005. International sanctions and protectionism are represented by a calibrated tariff equivalent that reproduces the actual trade and growth path. We model comparative advantage by allowing the substitution possibilities between sales to domestic markets versus export markets to differ across sectors. We are able to reproduce the South African relative wage path by taking into account the interaction between openness and skill biased technical change. The understanding is that the international isolation during the 1980s stimulated domestic innovation with less skill bias and consequently the wage gap decreased. Similarly, the opening of the economy in the 1990s increased the dependence of foreign technology, giving higher degree of skill bias and increased wage inequality.

The model allows a counterfactual analysis of increased openness, with consequences for the relationship between adoption and innovation and thereby skill bias and wage inequality. Eliminating the rise in the tariff equivalent during the period of sanctions and protectionism increases the wage gap by about 13%. This is driven by an increase in technological skill bias as the economy becomes more dependent on foreign technology. Interestingly, the degree and direction of comparative advantage has only minor impacts on the relative wage path. The quantitative results imply that an increase in trade as share of GDP of 10% points generates an

increase in the wage gap of 6.6%. The robustness of the result is investigated and the relative wage effect lies in the range 4.4-9.0% within standard parameterization.

The analysis reveals a trade off between growth and wage equality. Openness stimulates growth through technology spillovers, cheaper foreign capital goods and positive productivity-investment interaction, but worsens the wage inequality because foreign technology is skill biased. Overall the income level is higher with more openness due to higher growth, also for unskilled workers.

The paper presents the modeling of the productivity dynamics and skill bias (section 2) and the integration into a three-sector model of growth and distribution (section 3). Section 4 calibrates a growth and relative wage path that broadly reproduces the development in South Africa during 1960-2005. The last part of the analysis applies a counterfactual scenario to quantify the effect of a more open economy on wage inequality (section 5). Section 6 checks the robustness of the results based on certain parameter values. Section 7 concludes.

2. Productivity dynamics and skill bias

Productivity growth in middle income countries like South Africa is typically driven by a combination of innovation and technology adoption. Adoption of foreign technology is related to the technology gap to the world frontier and the extent of barriers. The understanding is based on early contributions by Gerschenkron (1962) and formalized by Nelson and Phelps (1966). The implied international spillovers have emerged as the dominating explanation of the world growth pattern, as argued by Lucas (2007). Growth experiences must be understood as cross-country flows of production-related knowledge from the successful economies to the less successful ones. Klenow and Rodriguez-Clare (2005) and Aghion and Howitt (2006) offer overviews of the growth-literature based on international spillovers. Recent development of the barriers to growth model is offered by Parente and Prescott (1994, 2005).

The role of innovation and adoption for productivity growth is backed up in an extensive empirical literature. Cross-country evidence about the importance of the world technology frontier is supplied by Benhabib and Spiegel (1994, 2005), Caselli and Coleman (2006), and Griffith et al. (2004). In a study of R&D spillover in 77 developing countries, Coe et al.

(1997) conclude that a developing country can boost its productivity by importing a larger variety of intermediate products and capital equipment embodying foreign knowledge. By taking into account the endogeneity of trade and institutional quality, Alcalá and Ciccone (2004) confirm the positive effect of trade on productivity. Benhabib and Spiegel (1994, 2005) show that human capital stimulates both innovation and technology adoption.

Country studies add to the evidence. Based on panel data for UK manufacturing industries Cameron et al. (2005) document a positive and significant effect of the distance to the technological frontier on productivity growth. They also show that international trade stimulates technology transfer. Cameron (2005) finds similar results for Japanese productivity growth. Several studies indicate the importance of openness for the TFP growth in South Africa. Harding and Rattsø (2007) address the endogeneity problem of trade policy and use other regions' tariff development as part of the WTO process as instruments for the tariff reductions since 1988. They find that tariffs have been important for labor productivity and their results are consistent with the importance of the world technology frontier. Fedderke (2005) puts more emphasis on domestic factors, and identifies important effects of R&D and human capital in South Africa. Inspired by this empirical evidence we study the endogenous formation of productivity growth driven by innovation and technology adoption.

We start out from the analytical formulation of Benhabib and Spiegel (2005, equation 2.3) combining foreign technology adoption with logistic diffusion and own innovations. Consistent with the empirical literature that trade policy and openness affects technology spillovers we extend their specification to include trade barriers. In the tradable sectors, the rate of growth of labor augmenting technical progress is specified as follows:

$$\begin{aligned}\hat{A}_{i,t} &= g(H_{i,t}) + c(H_{i,t}, T_{i,t}) \left(1 - \frac{A_{i,t}}{A_{i,t}^*} \right) \\ &= H_{i,t}^{\theta_{1,i}} + \lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}} \left(1 - \frac{A_{i,t}}{A_{i,t}^*} \right) \quad i = TR, M\end{aligned}\quad (1)$$

where $i = TR, M$ represents the traditional unskilled-intensive sector and the modern skill-intensive sector, respectively. The first term on the right-hand side of equation (1) represents the contribution from innovation activities, while the second term is the technology adoption function. $A_{i,t}$ and $A_{i,t}^*$ represent domestic and frontier productivity at the sector level, and

$A_{i,t}/A_{i,t}^*$ is relative productivity. λ_i , $\theta_{1,i}$, $\theta_{2,i}$ and $\theta_{3,i}$ are constant parameters. We measure human capital ($H_{i,t}$) by the share of skilled workers in sectoral production. The aggregate skill ratio in the economy is exogenous in the model, and is set according to the observed development in South Africa during 1960-2005. Since skilled and unskilled labor are allocated between sectors according to marginal productivities, the sectoral skill ratios affecting productivity develop endogenously. Trade barriers are represented by total trade as a share of production at the sector level ($T_{i,t}$), which is endogenously determined.

The complementarity between trade and human capital in technology adoption is also investigated by Stokke (2004) for the case of Thailand. The linear relationship between productivity growth and the technology gap limits the advantage of backwardness compared to the Nelson-Phelps specification and gives possible divergence in cases of high barriers to technology adoption. This is consistent with empirical evidence showing convergence among open economies, while high trade barriers may generate a development trap (see Sachs and Warner, 1995).

Under symmetric growth, long-run productivity growth is given by the exogenous frontier growth rate g , and the technology gap is constant. The degree of catch-up depends on the level of barriers and the innovative capacity of the economy. The long-run equilibrium consequently implies a proportional relationship between $A_{i,t}$ and $A_{i,t}^*$:

$$A_{i,t} = \frac{H_{i,t}^{\theta_{1,i}} + \lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}} - g}{\lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}}} \cdot A_{i,t}^* \quad i = TR, M \quad (2)$$

The equilibrium values of human capital and the trade share are constant, and, together with the frontier growth rate and the parameters, they determine relative productivity. Changes in the sources of innovation and adoption generate transitional growth to a new technology gap. The dynamics are consistent with the common understanding that differences in income levels are permanent, while differences in growth rates are transitory (Acemoglu and Ventura, 2002).

The formulation allows parameterization according to characteristics of the South African economy and implies endogenous productivity growth at the sectoral level responding to changes in the skill ratio and the trade share.

In the next step we link productivity growth and skill bias. Beaudry et al. (2006) show the basic analytics of a CES production function separating between low skill and high skill situations ('old' and 'new' technology). We specify the degree of bias in the same way, but allow for endogenous and continuous effect of productivity on skill bias.

Sectoral value added ($X_{i,t}$) is defined as a Cobb-Douglas function of capital ($K_{i,t}$) and total efficient labor use ($L_{i,t}$):

$$X_{i,t} = K_{i,t}^{\alpha_i} L_{i,t}^{1-\alpha_i} \quad i = TR, M, S \quad (3)$$

where $i = TR, M, S$ represents the traditional unskilled-intensive sector, the modern skill-intensive sector and the non-traded service sector, respectively. Efficient labor is a CES aggregate of unskilled ($Lu_{i,t}$) and skilled ($LS_{i,t}$) labor:

$$L_{i,t} = \left[\gamma_i A_{i,t}^{v-\frac{1}{2}\beta_{i,t}} Lu_{i,t}^v + (1-\gamma_i) A_{i,t}^{v+\frac{1}{2}\beta_{i,t}} LS_{i,t}^v \right]^{\frac{1}{v}} \quad i = TR, M, S \quad (4)$$

In the tradable sectors labor augmenting technical progress ($A_{i,t}$) develops endogenously according to equation (1). Productivity in services is assumed to grow exogenously at the long-run rate. The direction and degree of technological bias is introduced through the variable $\beta_{i,t}$, which gives the elasticity of the marginal productivity of skilled relative to unskilled labor with respect to labor augmenting technical progress. γ_i is the share parameters for unskilled labor, and $\sigma = \frac{1}{1-\nu}$ ($\nu < 1$) is the elasticity of substitution between the two labor types (which is assumed to be equal across sectors).

Marginal productivity of skilled relative to unskilled labor is given as:

$$\frac{\partial X_{i,t} / \partial LS_{i,t}}{\partial X_{i,t} / \partial Lu_{i,t}} = \frac{1-\gamma_i}{\gamma_i} A_{i,t}^{\beta_{i,t}} \left(\frac{LS_{i,t}}{Lu_{i,t}} \right)^{\nu-1} \quad i = TR, M, S \quad (5)$$

For $\beta_{i,t}$ equal to zero, technical change is neutral and does not affect the relative efficiency of the two labor types. With a positive value of $\beta_{i,t}$ technical change favors skilled workers (skill biased technical change), while negative values imply that improvements in technology are biased towards unskilled labor. In the service sector technical change is assumed to be neutral, and technological bias is set exogenously equal to zero ($\beta_{S,t} = 0$).

To have balanced growth, neutral technical change is a necessary long-run condition, but during transition the degree of technological bias in the traditional and the modern sector is

endogenously determined. The specification of technological bias is linked to the relative importance of technology adoption and innovation as sources of productivity growth. The background understanding is outlined by Acemoglu (1998). New technology innovated in skill-intensive developed countries is likely to be skill biased following from directed technical change. The more dependent the economy is on adoption of foreign technology, the higher is the degree of skill bias in technical change. We parameterize this based on a reduced form specification of technological bias assumed to be an increasing and convex function of the adoption share in productivity growth:

$$\begin{aligned}\beta_{i,t} &= b_i \left(\frac{c(H_{i,t}, T_{i,t})(1 - A_{i,t} / A_{i,t}^*)}{\hat{A}_{i,t}} \right)^2 \\ &= b_i \left(\frac{H_{i,t}^{\theta_{2i}} T_{i,t}^{\theta_{3i}} (1 - A_{i,t} / A_{i,t}^*)}{\hat{A}_{i,t}} \right)^2 \quad i = TR, M\end{aligned} \quad (6)$$

where b_i is a positive parameter. Given this specification, technical change is always skill biased ($\beta_{i,t} > 0$), but the degree of bias is determined by the relative importance of adoption and innovation as sources of growth.

3. Model of growth and distribution

The production functions with skill bias and the productivity dynamics explained above are embedded in a model of growth and distribution. We assume standard intertemporal decision making of a representative firm and a representative household. The model captures a small open economy, and the growth pattern does not influence world prices or the world interest rate, which are exogenously given. Investments can be financed through foreign borrowing, and the decisions about savings and investment can therefore be separated, although with a long-run restriction on foreign debt. The core of the model is the production technology, the representative firm investment decision and the household consumption-saving decision. The production functions and the productivity dynamics are presented in section 2, while the intertemporal dynamics are outlined below. Detailed documentation of the model is given in a separate model appendix available from the authors.

The representative firm makes its investment decision according to intertemporal profit maximization, subject to the accumulation of the aggregate capital stock over time:

$$\text{Max}_{I,K} \sum_{t=1}^{\infty} (1+r)^{-t} [Rk_t \cdot K_t - (PI_t \cdot I_t + ADJ_t)] \quad (7)$$

$$\text{s.t. } K_{t+1} = K_t \cdot (1 - \delta) + I_t \quad (8)$$

where r is the exogenous world market interest rate, Rk_t is the capital rental rate, PI_t is the unit cost of investment, I_t is aggregate investments, ADJ_t is investment adjustment costs, δ is the rate of depreciation, and K_t is the aggregate capital stock ($K_t = K_{TR,t} + K_{M,t} + K_{S,t}$). Following the common practice in the literature, unit adjustment costs are specified as a positive function of the investment-capital ratio. Therefore, total adjustment costs are given as:

$$ADJ_t = a \cdot P_{M,t} \cdot \frac{I_t^2}{K_t} \quad (9)$$

where a is a constant parameter and $P_{M,t}$ is the composite price of the traded modern good.

Differentiating the intertemporal profit function with respect to K_t gives the following no-arbitrage condition:

$$r \cdot q_{t-1} = Rk_t + a \cdot P_{M,t} \cdot \left(\frac{I_t}{K_t} \right)^2 - \delta \cdot q_t + \dot{q}_t \quad (10)$$

Equation (10) states that the marginal return to capital must equal the interest payments on a perfectly substitutable asset with a value of q_{t-1} , where q is the shadow price of capital. The first term on the right-hand side is the capital rental rate, while the second term is the partial derivative of the adjustment cost function with respect to capital. The marginal return to capital must be adjusted by the depreciation rate and by the capital gain or loss, \dot{q}_t .

The representative consumer maximizes an intertemporal utility function taking into account the current budget constraint for each period:

$$\text{Max} \sum_{t=1}^{\infty} (1+\rho)^{-t} U(Q_t) \quad (11)$$

$$\text{s.t. } PQ_t \cdot Q_t = Y_t - SAV_t \quad (12)$$

Assuming an intertemporal elasticity of substitution equal to unity, the utility function is defined as $U(Q_t) = \ln Q_t$, where Q_t is aggregate consumption in period t . PQ_t is the aggregate consumption price, Y_t is household income, SAV_t is private savings, and ρ is the positive rate of time preference. Utility maximization gives the Euler equation for optimal allocation of consumption over time:

$$\frac{PQ_{t+1}Q_{t+1}}{PQ_tQ_t} = \frac{1+r}{1+\rho} \quad (13)$$

Consumption growth depends on the interest rate, the time preference rate, and the price path.

The growth model describes an economy with macroeconomic stability, full employment of resources, and an open capital market. The assumptions imply unrealistic flexibility in resource allocation and investment financing without short-run imbalances. Some rigidity is built in with cost of investment adjustment, imperfect substitution between domestic and foreign goods, and imperfect substitution between sales to domestic markets versus export markets. Imports are endogenously determined through an Armington composite system, while exports are determined through constant elasticity of transformation (CET) functions. The labor market formulation separates between unskilled and skilled labor, and the relative wage is the key variable describing the wage inequality.

4. Reproducing the growth and wage path in South Africa

The parameters of the model are set to reproduce the broad economic development in South Africa during the past decades. Starting out from a consistent database in the base year 1998, we calibrate backwards a growth and relative wage path that is close to the observed development during 1960-2005. To reproduce actual GDP growth, the initial levels of capital and productivity are scaled down compared with the steady state path. The scaling back serves as an exogenous shock that takes the economy outside the equilibrium long-run path in 1960, and economic growth is driven by endogenous adjustment back to equilibrium growth. The model parameters are consistent with long-run equilibrium², where the long-run growth rate is assumed to equal 2% (1.3% technological progress rate and 0.7% labor growth).³ The long-run growth path must be consistent with the macroeconomic equilibrium as represented by the Euler equation: $r = (1 + \rho)(1 + g + n) - 1$, where $g + n$ is the exogenous long-run growth rate. The elasticity of substitution between labor categories is set so that unskilled and skilled labor are substitutes. Appendix Table 1 gives an overview of selected calibrated parameters.

² The calibration is documented in a separate appendix available from the authors.

³ The assumption of 0.7% labor growth is consistent with data on average annual employment growth in South Africa during 1971-2005 (Quantec Research, 2007).

The parameters of the productivity specifications given in equation (1) are set according to available econometric estimates. The elasticity of productivity growth with respect to the trade share is given by the parameter $\theta_{3,i}$ multiplied by the adoption share in productivity growth. In the model simulations the relative importance of technology adoption is endogenous and varies over time and across scenarios. We assume that trade openness has larger effect on productivity growth in the skill-intensive modern sector compared to the unskilled-intensive traditional sector. Assuming an elasticity of productivity growth with respect to the trade share in the range 0.6-0.8 in the modern sector and 0.3-0.5 in the traditional sector, we set $\theta_{3,M} = 1.3$ and $\theta_{3,TR} = 0.8$. For the modern sector, this implies that an increase in the trade share of 10% points gives 0.3-0.5% point higher productivity growth when starting from the assumed steady state rate. Similarly, 10% points higher trade share in the traditional sector generates 0.05-0.2% point higher productivity growth.⁴ The magnitude of the effects is consistent with econometric estimates offered by Romalis (2007). He applies US tariff data as instruments for openness in developing countries, and shows that 10% points increase in the trade share generates 0.2-0.5% point higher GDP per capita growth rate. Cameron et al. (2005) examine the role of international trade (measured by total imports as share of output) for TFP growth in UK manufacturing industries during 1970-92. In their preferred specification 10% points increase in the import share gives about 1% point higher TFP growth.⁵ Compared to this estimate, the elasticities of productivity growth with respect to the trade share applied in our model can be seen as conservative. Calibration of the other productivity parameters is documented in the Appendix. In section 6 we investigate how the quantitative effects of trade barriers depend on certain parameters.

We model comparative advantage by allowing the substitution possibilities between sales to domestic markets versus export markets to differ across sectors. The elasticity of substitution is assumed to be relatively higher in the traditional unskilled-intensive sector, which implies better international competitiveness compared to the skill-intensive modern sector. Available estimates of export elasticities are limited. Senhadji and Montenegro (1999) estimate export elasticities for 53 developing and developed economies, and find an average elasticity across middle income countries of 1.7. We set the elasticity of substitution equal to 1.2 in the modern

⁴ The calculations are based on trade shares in the range 0.2-0.4 for the modern sector and 0.3-0.9 for the traditional sector, which is consistent with the values in the model simulations.

⁵ This is calculated based on the coefficient on the interaction term between the import share and the technology gap in regression 2 in their Table 4. We proxy the average value of the technology gap by the average of the 1970 and 1992 value as reported in their Table 2.

sector and 3 in the traditional sector. Given these assumptions, the economy has a comparative advantage in unskilled labor and the traditional sector is relatively more able to take advantage of an open economy by expanding sales into world markets.

The development of the degree of openness and the relative supply of skilled labor affect both economic growth and wage inequality. The supply of labor is set according to Quantec Research (2007) data on employment shares by skill level.⁶ The share of unskilled labor in the total labor force declines from 78% to 46% during 1960-2005 with a corresponding increase in the skilled labor share from 22% to 54%. An important element of the South African experience is the changing trade conditions over time, and in particular the sanctions and protectionism from the mid 1970s to the early 1990s. Based on the model, we calibrate export and import taxes necessary to reproduce the actual trade path. The development of terms of trade and real effective exchange rate are calibrated consistent with data to adjust for the impact of world price shocks on the trade level. Total trade taxes as share of trade represents our measure of openness, and is illustrated in Figure 1 below. While the tariff equivalent decreases during the 1960s, the slow growth of exports and imports in the 1970s and 1980s requires a gradual increase of the tariff equivalent with a peak in the late 1980s of about 55%. After 1990 the removal of sanctions together with gradual liberalization of the trade policy increased trade rapidly, reflected in the model by decreasing tariffs. The calibrated openness indicator is consistent with existing measures of openness in South Africa, represented by Aron and Muellbauer (2002) and Edwards and Lawrence (2008).

Figure 1 about here.

Figure 2 shows how we track the actual growth rate as a steady decline in the model growth rate during 1961-90, followed by constant growth post Apartheid. The South African growth experience can be explained by neoclassical convergence, trade and human capital affecting international spillovers, and endogenous interplay between productivity and investment profitability. While the initial high growth was driven by investment and profitability, the stagnation involved a slowdown in productivity growth due to reduced technology adoption and an associated fall in investment profitability. Sanctions and protectionism have served as barriers to productivity growth, and the economy is unable to catch up with the frontier.

⁶ The supplies of skilled and unskilled labor are extended backwards to 1960 based on average growth rates during 1970-2005.

Average annual productivity growth rate during 1960-2005 equals 0.9% and 1.4% in the traditional and modern sector, respectively. The traditional unskilled-intensive sector is lagging behind the world frontier with the relative productivity level decreasing from 32% to 27%. Elimination of sanctions and trade liberalization has stimulated economic growth with reduced barriers post Apartheid. The modern skill-intensive sector takes advantage of the foreign technology and experiences some catching up with the frontier in this period (relative productivity increases from 32% to 34%). Rattsø and Stokke (2007, 2008) offer more comprehensive analyses of the growth mechanisms in South Africa and quantify the growth effect of trade barriers.

Figure 2 about here.

The South African relative wage path represents a puzzle. Wage inequality decreased during international isolation and increased with trade liberalization post Apartheid, contrary to the standard trade theory prediction for an economy with comparative advantage in unskilled labor. According to real wage data for the period 1970-98 offered by Fedderke et al. (2003), the wage gap decreases from an average of 4.5 in the 1970s, via 3.2 in the 1980s, to about 2.2 in the 1990s.⁷ A recent analysis of South African inequality by Leibbrandt et al. (2006) indicates a structural break in the mid 1990s, where the improvement in distribution since 1970 is turned into increased inequality post Apartheid (measured by the relative income between Whites and Africans). Ardington et al. (2006) address the robustness of this result and confirm the main finding. We are able to reproduce the distributive pattern of the relative wage by taking into account the interplay between openness and skill bias in productivity growth.

In the model simulations, the relative wage path is affected by both supply-side and demand-side factors. The relative supply of skilled labor increases over time and contributes to decreasing wage gap. Demand for different labor types is affected by the direction of comparative advantage and the development in technological bias. The degree of skill bias is endogenously determined by the relative importance of technology adoption and local productivity improvements. The more dependent the economy is on foreign technology, the

⁷ Fedderke et al. (2003) offer data on relative wages between unskilled, skilled and highly skilled labor. Our measure of skilled labor consists of highly skilled and skilled workers, and we use average employment shares from Quantec Research (2007) as weights to calculate the aggregate skill wage.

higher is the degree of skill bias in technical change. Along the South African reference path technology adoption initially accounts for about 45% of productivity growth in both tradable sectors, and the share increases to more than 50% during the first decade. With international isolation in the 1980s the adoption share gradually decreases to 43%. The economy is forced to rely more on own improvements of technology, and the degree of skill bias in technical change declines. This applies to both the traditional and the modern sector. Figure 5 in section 5 illustrates the development in the technological bias in the modern sector. In the post Apartheid period trade liberalization and removal of sanctions stimulate technology adoption (which accounts for about 60% of productivity growth in 2005), and gradually increase the degree of skill bias.

The development in the skilled-unskilled wage ratio along the calibrated South African reference path is illustrated in Figure 3 below. Even with increasing skill bias the wage gap decreases in the early high-growth period. This is driven from the supply side with increasing skill ratio. The positive distributive effect is stronger during international isolation as the degree of skill bias declines. In the post Apartheid period the higher demand for skilled labor from increasing skill bias contributes to worsened income distribution with larger wage gap. Increasing skill intensity during the 1990s is supported by empirical evidence. Edwards (2001) argues that skill bias has contributed to increased skill employment in South Africa, and based on two firm level surveys Edwards (2003) relates skill biased technical change to trade liberalization.

Figure 3 about here.

The relative wage path generated by the model is broadly consistent with the observed pattern, and follows from skill bias in technical change related to the dependence on foreign technology. Figure 3 compares the South African reference path with an alternative reference path that follows when the skill bias effect on relative wages is not taken into account. As seen from the figure, the interaction between openness and skill biased technical change is necessary to capture the distributional break in the mid 1990s. When the skill bias effect is ignored, the wage gap decreases during the whole period 1960-2005. The degree and direction of comparative advantage is found to have limited effects on the relative wage path.

5. Quantification of the distributional effects of trade barriers

The model allows a counterfactual analysis of the role of international trade and thereby a quantification of the distributive effect of trade barriers. As explained in section 4, we have calibrated a tariff-equivalent growing from the late 1960s and with a peak in the late 1980s to reproduce the actual trade and growth path. Eliminating the rise in the tariff-equivalent during the period of sanctions and protectionism, we can simulate the economic development in a more open economy. In the experiment, the tariff-equivalent decreases gradually from 48% in 1960 to 2% in 2005 (gradual trade liberalization), as illustrated in Figure 1.⁸ The average tariff rate during 1960-2005 equals 17%, down from about 40% along the South African reference path.

With lower tariffs the cost of technology transfer is kept low, and the economy takes advantage of foreign technology. The modern skill-intensive sector is more capable of utilizing the new technology, and catches up relative to the world frontier. During 1960-2005 relative productivity increases from 32% to 39%, and generates a long-run productivity gap of about 5%-points compared with the South African reference path (illustrated in Figure 4). Due to the economy's comparative advantage in unskilled labor, trade liberalization implies a structural shift towards the unskilled-intensive sector. Along the reference path the traditional sector expands during the 1960s and in the post Apartheid period, while the output expansion is held back during sanctions and international isolation. Over the period 1960-2005 the sector increases its value added share from 17% to 23.5%. With a more open economy, the output expansion is larger, and the 2005 value added share equals 29%. However, while the modern sector gains from trade liberalization in terms of higher productivity, the volume expansion in the traditional sector has limited effects on productivity. The sector avoids technological divergence, but is not able to catch-up with the frontier and relative productivity is about constant over time.

Figure 4 about here.

⁸ The tariff equivalent equals the sum of the export tax and the import tax, weighted by the export and import shares of total trade, respectively. During the first years the export and import tax are equal in the two scenarios, but since the weights are endogenous, the tariff equivalent is somewhat higher in the open economy scenario.

With a more open economy, the relative importance of technology adoption is higher than along the South African reference path. The new technology favors skilled workers and the degree of skill bias in technical change increases over time. Figure 5 illustrates the development of technological bias in the modern sector.⁹ The degree of skill bias follows a similar pattern in the traditional sector. The increase in skill bias generates an increase in the relative demand for skilled labor, and increases the wage inequality compared with the reference path. The wage gap is about 13% higher on average during the period after 1980 compared to the scenario with sanctions and protectionism (see Figure 3). The implied relationship between trade as share of GDP and relative wages is of interest. Given our parameterization, the tariff liberalization increases the trade share by about 19% points on average for the ‘effect period’ after 1980. Our quantitative results thus imply that an increase in the trade share of 10% points generates an increase in the wage gap of 6.6%. The result is consistent with the empirical analysis of Edwards (2006), where he finds that the South African tariff liberalization during the 1990s has contributed to an increase in the skilled-unskilled wage gap.

The quantitative effects are comparable to econometric studies. Based on mandated wage regressions, Esquivel and Rodriguez-Lopez (2003) try to separate out the effects of technical change and trade on wage inequality in Mexico. However, trade-induced technical change implies that the identified trade effect on the wage gap is likely to be underestimated. We combine the total effect on the wage gap estimated by Esquivel and Rodriguez-Lopez with the actual development in Mexican trade as share of GDP. The trade effect on wage inequality can be seen as an upper limit when the indirect effect via technical change is taken into account. Based on their results for the 1994-2000 period, the increase in the wage gap following 10% points higher trade share is at most 14.5%.¹⁰ This is the trade effect when all of the technical change effect is assigned to increased trade, and therefore represents the upper limit. Our calibrated quantitative effect (6.6%) is well below the calculated upper limit.

Figure 5 about here.

⁹ As explained in section 2, the value of the skill bias equals the elasticity of the marginal productivity of skilled relative to unskilled labor with respect to labor augmenting technical progress. Positive values imply bias towards skilled labor.

¹⁰ The total effect on the wage gap during 1994-2000 is estimated to 37.8% (given in Table 6 in Esquivel and Rodriguez-Lopez, 2003). In the same period, Mexican trade as share of GDP increased by 26% points.

Interestingly, the degree and direction of comparative advantage has only minor impacts on the relative wage path. When the skill bias channel is ignored, a more open economy decreases the wage inequality, consistent with the predictions of standard trade theory. But the effect is marginal; since 1980 the wage gap decreases with 1.3% on average. The understanding is that the structural change following comparative advantage is not large enough to generate significant relative wage effects. Even with more extreme parameter assumptions, the role of comparative advantage for the distributive effects of openness is limited (as documented in Section 6).

Given our model specification, there is a trade-off between economic growth and wage equality. Openness stimulates growth through technology spillovers, cheaper foreign capital goods and positive productivity-investment interaction, but increases the wage gap because foreign technology is skill biased. The average GDP growth rate during 1960-2005 increases by 0.7% point, and generates a permanent income gap between the two scenarios. The model predicts that the 2005 level of real GDP is 33% higher when trade barriers are eliminated. Wage inequality increases with trade liberalization, but overall the income level is higher with more openness due to higher growth, also for unskilled workers. The 2005 real wage of unskilled and skilled workers increases with 33% and 48%, respectively.

Economic research in South Africa has addressed the relationship between wage inequality, trade, and technical change. Abdi and Edwards (2002) address the puzzle that relative wages of unskilled has gone up, while unskilled employment has gone down since the mid-1970s. Since this is hard to explain in a standard labor market model, appeal to political and institutional factors to understand this is common, including increased union power. In our setting we emphasize a different channel of effects. The degree of skill bias is reduced with international isolation and the higher demand for unskilled labor decreases the wage gap. Institutional factors are not built into our analysis and are hard to handle in this context.

6. Robustness tests

The distributive effects of trade barriers discussed above obviously depend on parameter values. Of particular interest are parameters that determine the degree of comparative advantage, as well as parameters affecting the relationship between trade and skill bias. The latter involves trade elasticities in the productivity specifications and parameters in the

technological bias equations. To check the robustness of our quantitative results, we run sensitivity analyses on these parameter values. We find that the relationship between the trade share and wage inequality is quite robust across different parameterizations, both with respect to the trade elasticity in productivity growth and the bias parameter. Interestingly, comparative advantage plays a minor role for the distributive effects of openness.

The degree and direction of comparative advantage is modeled via the substitution possibilities between sales to domestic markets versus export markets. In the base-run simulations the elasticity of substitution is set to 1.2 in the skill-intensive modern sector, while the unskilled-intensive traditional sector has an export elasticity of 3. Better substitution possibilities in the traditional sector reflect an economy with comparative advantage in unskilled labor. Given the base-run assumptions on export elasticities, we find that without sanctions and protectionism during the 1980s the skilled-unskilled wage gap increases by 13% on average. Higher degree of comparative advantage in unskilled labor holds back the increase in the relative wage, but the magnitude of the effect is limited. Even with much better substitution possibilities in the traditional sector compared to the modern sector (elasticity of 4.5 versus 0.5), the effect of a more open economy on the wage gap is about the same. Similarly, the implied relationship between the trade share and wage inequality is not much affected by the degree of comparative advantage. The increase in the wage gap following an increase in the trade share of 10% points is always around 6.6%. The understanding is that the structural change following comparative advantage is not large enough to generate significant relative wage effects.

Tables 1 and 2 show how the quantitative effects of trade barriers depend on parameters affecting the relationship between trade and skill bias. Independent of the values of trade elasticity in productivity growth and bias parameters the increase in the wage gap following an increase in the trade share of 10% points lies in the range 4.4-9.0% (compared to 6.6% with the preferred parameter values).

Table 1 and 2 about here.

The elasticity of productivity growth with respect to the trade share is given by the parameter $\theta_{3,i}$ multiplied by the share of adoption in productivity growth. In the base-run simulations we set $\theta_{3,M} = 1.3$ and $\theta_{3,TR} = 0.8$, which gives an elasticity of productivity growth with respect to

the trade share in the range 0.6-0.8 in the modern sector and 0.3-0.5 in the traditional sector. As documented in section 4, this is broadly consistent with available econometric estimates. A higher elasticity means that the impact of changes in the trade share on productivity growth is larger. If the trade share increases with 1%, the technology adoption part of productivity growth increases with $\theta_{3,i}$ %. This implies that the impact of trade barriers on the adoption share in productivity growth, and consequently on technological skill bias and relative wages, increases with the trade elasticity in productivity growth. Hence, the distributive effects of a more open economy are larger the higher the elasticity of productivity growth with respect to the trade share. Similarly, the impact of increased adoption share on the degree of skill bias varies with the parameter b_i in the technological bias equations. The increase in the wage gap following 10% points higher trade/GDP increases with the value of the bias parameter.

7. Concluding remarks

The analysis addresses the relationship between international trade and wage inequality using South Africa as a case study. The study adds to the expanding literature on the importance of international trade for the wage gap between skilled and unskilled. Standard trade theory predicts worsened wage inequality during international isolation in a country with comparative advantage in unskilled labor. In South Africa the wage gap decreased during the period of international sanctions and protectionism. We offer an understanding of the South African experience based on the interaction between openness and skill biased technical change. International isolation reduces the inflow of skill-biased technology and allows more room for domestic innovation taking advantage of the unskilled labor surplus.

Our methodological contribution is the construction and calibration of a Ramsey growth model and counterfactual experiments of openness. The model allows for interaction between trade and technological change, an improvement compared to the econometric literature separating between trade and technology effects on wage inequality. The calibrated reference path captures the main elements of the South African experience during 1960-2005. International sanctions and protectionism are represented by a calibrated tariff equivalent that reproduces the actual trade and growth path. Future interaction of theoretical and empirical research can strengthen this analysis in terms of how to best capture the true productivity relationship.

The model allows quantification of the relationship between openness and wage inequality. Eliminating the rise in the tariff equivalent during the period of sanctions and protectionism increases the wage gap by about 13%. Based on the numerical analysis, we find that an increase in trade as share of GDP of 10% points generates an increase in the wage gap of 6.6%. This is driven by an increase in technological skill bias as the economy becomes more dependent on foreign technology. The result is well below econometric estimates that can be interpreted as upper limits of the trade effect on the wage gap. Interestingly, the degree and direction of comparative advantage has only minor impacts on the relative wage path.

The analysis reveals a trade off between growth and distribution. Openness stimulates growth through technology spillovers and less expensive capital goods, but worsens the wage inequality because foreign technology is skill biased. But overall the income level is higher with more openness due to higher growth, also for unskilled workers.

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Appendix: Calibration of trade and productivity elasticities

In the tradable sectors productivity growth is given by equation (1) in section 2:

$$\hat{A}_{i,t} = H_{i,t}^{\theta_{1,i}} + \lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}} \left(1 - \frac{A_{i,t}}{A_{i,t}^*} \right) \quad i = TR, M$$

where $H_{i,t}$ is the human capital level (measured by the sectoral skill ratio), $T_{i,t}$ is total trade as share of production at the sector level, and $A_{i,t} / A_{i,t}^*$ is the sectoral productivity level relative to the world frontier. The parameters of the productivity specifications are set in line with available econometric estimates.

The elasticity of productivity growth with respect to the trade share is given by the parameter $\theta_{3,i}$ multiplied by the adoption share in productivity growth. We assume $\theta_{3,M} = 1.3$ and $\theta_{3,TR} = 0.8$, which gives an elasticity in the range 0.6-0.8 in the modern sector and 0.3-0.5 in the traditional sector. As documented in section 4, this is consistent with available econometric estimates.

The elasticity of productivity growth with respect to the skill ratio is given by $\theta_{1,i}$ multiplied by the innovation share plus $\theta_{2,i}$ multiplied by the adoption share. We set $\theta_{1,TR} = \theta_{2,TR} = 0.5$ and $\theta_{1,M} = \theta_{2,M} = 0.8$, which gives an elasticity of 0.5 and 0.8 in the traditional and the modern sector, respectively. If the skill ratio increases with 1%, productivity growth increases with 0.5% in the traditional sector and 0.8% in the modern sector, and the effect works via both innovation and technology adoption. For the modern sector, this implies that an increase in the skill ratio of 10% points gives 0.15-0.3% point higher productivity growth when starting from the assumed steady state rate. Similarly, 10% points higher skill ratio in the traditional sector generates 0.2-0.65% point higher productivity growth.¹¹ In an analysis of 19 OECD countries during 1960-2000 Vandenbussche et al. (2006) find that human capital (measured by the share of the adult population with some tertiary education) stimulates TFP growth, and that the positive effect of human capital decreases with the distance to the technological frontier. Evaluated at the average technology gap among the OECD countries in the analysis ($A/A^* = 0.74$) their results imply that 10% points higher skill ratio generates about 1% point higher TFP growth rate¹². The smaller magnitude of effect assumed in our analysis seems reasonable since South Africa is further from the technological frontier.

The effect of the technology gap on productivity growth is given as $\frac{\partial \hat{A}_i}{\partial (A_i / A_i^*)} = -\lambda_i H_i^{\theta_{2,i}} T_i^{\theta_{3,i}}$,

which equals -1.6 and -3.3 in the traditional and modern sector, respectively, when calculated from base year values of the skill ratio and the trade share. If relative productivity increases by 10% points (for instance from 0.3 to 0.4), productivity growth decreases by 0.16% point in the traditional sector and 0.33% point in the modern sector (for instance from 1.3% to about 1%). This reflects the increase in adoption costs (lower learning potential) as the economy catches up towards the frontier. The magnitude of the effect is in line with econometric

¹¹ The calculation is based on skill ratios in the range 0.1-0.4 for the traditional unskilled-intensive sector and 0.4-0.8 for the modern skill-intensive sector, which reflects the development during 1960-2005 in the model simulations. Lack of skilled workers in the traditional sector explains the larger effect of increased skill ratio on productivity growth compared to the modern sector.

¹² The calculation is based on estimated coefficients in regression 5 of Table 4 in Vandenbussche et al. (2006). The average technology gap is given in their Table 1.

estimates offered by Hansson and Henrekson (1994). In a cross-country study they find a significant effect of the technology gap in interaction with human capital and trade openness on labor productivity growth. According to their estimates, 10% increase in the technology gap (A/A^*) gives 0.06-0.1% point lower labor productivity growth rate. This implies that if relative productivity increases by 10% points from 0.3 to 0.4 (33% increase), productivity growth decreases by 0.2-0.3% point.

The trade elasticities represent substitution possibilities between domestic and foreign goods (Armington), and between sales to domestic markets versus export markets (CET). We assume an Armington elasticity equal to 3 in both tradable sectors, which is consistent with available national and international estimates. Hertel et al. (2007) combine parameter estimation and general equilibrium modeling. Based on data from five Latin American countries, the US and New Zealand they estimate the elasticity of substitution among imports from different countries. The “rule of two” says that the elasticity of substitution across imports by sources is equal to twice the elasticity of substitution between domestic and foreign goods¹³. Based on this hypothesis the average Armington elasticity across sectors equals 3.5. IDC (1997) and Gibson (2003) offer Armington estimates for South African manufacturing industries and the average elasticity (among significant estimates) equals 1.8 and 1.1, respectively. However, these are short-run elasticities, which are normally smaller than long-run elasticities more relevant in our setting. As discussed in section 4, we model comparative advantage by allowing the substitution possibilities between sales to domestic markets versus export markets to differ across sectors. We set the elasticity of substitution equal to 1.2 in the modern sector and 3 in the traditional sector.

¹³ Empirical support for the “rule of two” hypothesis is offered by Liu et al. (2004).

Appendix Table 1. Selected calibrated parameters

Parameter	Description	Value
r	World market interest rate	0.11
ρ	Time preference rate	0.09
g	Long-run technical progress rate	0.013
n	Labor growth rate	0.007
α_{TR}	Capital share in production, traditional sector	0.47
α_M	Capital share in production, modern sector	0.53
α_S	Capital share in production, services	0.32
δ	Rate of depreciation	0.04
a	Parameter in adjustment cost function	3.4
$\theta_{1,TR}$	Parameter in the productivity equation, trad. sector	0.5
$\theta_{2,TR}$	Parameter in the productivity equation, trad. sector	0.5
$\theta_{3,TR}$	Parameter in the productivity equation, trad. sector	0.8
λ_{TR}	Parameter in the productivity equation, trad. sector	3.0
$\theta_{1,M}$	Parameter in the productivity equation, mod. sector	0.8
$\theta_{2,M}$	Parameter in the productivity equation, mod. sector	0.8
$\theta_{3,M}$	Parameter in the productivity equation, mod. sector	1.3
λ_M	Parameter in the productivity equation, mod. sector	10.9
σ	Labor elasticity (equal across sectors)	2.0
b_{TR}	Parameter in the bias equation, traditional sector	0.7
b_M	Parameter in the bias equation, modern sector	0.7
σ_{IM}	Armington elasticity (equal across tradable sectors)	3.0
$\sigma_{EX,TR}$	CET elasticity traditional sector	3.0
$\sigma_{EX,M}$	CET elasticity modern sector	1.2

Figure 1. Calibrated openness indicator for South Africa 1960-2005 and counterfactual trade liberalization path. Indicator measured as import tax and export tax as share of total trade.

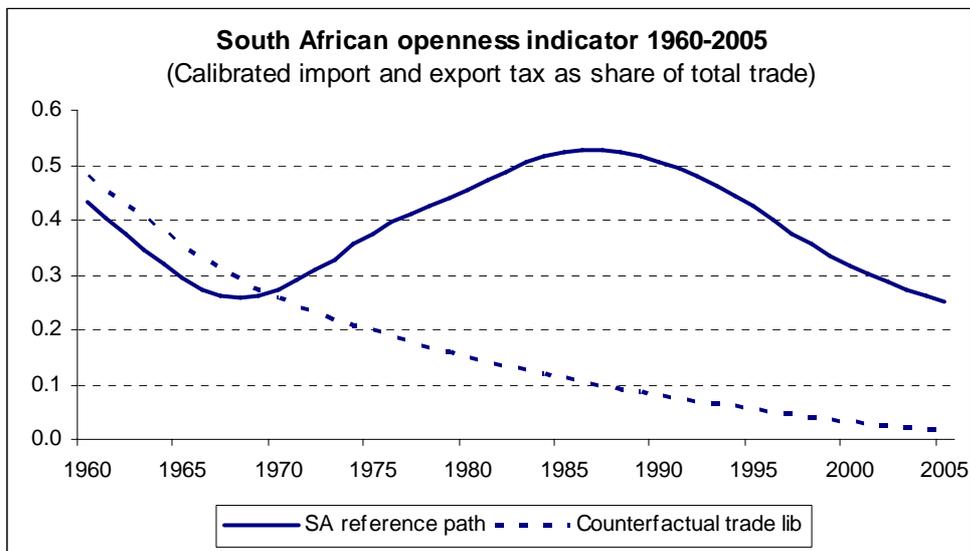


Figure 2. Real GDP growth rate: Calibrated South African reference path versus actual growth (measured as 3-year moving average)

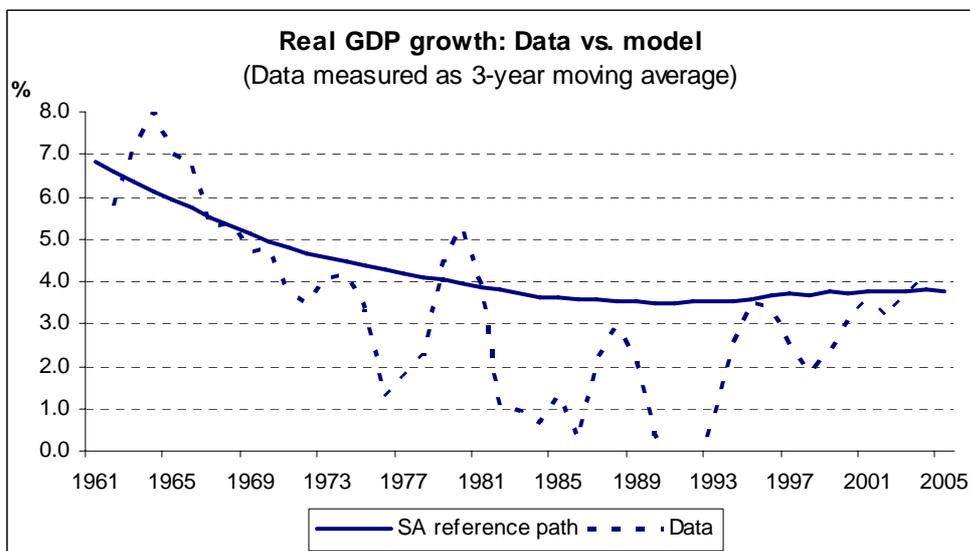


Figure 3. Skilled-unskilled wage gap: Calibrated South African reference path, reference path in model without skill bias effect, and counterfactual trade liberalization path.

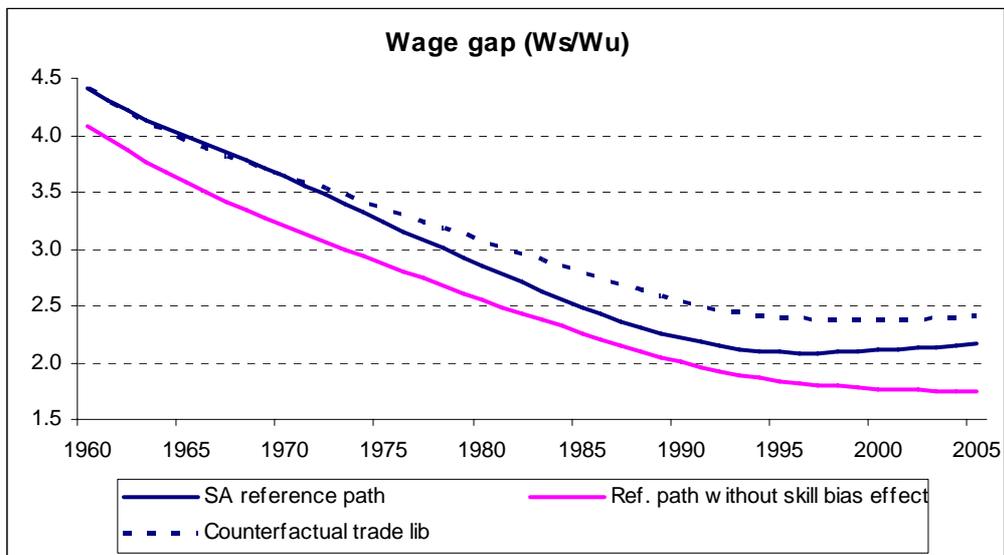


Figure 4. Productivity level in modern sector relative to the world frontier: Calibrated South African reference path versus counterfactual trade liberalization path.

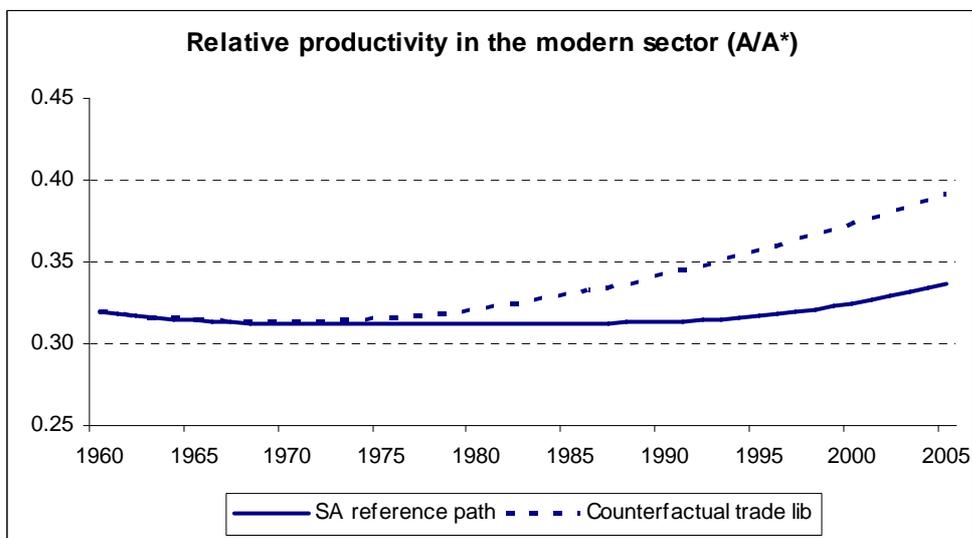


Figure 5. Degree of skill bias in technical change: Calibrated South African reference path versus counterfactual trade liberalization path.

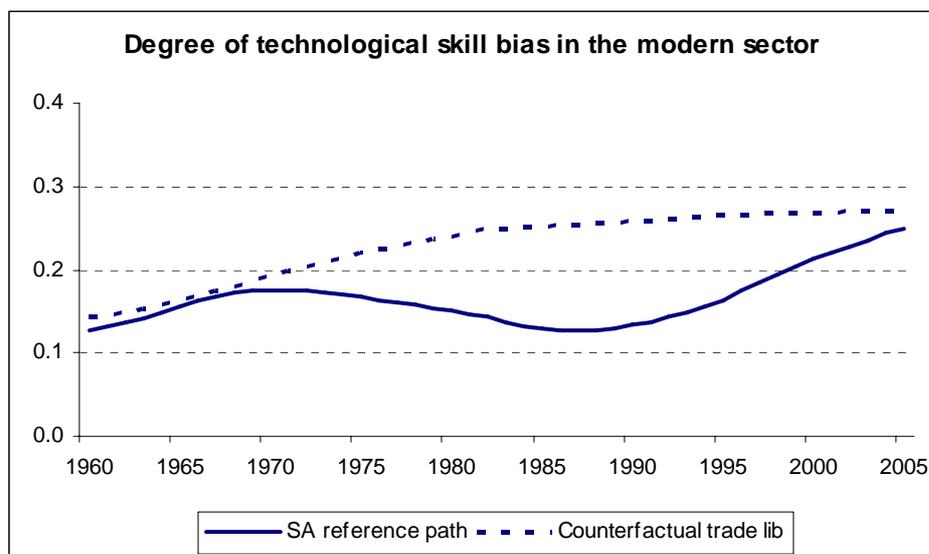


Table 1. Impact of 10% points increase in trade/GDP on wage inequality: Evaluated at different values of the elasticity of productivity growth with respect to the trade share.

	Low elasticity ¹	Base run ²	High elasticity ³
Ws/Wu	5.1 %	6.6 %	7.5 %

¹ Low elasticity: $\theta_{3,TR} = 0.5 \Rightarrow$ The elasticity equals about 0.3. $\theta_{3,M} = 0.8 \Rightarrow$ Elasticity in the range 0.4-0.5.

² Base run: $\theta_{3,TR} = 0.8 \Rightarrow$ Elasticity in the range 0.3-0.5. $\theta_{3,M} = 1.3 \Rightarrow$ Elasticity in the range 0.6-0.8.

³ High elasticity: $\theta_{3,TR} = 1.1 \Rightarrow$ Elasticity in the range 0.4-0.7. $\theta_{3,M} = 1.8 \Rightarrow$ Elasticity in the range 0.6-1.0.

Table 2. Impact of 10% points increase in trade/GDP on wage inequality: Evaluated at different values of the skill bias parameter b_i .

	Low: $b_i = 0.5$	Base run: $b_i = 0.7$	High: $b_i = 0.9$
Ws/Wu	4.4 %	6.6 %	9.0 %