Quantifying the effects of comparative advantage and skill biased technical change for wage inequality: Calibrating a growth model for South Africa*

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Abstract

Standard trade theory predicts that trade liberalization reduces wage inequality in an economy with comparative advantage in unskilled labor. But trade-induced technical change can be skill biased. South Africa is a case in point. Wage inequality decreased during sanctions and increased with trade liberalization post Apartheid. We use the South African experience to quantify the distributive effect of trade policy in a basic Ramsey growth model that includes the two channels of effects – comparative advantage and skill bias. The observed relative wage path can be explained by the variation in technology spillover and skill bias with changes in openness, while comparative advantage is of limited importance. Our model calibration allows for endogenous trade-technology interaction, and is an alternative to econometric studies separating between trade and technology effects. The quantitative results imply that an increase in trade/GDP of 10% points generates an increase in the wage gap of 5-10%.

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1. Introduction

A large literature addresses the relationship between trade openness and wage inequality (see overview by Goldberg and Pavcnik, 2007). The starting point has been standard trade theory suggesting that the relative wage of unskilled benefits from openness in an economy with comparative advantage in unskilled labor. But the wage gap between skilled and unskilled workers has been widening in many developing countries during a period of increased openness. The main alternative explanation for the increasing wage inequality has been skilled biased technological change. A series of econometric studies have addressed the economic importance of trade versus technology taking into account the market supply of skills. The econometric approach faces serious methodological challenges of trade and technology endogeneity. We suggest an alternative way of quantifying the effects of trade openness on wage inequality by calibrating a growth model. The strength of general equilibrium modeling is that trade, technology and wage gap all can be handled as endogenous variables, and in particular trade and technology are determined simultaneously.

Already Wood (1994) discussed how trade liberalization can induce technological change. The more recent understanding is that international technology spillovers represent the dominating explanation of the world growth pattern (see Lucas, 2007), and that trade is an important channel of such spillovers (Edwards, 1998, offers an early discussion of how trade policy is important for catching up with the technology gap). When trade influences technology, econometric estimates of effects of trade versus technology easily go wrong. In our context this is of particular importance when trade influences skill-bias of technology. The arguments for the relationship are worked out by Acemoglu (2003). In the quantification of the relationship between trade and wage inequality we explicitly build in endogenous skill-bias as a response to trade openness.

Our growth model is designed to reproduce the economic development in South Africa during a period of dramatic shifts in trade openness and large changes in wage inequality. The development of relative wages in South Africa reflects the puzzle observed elsewhere. According to comparative advantage, 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. [1] 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.

Our analysis is related to a large literature of country studies addressing trade and inequality. Hanson and Harrison (1999) turned the attention towards developing countries, as Mexico experienced a dramatic increase in the skilled-unskilled wage gap during a period of trade liberalization. They 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. Interestingly, Esquivel and Rodriguez-Lopez acknowledge the problem that technological change is strongly associated to the opening of the economy. The shortcomings of econometric studies such as these have led us to look for an alternative way of quantification.

Our starting point is a standard open economy Ramsey growth model with intertemporal decision making of a representative firm/household and an open world capital market. The model specification separates between a traditional unskilled-intensive sector, a modern skill-intensive sector, and a non-traded service sector. To capture the distributive effects of trade barriers the model includes the endogenous interaction between trade, technology adoption and technological bias, and allows for comparative advantage in unskilled labor. Productivity growth is generated by own innovations or adoption of foreign technology, where the latter is related to the technology gap to the world frontier and the trade barrier. The degree of skill

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[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.

bias in technical change is endogenously determined and increases with the economy's dependence on foreign technology. 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.

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 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 the model predicts 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 in the order of 5-10%. The result is well below econometric estimates where all the technology effect is assigned to trade, which can be interpreted as upper limits of the trade effect on the wage gap. The range indicated is robust to large changes in parameter values.

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 background literature is discussed in section 2, while section 3 presents the three-sector model of growth and distribution. 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. Background literature

Productivity growth in semi-industrialized 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 approach is based on the early broad discussion of 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. Nelson and Phelps emphasized human capital as a determinant of technology adoption, but the later literature has broadened the understanding of barriers to adoption (notably Parente and Prescott, 2005). The importance of trade policy for catching up with the technology gap was introduced by Edwards (1998).

The linkage between trade and technology is investigated 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. Frankel and Romer (1999) introduced geography variables as instruments for trade to identify causal effects of trade on productivity. The more recent contribution by Alcala and Ciccone (2004) attempts at separating the trade effect between productivity and capital accumulation and concludes that trade is a significant determinant of productivity. In our approach we are able to take into account that productivity and investment are determined simultaneously. More disaggregated evidence confirms the relationship between trade and productivity. 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 (2010) 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. Following this empirical evidence we study the endogenous formation of productivity growth driven by innovation and technology adoption.

The next step needed here is a relationship between technology and labor demand in terms of skill. A large literature provides evidence of worldwide skill bias in technical change. The understanding is that technical change has a positive effect on the demand for skilled workers. Acemoglu (1998) emphasizes that technical change is not skill biased by nature, and offers a theoretical explanation of why new technologies complement skills based on endogenous directed technical change. In a skill-intensive economy the market size effect implies that it is profitable to develop technologies directed towards skilled workers. Zhu and Trefler (2005) studies skill-bias in a trade model and show how technological catch-up shifts the composition of goods with respect to skill-intensity. Empirical support of the link between trade openness and skill biased technical change is offered by Acemoglu (2003), Attanasio, Goldberg and Pavcnic (2004), and Zhu and Trefler (2005).

In the introduction we have referred to country studies separating between trade and technical change as the main determinants of wage inequality. For developed countries, both skill biased technical change and trade effects related to comparative advantage contribute to the increase in the skill premium. However, empirical studies seem to favor the skill bias channel. For developing countries with comparative advantage in unskilled labor, standard trade theory predicts a reduction in the wage gap following trade liberalization. For instance, in an analysis of Mexico Esquivel and Rodriguez-Lopez (2003) find a positive effect of technical change on the wage gap while the trade effect is negative (consistent with the theory of comparative advantage). Goldberg and Pavcnik (2007) provide a nice overview of the empirical research on how globalization affects wage inequality in developing countries. The separation between trade and technology is difficult in econometric studies when the two channels interact. This problem motivates our modeling approach where the endogeneity can be made explicit. Atolia (2007) has developed a similar growth model to study how the transitional effects of trade liberalization are different from the long run effects. Our contribution is to address and quantify the skill-bias effect and in our setting the transitional and steady state effects goes in the same direction – more openness leads to more wage inequality.

3. Model of growth and distribution

We apply a three-sector general equilibrium model of growth and distribution. The labor market separates between unskilled and skilled labor, and the relative wage is the key variable describing the wage inequality. The model includes a traditional unskilled-intensive sector, a modern skill-intensive sector, and a non-traded service sector. The starting point is the standard open economy Ramsey growth model with intertemporal decision making of a representative firm/household and an open world capital market. To capture the distributive effects of trade barriers we extend the model in two directions. First, productivity growth and technological bias are endogenously determined, and the model specification links trade barriers, technology adoption and skill-biased technical change. Second, we assume imperfect substitution between sales to domestic markets versus export markets and allow the substitution possibilities to differ across sectors to reflect the degree and direction of comparative advantage in the economy. The model thus includes the two main channels of effect from trade to wage inequality highlighted in the literature.

3.1 Production technology, productivity dynamics and skill biased technical change

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

$$X_{i,t} = K_{i,t}^{\alpha_i} L_{i,t}^{1-\alpha_i} \qquad i = TR, M, S \tag{1}$$

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:

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

The direction and degree of technological bias is defined as a relationship between the overall labor efficiency $A_{i,t}$ and the relative marginal productivities of the two labor types as in Acemoglu (1998). It is represented by the parameter $\beta_{i,t}$, which gives the elasticity of the marginal productivity of skilled relative to unskilled labor with respect to labor augmenting technical progress. Relative marginal productivity is given as:

$$\frac{\partial X_{i,t} / \partial Ls_{i,t}}{\partial X_{i,t} / \partial Lu_{i,t}} = \frac{1-\gamma_i}{\gamma_i} A_{i,t}^{\beta_{i,t}} \left(\frac{Ls_{i,t}}{Lu_{i,t}} \right)^{\nu-1} \qquad i = TR, M, S \tag{3}$$

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 ($\beta_{S,t} = 0$). It should be noticed that our specification of skill bias differs from the conventional separation between 'old' and 'new' technology. Beaudry et al. (2006) show the basic analytics of a CES production function in this case.

The share parameters for unskilled labor are given by γ_i, 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). Intermediate goods are employed according to fixed input-output coefficients.[2] The first order conditions equilibrate factor prices with the marginal productivities of each factor. The capital rental rate, the unskilled wage rate and the skilled wage rate are determined from the factor market equilibrium.

In the tradable sectors labor augmenting technical progress ($A_{i,t}$) develops endogenously. We start out from the analytical formulation of Benhabib and Spiegel (2005, equation 2.3) combining logistic technology 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. The productivity growth rate is specified as follows:

[2] The value added price ($PV_{i,t}$) is defined as $PV_{i,t} = PX_{i,t}(1-ta_i) - \sum_j P_{j,t} IO_{j,i}$, where $PX_{i,t}$ is the producer price, ta_i is the sales tax rate, $P_{i,t}$ is the demand-side price level, and $IO_{i,j}$ is the fixed input-output coefficient for good i in sector j. Gross domestic product (GDP_t) is thus given as $GDP_t = \sum_i PV_{i,t} \cdot X_{i,t}$, where $i = TR, M, S$.

$$\hat{A}_{i,t} = g(H_{i,t}) + c(H_{i,t}, T_{i,t})\left(1 - \frac{A_{i,t}}{A^*_{i,t}}\right)$$

$$= H_{i,t}^{\theta_{1,i}} + \lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}}\left(1 - \frac{A_{i,t}}{A^*_{i,t}}\right) \qquad i = TR, M \qquad (4)$$

The first term on the right-hand side of equation (4) 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. The parameters λ_i, $\theta_{1,i}$, $\theta_{2,i}$ and $\theta_{3,i}$ are constant. We measure human capital ($H_{i,t}$) by the share of skilled workers in sectoral production, while trade barriers are represented by total trade as a share of production at the sector level ($T_{i,t}$).[3] Productivity in services is assumed to grow exogenously at the long-run rate.

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, consistent with 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 developing 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:

$$\beta_{i,t} = b_i\left(\frac{c(H_{i,t}, T_{i,t})(1 - A_{i,t} / A^*_{i,t})}{\hat{A}_{i,t}}\right)^2$$

$$= b_i\left(\frac{\lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}}(1 - A_{i,t} / A^*_{i,t})}{\hat{A}_{i,t}}\right)^2 \qquad i = TR, M \qquad (5)$$

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.

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[3] The complementarity between trade and human capital in technology adoption is also investigated by Stokke (2004) for the case of Thailand.

3.2 The investment decision

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

$$\underset{I,K}{Max} \sum_{t=1}^{\infty}(1+r)^{-t}\left[Rk_t \cdot K_t - (PI_t \cdot I_t + ADJ_t)\right] \tag{6}$$

$$s.t.\ K_{t+1} = K_t \cdot (1-\delta) + I_t \tag{7}$$

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. Hence, total adjustment costs are given as:

$$ADJ_t = a \cdot P_{M,t} \cdot \frac{I_t^2}{K_t} \tag{8}$$

where a is a constant parameter and $P_{M,t}$ is the composite price of the traded modern good. Aggregate investment is a Cobb-Douglas function of the investment demand for each of the three goods in the model. The investment demand for the modern good includes the adjustment costs.

Differentiating the intertemporal profit function with respect to I_t gives:

$$q_t = PI_t + 2 \cdot a \cdot P_{M,t} \cdot \frac{I_t}{K_t} \tag{9}$$

This relationship says that the investor equilibrates the marginal cost of investment, which is given on the right hand side, and the shadow price of capital, q_t. Differentiating the same function with respect to K_t gives the following no-arbitrage condition:

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

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}. 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, $\Delta q_t = q_t - q_{t-1}$.

3.3 Household utility maximization

The representative household receives income through the primary factors, while interest payments on its foreign debt are subtracted. There is no independent government sector, so public tax revenues (sales and trade taxes) are transferred to the household in the form of a lump sum. The household is forward-looking and maximizes an intertemporal utility function taking into account the current budget constraint for each period:

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

$$s.t. \; PQ_t \cdot Q_t = Y_t - SAV_t \tag{12}$$

Assuming an intertemporal elasticity of substitution equal to unity, the utility function is defined as $U(Q_t) = \ln Q_t$. Aggregate consumption (Q_t) is a Cobb-Douglas function of the consumption demand for each of the three goods in the model. The aggregate consumption price is given as PQ_t, while Y_t is household income, SAV_t is private savings, and ρ is the positive rate of time preference. The utility maximization gives the Euler equation for optimal allocation of consumption over time:

$$\frac{PQ_{t+1}Q_{t+1}}{PQ_tQ_t} = \frac{1+r}{1+\rho} \tag{13}$$

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

3.4 The export decision and modeling of comparative advantage

The tradable sectors face imperfect substitution between producing for the domestic market and for the world market. The supply functions for exports ($E_{i,t}$) and domestic sales ($D_{i,t}$) are derived from maximizing current sales income subject to the constant elasticity of transformation (CET) functions:

$$Max \quad PD_{i,t} \cdot D_{i,t} + PWE_{i,t}(1-te_{i,t}) \cdot E_{i,t} \tag{14}$$

$$s.t. \quad X_{i,t} = ac_i[mc_i \cdot E_{i,t}^{\frac{1+\sigma_{EX,i}}{\sigma_{EX,i}}} + (1-mc_i)D_{i,t}^{\frac{1+\sigma_{EX,i}}{\sigma_{EX,i}}}]^{\frac{\sigma_{EX,i}}{1+\sigma_{EX,i}}} \qquad i = TR, M \tag{15}$$

where ac_i and mc_i are constant parameters. The producer price is a composite of the exogenous world market price of export goods ($PWE_{i,t}$) adjusted by export taxes ($te_{i,t}$) and the endogenous domestic price ($PD_{i,t}$). The constant elasticity of substitution between sales to domestic and foreign markets for sector i is given by $\sigma_{EX,i}$. To capture the degree and direction of comparative advantage we allow the substitution possibilities to differ across sectors. Relatively higher elasticity of substitution in the traditional unskilled-intensive sector implies better international competitiveness compared to the skill-intensive modern sector, and the economy has comparative advantage in unskilled labor.

3.5 The import decision and foreign debt

We assume imperfect substitution between domestic and foreign tradable goods, so the model consequently operates with two composite goods, one traditional and one modern. The demand functions for imports ($M_{i,t}$) and domestic goods ($D_{i,t}$) are derived from minimizing current expenditure subject to the Armington functions:

$$Min \;\; PWM_{i,t}(1+tm_{i,t})\cdot M_{i,t} + PD_{i,t}\cdot D_{i,t} \tag{16}$$

$$s.t. \;\; CC_{i,t} = aa_i[ma_i \cdot M_{i,t}^{\frac{\sigma_{IM}-1}{\sigma_{IM}}} + (1-ma_i)D_{i,t}^{\frac{\sigma_{IM}-1}{\sigma_{IM}}}]^{\frac{\sigma_{IM}}{\sigma_{IM}-1}} \qquad i = TR, M \tag{17}$$

where σ_{IM} is the constant elasticity of substitution between domestic and foreign goods, which is set equal for traditional and modern goods. $CC_{i,t}$ represents total absorption of composite good i, including intermediate, consumption and investment demand. The parameters aa_i and ma_i are constant. The price level facing domestic agents ($P_{i,t}$) is a composite of the exogenous world market price of import goods ($PWM_{i,t}$) adjusted by import tariffs ($tm_{i,t}$) and the endogenous domestic price ($PD_{i,t}$), and follows from the commodity market equilibrium. Services are not traded internationally and the price level ($P_{S,t}$) is determined endogenously in the domestic market.[4]

Foreign debt ($DEBT_t$) is accumulated over time from trade deficits ($FSAV_t$) and interest payments on outstanding debt:

$$DEBT_{t+1} = DEBT_t \cdot (1+r) + FSAV_t \tag{18}$$

$$FSAV_t = \sum_i \left(PWM_{i,t}M_{i,t} - PWE_{i,t}E_{i,t} \right) \qquad i = TR, M \tag{19}$$

3.6 Long-run equilibrium

[4] In the non-traded service sector the producer price equals the demand-side price level, $PX_{S,t} = P_{S,t}$.

The linear relationship between productivity growth and the technology gap in equation (4) limits the advantage of backwardness, and with low level of absorptive capacity (represented by high trade barriers and/or low level of human capital) long-run technological divergence is a possible outcome. 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). With sufficient level of absorptive capacity, the long-run growth rate is exogenously given as $g+n$, where g is the frontier rate of labor augmenting technical progress and n is the labor supply growth rate. The growth rate of the capital stock and the foreign debt approaches the constant rate in the long run. Productivity growth equals the world frontier rate, and the technology gap is constant:

$$A_{i,t} = \frac{H_{i,t}^{\theta_{1,i}} + \lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}} - g}{\lambda_i H_{i,t}^{\theta_{2,i}} T_{i,t}^{\theta_{3,i}}} \cdot A_{i,t}^{*} \qquad i = TR, M \qquad (20)$$

The long-run values of human capital and the trade share are constant, and, together with the frontier growth rate and the parameters, they determine relative productivities. The degree of catch-up depends on the level of barriers and the innovative capacity of the sector. Changes in the sources of innovation and adoption generate transitional growth to a new technology gap.

These dynamics are consistent with the common understanding that differences in income and productivity levels are permanent, while differences in growth rates are transitory (Acemoglu and Ventura, 2002). The model reproduction of South African growth during 1960-2005 below treats this period as a transition towards steady state.

4. Reproducing the growth and relative wage path in South Africa

The starting point for the quantification of the distributive effects of trade liberalization is the calibration of a reference path that captures the broad economic development in South Africa during 1960-2005. The parameters are set based on a 1998 Social Accounting Matrix, as well as available econometric estimates and stylized facts. The parameters are made consistent with long run equilibrium, where the growth rate is assumed to equal 2% (1.3% technological progress rate and 0.7% labor growth).[5] Long run technical progress follows the growth rate of the world technology frontier. Calibration of key parameters, including trade and productivity

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[5] 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).

elasticities, is documented in the appendix.[6] To reproduce actual GDP growth, the initial levels of capital and productivity are scaled down compared to 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 transitional economic growth is driven by endogenous adjustment back to equilibrium growth.

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. The empirical literature addressing foreign trade and trade policy faces the problem that sanctions cannot be measured directly. As in Rattsø and Stokke (2010), we capture the protectionist effect of international isolation by calibrating export and import taxes necessary to reproduce the observed trade path during 1960-2005. 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 Fig. 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] Detailed documentation of the calibration and the 1998 South African Social Accounting Matrix is given in a separate appendix available from the authors.

Average annual productivity growth rate during 1960-2005 equals 0.9% and 1.4% in the traditional and modern sector, respectively, compared to 1.3% at the world technology frontier. 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, 2010) offer more comprehensive analyses of the growth mechanisms in South Africa and quantify the growth effect of trade barriers.

Figure 2 about here.

Starting out with a standard trade theory perspective, the development of the South African relative wage path has been puzzling. Wage inequality decreased during international isolation and increased with trade liberalization post Apartheid. We concentrate the wage story to the period 1970-98 when we have real wage data as used 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. Our simulations indicate a similar stop of the declining trend in the end of the 1990s.

In the model simulations, the relative wage path is affected by both supply-side and demand-side factors. The relative supply of labor is set according to Quantec Research (2007) data on employment shares by skill level.[8] The share of skilled labor in the total labor force increases from 22% to 54% during 1960-2005, 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 substitution possibilities between sales to domestic

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[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.

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

markets versus export markets are set relatively higher in the traditional unskilled-intensive sector. This implies that 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.

Given the labor market conditions and the development of human capital and openness, the degree of skill bias is calibrated to reproduce the development of the wage gap. The implied *b*-parameter means that an increase in the adoption share of 10% points leads to an increase in the skill-bias parameter β of about 0.07. The effect is low compared to the estimates available in the literature. Given this calibration, the degree of skill bias is endogenously determined by the relative importance of technology adoption in productivity growth. The more dependent the economy is on foreign technology, the 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. 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. Figure 5 in section 5 illustrates the development in the technological bias in the modern sector given our assumptions. The degree of skill bias is in the range 0.1-0.3, and implies that 1% productivity growth generates an increase in the relative marginal productivity between skilled and unskilled workers (which equals the wage gap in this model) of 0.1-0.3%. The assumed effect is modest, and with a skilled wage gap equal to 3, productivity growth of 10% increases the wage ratio up to 3.1.

The development in the skilled-unskilled wage ratio along the calibrated South African reference path is illustrated in Fig. 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 share. 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, as further discussed in the following sections.

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 Fig. 1.[9] 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

[9] 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.

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 Fig. 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.

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.[10] 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 Fig. 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.

[10] As explained in section 3, 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.

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. The combined effect on wage inequality of trade and technical change estimated by Esquivel and Rodriguez-Lopez can be seen as an upper limit for the true trade effect (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%.[11] 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.

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

[11] 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 (World Bank, 2008).

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 the *b*-parameter 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 ($\sigma_{EX,TR} = 4.5$ versus $\sigma_{EX,M} = 0.5$), 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 5-10% (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 the appendix, 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* 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 contributes to the quantification of the relationship between international trade and wage inequality. Given the econometric challenges related to the handling of endogenous trade and technology, we suggest quantification based on the calibration of a growth model. The calibration is based on the growth path of South Africa, which reflects large changes in trade openness of the economy. 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, while it increased with trade liberalization post Apartheid. This ‘puzzle’, which is well known from many country experiences, can be understood as a result of 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. Similarly, the opening of the economy post Apartheid increases the dependence on foreign technology and thus the degree of skill bias in technical change.

Our methodological contribution is the construction and calibration of a Ramsey growth model and counterfactual experiments of openness. 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. Eliminating the rise in the tariff equivalent during the period of sanctions and protectionism the model predicts 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 in the order of 5-10%. The result is well below econometric estimates where all the technology effect is assigned to trade, which can be interpreted as upper limits of the trade effect on the wage gap. The range indicated is robust to large changes in parameter values.

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. Future research should address alternative sources of skill bias and clarify the microeconomics of the technology choices made.

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Appendix: Calibration of trade and productivity elasticities

The parameters of the model are partly based on available econometric estimates and partly set to reproduce the historical 'reference path'.

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 ($\sigma_{IM} = 3$), 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 goods[12]. 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.

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 sector ($\sigma_{EX,M} = 1.2$) and 3 in the traditional sector ($\sigma_{EX,TR} = 3$). 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 effect of the technology gap on productivity growth is given as $\dfrac{\partial \hat{A}_i}{\partial \left(A_i / A_i^* \right)} = -\lambda_i H_i^{\theta_{2,i}} T_i^{\theta_{3,i}}$,

which equals -1.6 and -3.3 in the traditional and modern sector, respectively, when calculated from base year values of the skill share 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 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.

[12] Empirical support for the "rule of two" hypothesis is offered by Liu et al. (2004).

The elasticity of productivity growth with respect to the skill share 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 share 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 share 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 share in the traditional sector generates 0.2-0.65% point higher productivity growth.[13] 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 share generates about 1% point higher TFP growth rate[14]. The smaller magnitude of effect assumed in our analysis seems reasonable since South Africa is further from the technological frontier.

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.[15] 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.[16] Compared to this estimate, the elasticities of productivity growth with respect to the trade share applied in our model can be seen as conservative.

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[13] 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.

[14] 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.

[15] 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.

[16] 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.

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

Fig. 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.

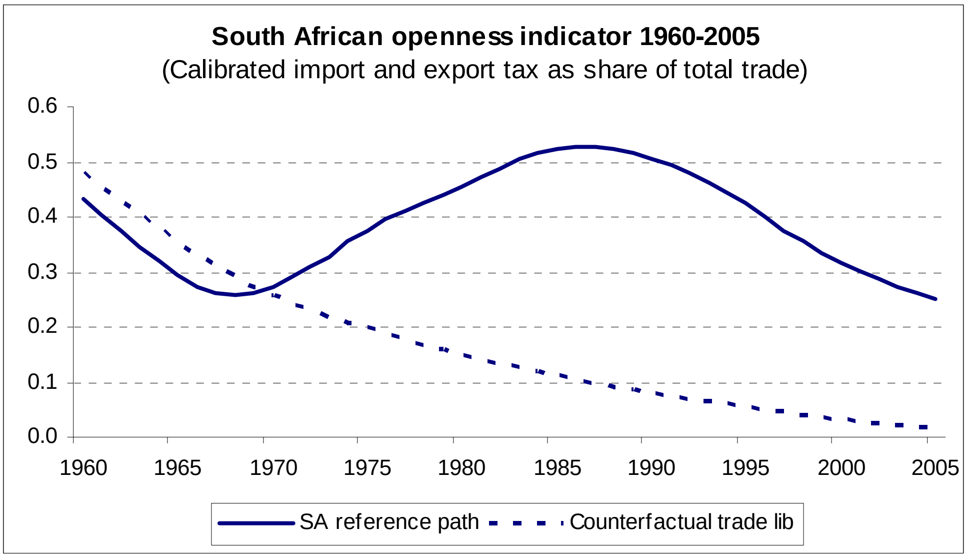

Fig. 2. Real GDP growth rate: Calibrated South African reference path versus actual growth (measured as 3-year moving average)

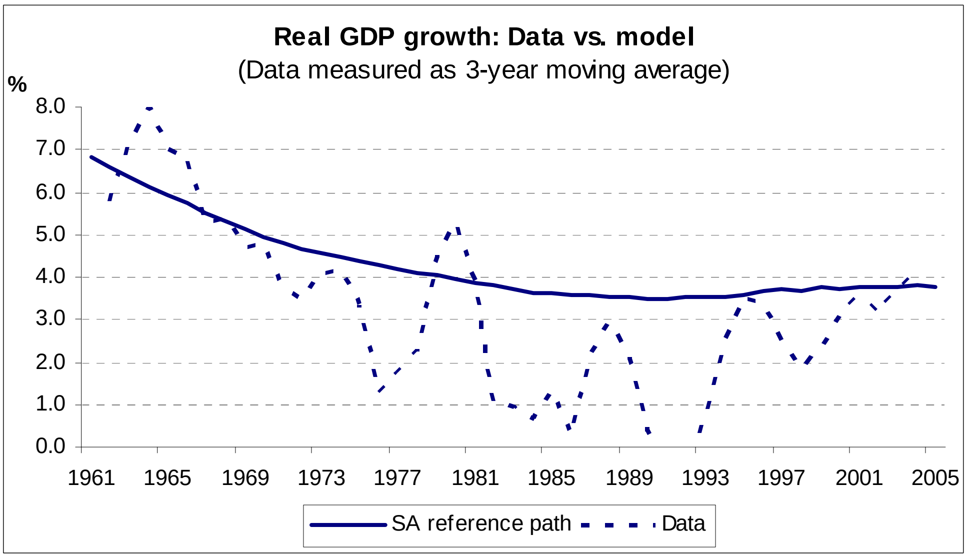

Fig. 3. Skilled-unskilled wage gap: Calibrated South African reference path, reference path in model without skill bias effect, and counterfactual trade liberalization path.

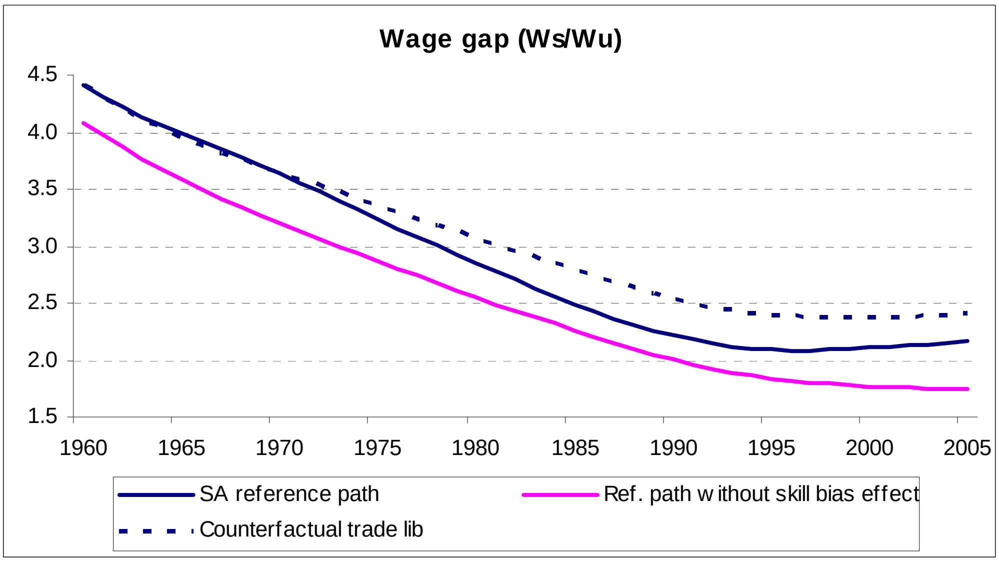

Fig. 4. Productivity level in modern sector relative to the world frontier: Calibrated South African reference path versus counterfactual trade liberalization path.

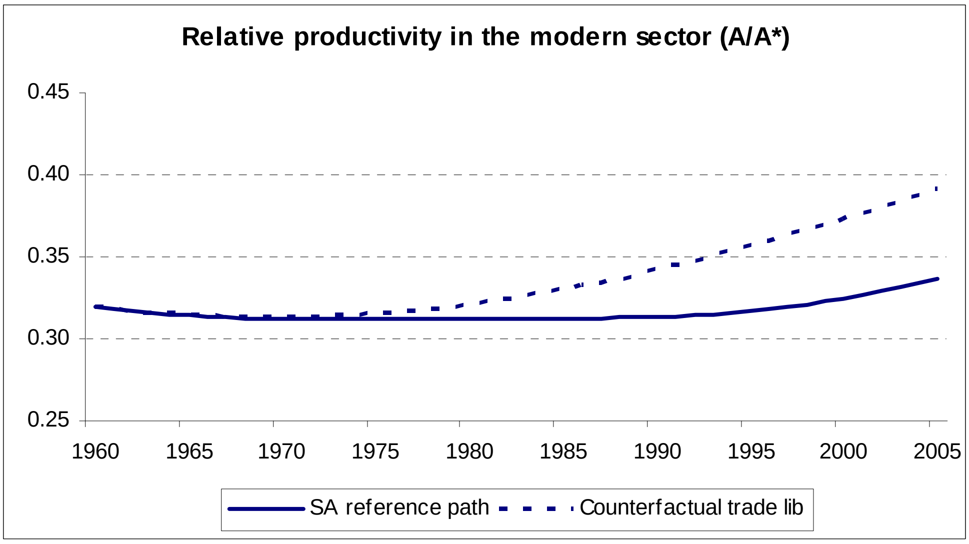

Fig. 5. Degree of skill bias in technical change: Calibrated South African reference path versus counterfactual trade liberalization path.

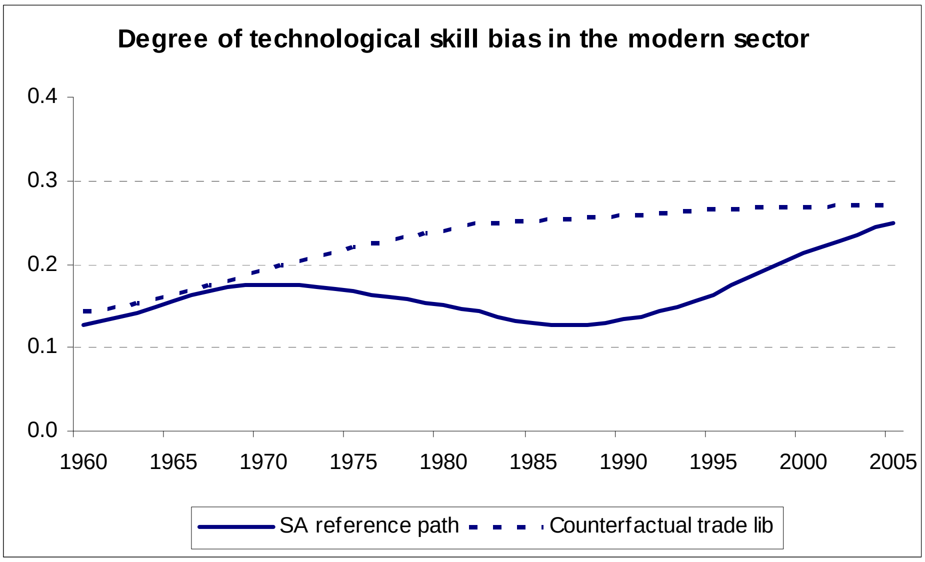

Table 1. Impact of 10% points increase in trade/GDP on wage inequality: Evaluated at different values of the elasticity of productivity growth with respect to the trade share.

	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 %