

Trade policy in a growth model with technology gap dynamics and simulations for South Africa^{*}

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Abstract

Trade policy may affect growth in semi-industrialized countries via investment and productivity dynamics. We develop the understanding of foreign trade for growth by extending an open economy Ramsey model to include the technology gap. Productivity growth is assumed generated by technology adoption, and trade openness affects international productivity spillover and thereby catching up to the world technology frontier. Technology adoption interacts with capital accumulation to generate prolonged transition growth. The interaction between productivity and investment strengthens the growth effect of increased openness. The model is simulated to reproduce the changing openness in South Africa 1960-2005. International sanctions and protectionism are represented by a calibrated tariff equivalent, and the counterfactual elimination of the tariff equivalent shows large potential for GDP growth. According to our preferred parameterization increased trade share by 10% points raises GDP level over time by about 15%. Separating the effects of openness between investment and productivity we find that about 2/3 of the increase in GDP is due to increased productivity, working either directly or indirectly through investment profitability.

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1. Introduction

Foreign trade openness may influence both investment and productivity and thereby economic growth. When productivity growth in semi-industrialized countries is driven by the technology gap towards the world leaders, openness is of importance for technology adoption. The understanding of trade policy and technology gap is developed in a convergence model separating between transitional and long run growth. We extend the standard open economy Ramsey model to take into account trade openness affecting barriers to technology adoption. Turnovsky (2009) offers an overview of small open economy models in this tradition. The technology gap dynamics typically is formulated as long run equilibrium gap and productivity growth equal to the world frontier. The technology gap affects the transitional growth towards a long run growth determined by exogenous and external factors. The role of the technology gap has been given a first analysis in such models by Duczynsky (2003), but has not been related to trade openness. We allow trade openness to affect the speed of technology adoption. The dynamics of the model includes the shadow price of capital (Tobin's q), capital accumulation and productivity (efficiency of labor). We use the model to clarify the adjustment mechanisms and the role of trade in phase diagrams. Simulation of the model using growth data for South Africa allows realistic quantification of the effects involved.

The recent literature on productivity growth has taken up the Nelson and Phelps (1966) understanding of the world technology frontier and barriers to technology adoption (Aghion and Howitt, 2006; Caselli and Coleman, 2006; Lucas, 2007). 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 is discussed by Edwards (1998). We introduce endogenous trade openness influenced by tariffs as a determinant of technology adoption in the Nelson-Phelps model. This is consistent with empirical evidence showing convergence among open economies that is held back by high trade barriers (see Sachs and Warner, 1995).

The theoretical part of the paper investigates the dynamics of the standard open economy Ramsey model extended to include productivity dynamics determined by the world technology frontier and trade openness. The starting point is a transition growth path driven by capital accumulation and with exogenous productivity growth. The inclusion of the

technology gap implies a high and declining growth rate of productivity starting with a large gap to the world frontier. Compared to the standard transition path higher productivity growth stimulates investment and leads to higher long term equilibrium income and capital per worker. The higher productivity growth adds to the transition growth directly and indirectly by raising the capital accumulation. This is in accordance with the argument of Hulten (2001) that productivity improvements contribute to higher capital accumulation and must be seen as interdependent growth mechanisms.

The growth effects of tariff liberalization are channelled through three adjustment mechanisms. First, tariffs influence the openness of the economy and thereby the technology adoption. Second, tariffs influence relative prices including the cost of investment and lead to substitution effects towards foreign goods. Third, the productivity and investment effects interact and strengthen the overall consequences for economic growth. Trade liberalization and increased trade openness in this situation stimulates transition growth because of more technology adoption, cheaper investment goods and productivity induced capital accumulation. Permanent anticipated trade liberalization leads to lower long run cost of investment and higher long run productivity level. The steady state path has higher income and capital per worker. The core capital accumulation channel is already studied by Sen and Turnovsky (1989). The new mechanism introduced here in interaction with investment is the dynamics of the technology gap and the role of trade openness.

We offer an attempt at quantifying the importance of investment and productivity and their interaction in the growth process. The model is simulated based on the growth experience of South Africa. The country represents an interesting case study of openness with changing relationship to the world market related to sanctions and trade policy reform. We calibrate a reference path that reproduces the broad economic development in South Africa during 1960-2005. Due to international sanctions against the Apartheid regime and a complex system of import quotas the degree of protectionism cannot be measured directly. Based on the model we offer an openness index by calibrating export and import taxes that reproduces the actual trade and growth path during the past decades. The effects of openness are analyzed by gradual elimination of the rise in the tariff equivalent. It should be noticed that the tariff equivalent captures both trade reform and changes in external trade conditions (sanctions). This counterfactual experiment raises the trade share by about 25% points and leads to an increase in the 2005 end of period GDP by 35%. The robustness of the result is investigated

and the GDP-effect is in the range of 22-45% within standard parameterization. The quantitative effect is consistent with econometric studies. The cross-country analysis of Frankel and Romer (1999) finds that an increase in the trade share of 1% point raises the income level by 2%. By comparison a 1% point higher trade share leads to 1.4% higher GDP in our model. Our calibration follows Romalis (2007), who finds that 10% point increase in the trade share raises the GDP per capita growth rate by 0.2-0.5% point in a set of developing countries. Our numbers imply that 10% points higher trade share translates into about 0.3% point higher GDP per capita growth rate during transition.

A more open economy implies higher degree of technological catch-up, and given the productivity mechanism assumed the 2005 productivity level relative to the world technology frontier increases from 43% to 53%. Separating the effects of openness between investment and productivity we find that about 2/3 of the increase in GDP is due to increased productivity (including the induced capital accumulation effect). International technology spillovers feeding productivity are important to raise investment and growth. By decomposing the growth channels we find that the openness effect on long-run GDP is divided by about 1/3 for each channel (directly via investment, directly via productivity, and indirectly via the productivity effect on investment profitability). Robustness tests show how the quantitative results depend on parameter values, in particular trade and productivity elasticities. The broad conclusion holds over a wide range of parameter values.

Our method of quantification represents an alternative to econometric analyses of the trade-growth relationship. A critical survey of the econometric literature is offered by Rodriguez and Rodrik (2001). The econometric approach struggles with endogeneity of trade and trade policy. Even successful econometric identification of trade and trade policy effects on GDP growth does not clarify the channels of effect. A model analysis helps clarify the quantitative importance of investment and productivity.

The background literature is discussed in section 2. The extended Ramsey model with endogenous technology gap dynamics is developed in section 3 with analysis of the consequences of trade policy. Section 4 calibrates a reference growth path and an openness index that reproduces the trade and growth observed in South Africa during 1960-2005. Furthermore, we simulate the growth effects of trade barriers, and clarify the quantitative

importance of the productivity and investment channels. The robustness of the results is checked using alternative parameter values. Concluding remarks are offered in section 5.

2. Background growth literature

Our starting point is the understanding of economic growth in small open economies. The standard open economy Ramsey model concentrates on capital accumulation and assumes exogenous productivity growth in a setup with transitional dynamics towards long run balanced growth. Turnovsky (2009) discusses alternative model frameworks and argues that transitional growth is important as shown in a large literature on convergence. We study the role of technology adoption and the gap towards the technology frontier in this kind of model. As argued in the introduction the technology gap formulation fits well with long run equilibrium gap and productivity growth equal to the world frontier. Only Duczynsky (2003) has investigated the dynamics of a model with productivity growth driven by the technology gap. The consequences of trade policy have been analyzed in various related model specifications. Sen and Turnovsky (1989) study the investment channel in a model separating between domestic and foreign goods and in an economy large enough to influence foreign terms of trade. Osang and Pereira (1996) analyze trade policy in a small open economy with real and human capital accumulation. Osang and Turnovsky (2000) separate between consumption and investment tariffs with endogenous labor supply.

We take advantage of the recent literature on productivity growth emphasizing the world technology frontier and barriers to technology adoption. The understanding that productivity growth is driven by learning and technology adoption from the world technology frontier is of particular relevance to semi-industrialized countries. Economic growth in these countries such as South Africa is typically understood as catching up to the world technology frontier. The approach 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. Aghion and Howitt (2006), Caselli and Coleman (2006) and Klenow and Rodriguez-Clare (2005) offer overviews of the growth-literature based on international spillovers.

We link the Ramsey open economy model and the technology gap dynamics and develop the analytical understanding between trade and growth. But also the quantification of the relationships between trade and growth are of interest. Calibrated general equilibrium models have been used in the Parente and Prescott (1994) tradition including barriers to capital accumulation (see for instance Chari et al., 1996; Restuccia, 2004). Broader applied growth models dealing with economic growth and productivity dynamics have been developed by Ngai (2004) for different country groups and Japan, Coleman (2005) for Japan, Duarte and Restuccia (2007) for Portugal, and Diao et al. (2005, 2006) for Thailand. The growth model of South Africa by Rattsø and Stokke (2007) has been the starting point for the analysis developed below. Simulation of open economy dynamics has been offered by Ferreira and Trejos (2006) combining the Heckscher-Ohlin trade framework with a standard neoclassical model. Quantification of the model illustrates how protectionism may explain cross-country income and productivity differences. Similar results are found by Waugh (2009). While these analyses focus on the productivity effect from comparative advantage, we relate trade barriers to the adoption of foreign technology.

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. 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. Aghion, Fedderke, Howitt, Kularatne and Viegli (2008) investigate the economic mechanisms involved in the relationship between trade and growth based on nominal tariffs, effective protection rates, and export taxes. 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.

Inspired by the recent economic history of South Africa we suggest a calibration of the growth model to reproduce the economic development in South Africa 1960-2005. The economic growth was promising post WWII and the country was named 'the Japan of Africa'. This growth period has been understood as catching up growth based on openness and industrial diversification, but ended in the 1970s and was turned into a long period of stagnation. Pritchett (2000) describes South Africa as a 'mountain', where per capita growth above 1.5% per year is turned into negative numbers. Economic growth is on the policy agenda in South Africa with the government's Accelerated and Shared Growth Initiative (ASGI-SA). The policy program primarily discusses domestic binding constraints on growth. The government has invited a group of experts to do a growth diagnostic, and input to this process has been produced by Aghion, Braun and Fedderke (2008), Edwards and Lawrence (2008), Hausmann and Klinger (2008), and Rodrik (2008), among others. The background growth diagnostic approach is outlined by Hausmann, Rodrik and Velasco (2008). Our analysis concentrates on the links to the rest of the world as constraints for growth in a general equilibrium model.

3. Trade openness in a growth model with technology gap

The standard open economy Ramsey growth model with intertemporal decision making of a representative firm/ household and an open world capital market is extended to include productivity dynamics determined by the world technology frontier and trade openness. The starting point is a model concentrating on capital accumulation and exogenous productivity growth and assuming installation cost of investment. We assume imperfect substitution between domestic and foreign goods to allow for the basic price effects of trade policy. The productivity dynamics added is explained below. The analysis addresses the dynamic consequences of changing trade barriers in the form of import tariffs.

3.1 The household's consumption/savings decision

The representative household receives income through the primary factors, while interest payments on its foreign debt are subtracted. There is no independent government sector, and 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 lifetime budget constraint:

$$\text{Max} \int_0^{\infty} U(C_t) e^{-\rho t} dt \quad (1)$$

$$\text{s.t.} \int_0^{\infty} P_t C_t e^{-rt} dt = \int_0^{\infty} (Y_t - S_t) e^{-rt} dt \quad (2)$$

Assuming intertemporal elasticity of substitution equal to unity, the iso-elastic utility function is defined as $U(C_t) = \ln C_t$, where C_t is consumption in period t . Y_t is household income, S_t is private savings, P_t is the endogenous price level, ρ is the positive rate of time preference, and r is the exogenous world market interest rate. The utility maximization gives the Euler equation for optimal allocation of consumption over time:

$$\frac{\dot{C}_t}{C_t} = r - \rho - \frac{\dot{P}_t}{P_t} \quad (3)$$

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

3.2 Export and import decisions

We assume imperfect substitution between domestic and foreign goods, and the model consequently operates with a composite good. The demand functions for imports (M_t) and domestic goods (D_t) are derived from minimizing current expenditure subject to the Armington function:

$$\text{Min} \quad PWM_t(1 + tm_t) \cdot M_t + PD_t \cdot D_t \quad (4)$$

$$\text{s.t.} \quad CC_t = aa \left[ma \cdot M_t^{\frac{\sigma_m - 1}{\sigma_m}} + (1 - ma) D_t^{\frac{\sigma_m - 1}{\sigma_m}} \right]^{\frac{\sigma_m}{\sigma_m - 1}} \quad (5)$$

where σ_m is the constant elasticity of substitution between domestic and foreign goods. CC_t represents total absorption of the composite good, including intermediate, consumption and investment demand. The price level facing domestic agents (P_t) is a composite of the exogenous world market price of import goods (PWM_t) adjusted by import tariffs (tm_t) and the endogenous domestic price (PD_t).

We model imperfect substitution between producing for the domestic market and for the world market. The supply functions for exports (E_t) and domestic sales (D_t) are derived from

maximizing current sales income subject to the constant elasticity of transformation (CET) function:

$$\text{Max} \quad PD_t \cdot D_t + PWE_t(1 - te_t) \cdot E_t \quad (6)$$

$$\text{s.t.} \quad X_t = ac[mc \cdot E_t^{\frac{1+\sigma_e}{\sigma_e}} + (1 - mc)D_t^{\frac{1+\sigma_e}{\sigma_e}}]^{\frac{\sigma_e}{1+\sigma_e}} \quad (7)$$

where σ_e is the constant elasticity of substitution between domestic and foreign markets. The producer price is a composite of the exogenous world market price of export goods (PWE_t) adjusted by export taxes (te_t) and the endogenous domestic price (PD_t).

3.3 Production technology and the firm's investment decision

Gross output (X_t) is defined as a Cobb-Douglas function of effective labor ($A_t L_t$) and capital (K_t):

$$X_t = (A_t L_t)^\alpha K_t^{1-\alpha} \quad (8)$$

which implies a proportional relationship between output per effective worker (x_t) and capital per effective worker (k_t):

$$x_t = k_t^{1-\alpha} \quad (9)$$

The labor force (L_t) grows exogenously at rate n , while labor augmenting technical progress (A_t) in the benchmark version is exogenously determined at rate g .

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

$$\text{Max}_{L_t, I_t, K_t} \int_0^{\infty} e^{-rt} (PV_t X_t - w_t L_t - I_t (P_t + \phi_t)) dt \quad (10)$$

$$\text{s.t.} \quad \dot{K}_t = I_t - \delta K_t \quad (11)$$

where w_t is the wage rate, I_t is investments, ϕ_t is investment adjustment costs, δ is the rate of depreciation, and PV_t is the value added price.¹

Following the common practice in the literature, unit adjustment costs are specified as a positive function of the investment-capital ratio:

¹ The value added price (PV_t) is defined as $PV_t = PX_t(1 - ta) - P_t IO$, where PX_t is the producer price, ta is the sales tax rate, P_t is the demand-side price level, and IO is the fixed input-output coefficient. Gross domestic product (GDP_t) is thus given as $GDP_t = PV_t X_t$.

$$\phi_t = P_t \cdot \frac{b}{2} \cdot \frac{I_t}{K_t} \quad (12)$$

where b is a constant parameter.

The first order conditions from the profit maximization follow as:

$$\alpha P V_t X_t = w_t L_t \quad (13)$$

$$q_t = P_t \left(1 + b \cdot \frac{I_t}{K_t} \right) \quad (14)$$

$$r \cdot q_t = R k_t + P_t \cdot \frac{b}{2} \cdot \left(\frac{I_t}{K_t} \right)^2 - \delta \cdot q_t + \dot{q}_t \quad (15)$$

The equality between the wage rate and the marginal product of labor is given in equation (13). Equation (14) 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 . The shadow price of capital exceeds the price of investment goods due to investment adjustment costs. Equation (15) is the no-arbitrage condition and states that the marginal return to capital must equal the interest payments on a perfectly substitutable asset with a value of q_t . $R k_t$ is the capital rental rate (which equals the marginal product of capital), while the second term on the right hand side 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 .

3.4 Model solution and transition dynamics

In the long run equilibrium capital per effective worker and the shadow price of capital are constant, while output and capital grow at the exogenous long run rate equal to $g + n$, where g is the rate of labor augmenting technical progress and n is the labor supply growth rate. The model includes a long-run restriction on foreign debt.

Based on the capital accumulation constraint in equation (11) the dynamics of capital per effective worker are given as:

$$\dot{k}_t = i_t - (\delta + n + \hat{A}_t) k_t \quad (16)$$

where \hat{A}_t is the productivity growth rate. From equation (14) investment per effective worker (i_t) equals:

$$i_t = \frac{q_t - P_t}{P_t b} k_t \quad (17)$$

Combining (16) and (17) gives us the dynamics of capital per effective worker as a function of the capital shadow price and the productivity growth rate:

$$\dot{k}_t = \left(\frac{q_t - P_t}{P_t b} - (\delta + n + \hat{A}_t) \right) k_t \quad (18)$$

The long-run stability condition of $\dot{k}_t = 0$ implies a horizontal curve in the q - k diagram, which is constant as long as productivity growth is constant:

$$q_t = P_t (1 + b(\delta + n + \hat{A}_t)) \quad (19)$$

From the no-arbitrage condition in equation (15) the dynamics of the capital shadow price follows as:

$$\dot{q}_t = (r + \delta)q_t - PV_t(1 - \alpha)k_t^{-\alpha} - \frac{(q_t - P_t)^2}{2bP_t} \quad (20)$$

where the capital rental rate Rk_t is substituted with the marginal product of capital. The long-run stability condition of $\dot{q}_t = 0$ implies the following relationship between the shadow price of capital and capital per effective worker:

$$(q_t - P_t)^2 - 2bP_t(r + \delta)q_t + 2bP_tPV_t(1 - \alpha)k_t^{-\alpha} = 0 \quad (21)$$

This gives a decreasing curve in the q - k diagram (documented in the appendix).

When the productivity growth is exogenous and equal to g , the equations (18) and (20) form a two-dimensional system of differential equations in capital per effective worker k_t and the shadow price of capital q_t (Tobin's q). The phase diagram is drawn in Figure 1. The model has a long run equilibrium capital per effective worker equal to k^* . Given an initial low capital per effective worker k_0 , and with a shadow price of capital q_0 above total investment cost, the economy follows the saddle path (drawn with arrows) towards the equilibrium k^* . The transition growth path is driven by capital accumulation. High investment initially declines towards the equilibrium. The equilibrium capital per effective worker implies that the capital stock grows at the rate $g + n$, the productivity growth plus the population growth. Investment covers this capital accumulation in addition to replacement investment.

Figure 1 about here.

3.5 Extending the model with productivity dynamics

The next step is to understand the role of the technology gap. In the simplest form, the technology gap can be introduced as:

$$\hat{A}_t = \lambda \left(1 - \frac{A_t}{A_{F,t}} \right) \quad (22)$$

The domestic and the frontier level of productivity are given by A_t and $A_{F,t}$ respectively, and $A_t/A_{F,t}$ is relative productivity. The technology gap is measured as the productivity distance to the world technology frontier. The linear (rather than exponential) relationship between productivity growth and relative productivity implies logistic technology diffusion, as suggested by Benhabib and Spiegel (2005). The growth rate of productivity is determined by the gap and the speed of adjustment parameter λ . Productivity growth at the technology frontier is set exogenously equal to g . In the long run equilibrium productivity growth equals the world frontier rate, and the technology gap is constant. This implies a proportional relationship between A_t and $A_{F,t}$:

$$A_t = \frac{\lambda - g}{\lambda} \cdot A_{F,t} \quad (23)$$

The mechanics of the productivity growth is explained in Figure 2, separating between transitional and long-run effects as in the full model. The horizontal axis measures the relative position to the world frontier, while the productivity growth rate is given on the vertical axis. The relationship between the growth rate and the distance to the frontier is downward sloping. The further to the left the economy is positioned, the larger is the technology gap. When the productivity growth rate exceeds the growth rate of the frontier, the economy is catching up and the gap decreases. The equilibrium gap is marked with * and implies that the domestic productivity growth is equal to the growth at the world frontier. This is a long-run equilibrium with constant technology gap.

Figure 2 about here.

The basic dynamics of the technology gap dynamics similar to (22) has been solved analytically by Duczynsky (2003). The solution is made simple by the dynamic adjustment rule for productivity that is independent of the rest of the model. Equations (18), (20) and (22) form a three-dimensional system of differential equations. Duczynsky (2003) draws the conclusion that the gap dynamics leads to fast convergence for ‘undercapitalized countries’. The growth process depends on initial conditions, in particular the gap to the world frontier. We illustrate the technology gap dynamics in the phase diagram of Figure 1. Since long run productivity growth equals the exogenous productivity growth rate (and the world frontier rate), the equilibrium k^* is not affected. The initial gap generates a high productivity transition growth that declines towards the long run rate. The consequences for the transition growth can be described by an upward shift in the $\dot{k} = 0$ curve resulting from a positive shift in the growth rate of productivity given the starting point k_0 (see equation (19)). The size of the shift in the growth rate of A depends on the size of the gap, as seen from equation (22). The dynamics of the productivity growth is imposed on the diagram, and the declining productivity growth towards the frontier rate generates gradual shifts down in the $\dot{k} = 0$ curve (not shown) back to the original curve with productivity growth g . It follows that the economy will move along a shifting saddle path towards the old equilibrium. The speed of convergence is determined by the interaction of productivity and investment. While the long run capital per effective worker is the same, the income and capital per worker are higher since the level of productivity is higher. Compared to the standard transition growth higher productivity growth stimulates the investment profitability.

We expand this model by introducing trade openness as a barrier to technology adoption. The speed of adjustment parameter λ is assumed to be a function of the trade share of GDP (T_t). The formulation is consistent with the original model of Nelson and Phelps (1966), where they study the stock of human capital as important for the barrier. The rate of growth of labor augmenting technical progress is specified as:

$$\hat{A}_t = \lambda(T_t) \left(1 - \frac{A_t}{A_{F,t}} \right) \quad (24)$$

where $\lambda(T_t) = \lambda_0 T_t^\theta$, and θ is the elasticity of productivity growth with respect to the trade share. In the long run equilibrium productivity growth equals the world frontier rate, and the technology gap is constant. The long-run value of the trade share is constant, and, together with the frontier growth rate and the parameters, it determines relative productivity. The

degree of catch-up (or speed of adjustment) depends on the level of barriers to technology adoption, and is here determined by the endogenous trade share.

Compared to the Duczynsky (2003) model with technology gap we have added the endogenous effect of trade openness for the ability to take advantage of the world frontier. The extension is important for the effect of trade policy (as described in section 3.6), but does not change the transition growth path much in the case of stable trade openness over time. The productivity growth is primarily determined by the technology gap, and productivity growth and investment are declining from an initial gap towards the long run equilibrium. The convergence is faster than in the standard open economy model because of the interaction between high and declining productivity growth and investment.

3.6 The effects of lower trade barriers

The growth consequences of trade liberalization have mainly been analyzed as a price effect of changing tariffs. Sen and Turnovsky (1989) assume separate domestic and foreign goods and the change of tariffs induces substitution in consumption. They allow for terms of trade effects and the model is more relevant for a large country. A reduction in the tariff rate increases the demand for the import good and the higher relative price of the domestic good stimulates domestic output and employment. The main contribution of their article is to clarify the different effects of anticipated versus unanticipated and permanent versus temporary reform. Osang and Turnovsky (2000) study a small open economy and separate between consumption and investment tariffs. They include endogenous labor supply, which complicates the dynamics and motivates numerical simulations. Their main finding is that investment tariff has more adverse effect on growth than consumption tariff.

Trade liberalization here is analyzed as an anticipated permanent reform. As shown above, we assume an aggregate Armington good and the tariffs influence the composition of this aggregate. Important for the growth effect, lower import tariffs reduce the cost of foreign investment goods, and the composite price facing domestic agents (P_I) decreases. As seen from section 3.4, lower investment costs stimulate investment activity. The strength of this effect depends on the elasticity of substitution between domestic and foreign goods. The better substitution possibilities, the easier it is to take advantage of less expensive foreign capital goods.

We add a possible channel of effects of tariff reform through productivity growth. A more open economy reduces the cost of technology adoption and stimulates productivity growth. The implication for productivity growth can be described in Figure 2. Trade liberalization implies reduced trade barrier and the curve shifts upward. Productivity growth is higher given the technology gap. The equilibrium gap marked by $**$ implies that the distance to the frontier in equilibrium is smaller, although the long run growth rate remains unchanged. Trade liberalization generates higher transitional growth toward a reduced gap to the world frontier. 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 full effect of trade liberalization is a combination of investment and productivity responses and they strengthen each other. The reduction in the composite price of investment goods (P_i) generates a downward shift in the $\dot{k} = 0$ curve and an outward shift to a steeper $\dot{q} = 0$ curve (see calculations in the appendix). The shifts, shown as dotted lines in Figure 3, determine the new and higher long run equilibrium capital per effective worker k^{**} . Trade liberalization has positive long run level effects. The endogenous interaction between productivity and investment generates prolonged transition growth towards the higher long run capital per effective worker. Income and capital per worker will be higher. But the road to get to the new equilibrium is complicated and has not been fully worked out analytically. The reduced tariff implies temporary higher productivity growth rate, as shown in Figure 2. The higher productivity growth tends to give a temporary upward shift in the $\dot{k} = 0$ curve that gradually shifts back down as productivity growth returns to the frontier rate (similar to that described in Figure 1). It follows that the immediate effect of reduced trade barriers on the $\dot{k} = 0$ curve is ambiguous, but we know that the curve must shift down in the long run. The new saddle path (not drawn) may be above or below the saddle path without trade liberalization (to k^*). Given our focus on international spillover for productivity growth, the feedback from investment to productivity is limited. Investment here basically influences productivity through the composition of the capital stock with respect to domestic and foreign investment goods. Trade liberalization and increased trade openness in this situation prolongs transition growth because of more technology adoption, cheaper foreign investment goods and productivity induced capital accumulation.

Figure 3 about here.

In this section we have considered the effects of lower import tariffs. Reduced trade barriers can also follow from lower export taxes. The implications for the transition dynamics and long run equilibrium are straightforward given the analysis of import tariffs above. The cost of investment goods is not affected by lower export taxes, but technology adoption is stimulated and generates temporary higher productivity growth. The $\dot{k} = 0$ curve shifts upward, but gradually returns to its original position. Lower export taxes increase the price of export goods and thus the producer price and the value added price PV . This generates an outward shift to a steeper $\dot{q} = 0$ curve, and the long run equilibrium has higher capital per effective worker.

We offer an attempt at quantifying the importance of investment and productivity and their interaction in the growth process. In the next section we apply the model to the case of South Africa to identify the relative importance of these channels. The model reproduction of South African growth during the past decades is of transitional character, and thus endogenous.

4. Quantification of trade openness effects in South Africa

The starting point for the quantitative evaluation of the adjustment mechanisms following change in trade openness is a reference growth path and a measure of trade restrictions. The model is calibrated to reproduce the broad economic development in South Africa during 1960-2005.² The effects of trade openness can be studied in a counterfactual analysis of reduced tariff equivalent and thereby offer a quantification of the growth effect of trade barriers. The robustness of the results is investigated by using alternative parameter values.

4.1 Calibrating the growth path and the tariff equivalent for South Africa

The parameters are set based on a 1998 Social Accounting Matrix, as well as available econometric estimates and stylized facts.³ The parameters are made consistent with long run

² The model is solved numerically in discrete time using the software GAMS.

³ Detailed documentation of the calibration and the 1998 South African Social Accounting Matrix is given in a separate appendix available from the authors.

equilibrium, where the growth rate is assumed to equal 2% (1.3% technological progress rate and 0.7% labor growth).⁴ Long run technical progress follows the growth rate of the world technology frontier. 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.

The key parameter determining the role of the trade barrier is the elasticity of productivity growth with respect to the trade share [given by the parameter θ in equation (24)]. This is set equal to 0.8 and implies that an increase in the trade share of 10% points gives 0.2-0.35% point higher productivity growth rate when starting from the assumed steady state rate.⁵ The magnitude of the effect 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.⁶ Compared to this estimate, the elasticity of productivity growth with respect to the trade share applied in our model can be seen as conservative.

The foreign trade conditions have been changing over time in South Africa, in particular related to the sanctions and protectionism from the mid 1970s to the early 1990s. The general equilibrium model allows for measurement of the various internal and external trade restrictions. We calibrate export and import taxes necessary to reproduce the observed export and import paths 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. Figure 4 reports the reproduction of the trade path, while the tariff equivalent is illustrated in Figure 5.

⁴ 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).

⁵ The calculation is based on trade shares in the range 0.3-0.6, which is consistent with the values in the model simulations.

⁶ 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.

Figure 4 and 5 about here.

While the tariff equivalent decreases during the 1960s, the slow growth of exports and imports in the 70s and 80s 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 a gradual liberalization of the trade policy increased trade rapidly, reflected in the model by decreasing tariffs. The underlying paths of the export tax and the import tax are documented in a separate appendix available from the authors. Interestingly, the calibrated tariff paths are consistent with tariffs calculated from partial analyses of exports and imports with reasonable values of elasticities.

Existing measures of openness in South Africa are scarce. A recent contribution by Edwards and Lawrence (2008) offers data on tariffs and surcharges since 1960. The development path (illustrated in their Figure 3) with liberalization in the 1960s, increasing protectionism since the mid 70s, peak in 1990, and liberalization since 1990, is consistent with our calibrated tariff equivalent measure of openness. Aron and Muellbauer (2002) develop an openness indicator for South Africa based on econometric estimation. Their model includes a measure of tariffs and surcharges, while the unobservable effect of sanctions and quotas are captured by a non-linear stochastic trend. The indicator illustrates the changing degree of openness during 1970-2000 with increasing protectionism in the 70s, sanctions and protectionism in the 80s and trade liberalization after 1990. Compared to the analysis by Aron and Muellbauer our openness indicator takes into account that both imports and exports are held back by sanctions, covers a longer time period, and gives a more intuitive measure of openness (export and import tax as share of total trade).

Figure 6 shows how we track the actual growth rate as a steady decline in the model growth rate during 1961-90, followed by constant growth since 1990. The South African growth experience can be understood as neoclassical convergence, trade barriers 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 drop 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 investment, and the economy is not able to catch up with the

frontier. Post Apartheid the elimination of sanctions and trade liberalization have stimulated economic growth with reduced barriers.

Figure 6 about here.

4.2 Quantification of the investment and productivity responses to openness

As explained in section 4.1, we have calibrated a tariff equivalent growing from the late 60s 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 level decreases gradually (gradual trade liberalization), as illustrated in Figure 5.⁷ The average tariff rate during 1960-2005 equals 16%, down from 38% along the reference path reproducing the actual growth in South Africa.

The new GDP growth path is shown in Figure 7 below. Given the investment and productivity links to openness assumed, the analysis shows that South Africa could have avoided some of the decline in the growth rate. The sanctions and protectionism have contributed to more costly investment goods and less technology adoption and consequently held back economic growth. In the counterfactual open economy scenario the average trade share during 1980-2005 is 25% points higher than along the reference path. Productivity growth increases, and the period of technological stagnation is avoided. As seen from Figure 8, the economy catches up relative to the world technology frontier. Relative productivity at the end of the period increases from 43% to 53%, and generates a long-run productivity gap of about 10% points between the two scenarios. Investment profitability is stimulated by less expensive foreign capital goods and higher productivity growth. The quantification shows that investments are raised by 48% compared to the reference path with sanctions and protectionism. The growth effect adds up to a rather large permanent income gap between the two scenarios. The model predicts that the 2005 level of real GDP is 35% higher when trade barriers are eliminated.

Figure 7 and 8 about here.

⁷ 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.

The quantitative effects reported above are comparable to econometric studies. The relationship between trade share and GDP is the key issue. Given our parameterization, the tariff liberalization increases the trade share by about 25% points on average for the ‘effect period’ after 1980. The higher trade share is associated with an increase in the 2005 end of period GDP by 35%. The cross-country analysis of Frankel and Romer (1999) finds that an increase in the trade share by 1% point raises the income level by 2%. By comparison a 1% point higher trade share leads to 1.4% higher GDP level in our model. Our calibration follows Romalis (2007), who finds that 10% point increase in the trade share raises the GDP per capita growth rate by 0.2-0.5% point in a set of developing countries. The general equilibrium effects included here do not change the size of the effect. Our numbers imply that 10% point higher trade share translates into about 0.3% point higher GDP per capita growth rate during transition.

The model shows how the timing and expectation of trade policy can generate a complicated dynamic pattern of response. In our setting, future trade liberalization is expected and influences current investment and production decisions. Gradual trade liberalization gives an immediate drop in both the investment rate and the trade share compared to the reference path. Current investments are postponed since investors will take advantage of cheaper imported investment goods in the future. In addition, higher expected productivity with a more open economy increases the expected profitability of future investments and contributes to lower initial investment rate. Over time the profitability of capital accumulation increases, and the 2005 investment rate is higher in the open economy scenario. Gradual trade liberalization has a similar effect on foreign trade. The initial trade share falls by about 2% points, driven by lower export share. When cheaper foreign goods and lower export taxes are expected in the future, current trade is held back. Over time the trade share increases, and is about 25% points higher than along the calibrated South Africa path.

Our main interest is a clarification of the vehicles from openness to growth, the endogenous adjustment of productivity and investment. To separate different channels of effects we run counterfactual experiments with exogenous productivity growth and compare the quantitative effects of reduced tariffs to the results with endogenous productivity growth. The share of the effects of reduced tariffs on GDP, investment, and the trade share working via the productivity channel are illustrated in Table 1.

Table 1 about here.

The effect of trade liberalization on capital investments works via two channels. First, lower tariffs imply less expensive foreign capital goods. Second, a more open economy benefits from technology adoption and has higher productivity level, which in turn increases the profitability of investments. As seen from Table 1, the increase in the 2005 real investment level of 48% is reduced to 15% when the productivity effect is not included. This implies that about 2/3 of the investment response to trade liberalization is due to increased productivity. This is the induced capital accumulation effect highlighted by Hulten (2001).⁸

The effect of trade liberalization on long-run GDP works via three channels. First, more openness reduces the cost of adopting foreign technology by limiting the trade barriers to technology transfer, and productivity growth increases (the direct productivity effect). Second, lower tariffs imply less expensive foreign capital goods, which generates more capital accumulation (the direct investment effect). Third, trade liberalization increases GDP growth indirectly through the endogenous interplay between productivity and investment profitability. As seen from Table 1, 71% of the increase in real GDP comes from higher productivity, working either directly or indirectly in interaction with investment profitability. To separate the direct productivity effect from the induced capital accumulation effect, we calculate the long-run GDP effect of trade liberalization without the interaction effect.⁹ We find that the openness effect on growth is divided by about 1/3 for each channel (29% directly via investment, 34% directly via productivity and 37% indirectly via the productivity effect on investment profitability).

4.3 Robustness tests

The quantitative results reported above obviously depend on parameter values, in particular trade and productivity elasticities. The trade elasticities represent substitution possibilities between domestic and foreign goods (σ_m), and between sales to domestic markets versus

⁸ The trade/GDP response to lower tariffs is roughly independent of the investment response, which confirms the lack of feedback from investment to productivity in this model.

⁹ This calculation is based on the capital path from the exogenous productivity scenario and the productivity path implied by the trade share in the exogenous productivity scenario.

export markets (σ_e). In the base-run simulations we set $\sigma_m = 3$ and $\sigma_e = 2$, which is consistent with national and international estimates (Hertel et al., 2007; Senhadji and Montenegro, 1999). As documented in section 4.1, we assume an elasticity of productivity growth with respect to the trade share of 0.8, in line with available econometric estimates. Below we investigate how the quantitative effects of trade barriers depend on these parameter values.

Table 2 shows how the quantitative results change with the level of trade elasticities. A low elasticity of substitution implies that it is hard to substitute between domestic and foreign goods, as well as between domestic and foreign markets. Trade is therefore kept relatively high also along the reference path with an increasing tariff equivalent. The lower the elasticity of substitution, the smaller the quantitative effects of reducing trade barriers (the difference between a closed and an open economy is reduced). With trade elasticities equal to 1.5 the difference in degree of catch-up is 5% points, compared to 10% points in the base run scenario with higher elasticities. The 2005 level of real GDP is 22% (rather than 35%) higher in the more open economy. With high elasticity of substitution (equal to 4.5 for imports and 2.5 for exports) trade is reduced more when the tariff equivalent increases, which means that the degree of catch-up is held back along the reference path. The quantitative effects of reduced tariffs are larger than in the low elasticity scenario.

Table 2 about here.

Table 3 shows how the elasticity of productivity growth with respect to the trade share (θ) alters the quantitative effects of trade barriers. A lower value of θ means that the impact of changes in the trade share on productivity growth is smaller. During international isolation the trade share decreases and productivity growth is held back. The lower the value of θ , the smaller is the negative effect of isolation on productivity growth and the higher is the degree of catch-up. Hence, the quantitative effects of trade barriers are lower the lower the elasticity of productivity growth with respect to the trade share. With low (0.6) and high (1.0) elasticity the increase in the 2005 real GDP level due to a more open economy is 28% and 42%, respectively, compared to 35% in the base run scenario.

Table 3 about here.

Independent of the values of trade and productivity elasticities the relationship between the trade share and GDP is quite robust. As illustrated in the bottom row of Tables 2 and 3, the GDP effect of an increase in the trade share of 1% point is in the range 1.1-1.7% (compared to 1.4% with the preferred values of elasticities). The decomposition of the effects of trade liberalization is fairly stable across different parametrizations. The importance of the productivity channel for the investment response to lower tariffs remains high and lies in the range 59-75% (compared to 69% with the preferred values of elasticities). Higher productivity (working either directly or indirectly as an induced capital accumulation effect) contributes to 55-80% of the increase in GDP. The endogenous interaction between productivity and investment profitability (the third channel of growth) accounts for 27-41% of the long-run GDP effect of trade liberalization (compared to about 37% in the base run simulation).

5. Concluding remarks

Trade openness influences investment and productivity and thereby the growth path of the economy. We study a model where trade barriers affect the technology adoption dependent on the gap to the world technology frontier. Technology gap productivity growth implies a constant long run productivity growth equal to the frontier and is well suited to study transition dynamics. The standard open economy Ramsey model is extended to include the technology gap, and we allow technology adoption to be affected by trade openness. The inclusion of the technology gap implies a high and declining growth rate of productivity starting with a large gap to the world frontier. Compared to the standard transition path higher productivity growth stimulates investment and leads to higher long term equilibrium income and capital per worker. The higher productivity growth adds to the transition growth directly and indirectly by raising the capital accumulation.

The growth effects of tariff liberalization are channelled through three adjustment mechanisms. First, tariffs influence the openness of the economy and thereby the technology adoption. Second, tariffs influence relative prices including the cost of investment and lead to substitution effects towards foreign goods. Third, the productivity and investment effects interact and strengthen the overall consequences for economic growth. Trade liberalization and increased trade openness in this situation stimulate transition growth because of more technology adoption, cheaper investment goods, and productivity induced capital

accumulation. Permanent anticipated trade liberalization leads to lower long run cost of investment and higher long run productivity level. The steady state path has higher income and capital per worker.

We offer an attempt at quantifying the importance of investment and productivity and their interaction in the growth process. The model is implemented for South Africa to make lessons from the large shifts in openness observed. We produce a quantification of how investment and productivity interact and respond to change of openness based on calibration. Due to international sanctions against the Apartheid regime and a complex system of import quotas the degree of protectionism cannot be measured directly. Based on the model we offer an openness index by calibrating a tariff equivalent that reproduces the actual trade path during 1960-2005.

The growth model allows a counterfactual analysis of the role of international trade. The effects of openness are analyzed by gradual elimination of the rise in the tariff equivalent. This counterfactual experiment raises the trade share by about 25% points and leads to an increase in the 2005 end of period GDP by 35%. The robustness of the result is investigated and the GDP-effect is in the range of 22-45% within standard parameterization. The implied relationship between trade share and GDP is consistent with recent econometric studies. Given the productivity mechanism assumed, a more open economy reduces the cost of technology adoption and contributes to higher degree of technological catch up. Separating the effects of openness between investment and productivity we find that about 2/3 of the increase in GDP is due to increased productivity (including the induced capital accumulation effect). By decomposing the growth channels we find that the openness effect on long-run GDP is divided between 1/3 directly via investment, 1/3 directly via productivity and 1/3 indirectly via the productivity effect on investment profitability. Robustness tests show how the quantitative results depend on parameter values, in particular trade and productivity elasticities. The broad conclusion holds over a wide range of parameter values.

The quantitative results of the analysis reflect the growth potential assuming well-functioning domestic markets taking advantage of international spillovers. South African growth under new rule has been reluctant and there is widespread disappointment about the recent growth results. The lack of growth response to more openness points to domestic market imperfections beyond the growth constraints discussed in this paper. The econometric

analysis of Aghion, Fedderke, Howitt, Kularatne and Vieggi (2008) indicates that competition may be important for the foreign spillover channel in South Africa, which is consistent with the analysis of domestic competition conditions by Aghion, Braun and Fedderke (2008). Our model calibration approach can be extended in this direction in further analysis of how domestic market imperfections hold back the potential gains from openness identified here.

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APPENDIX: Documentation of phase diagrams in Figures 1 and 3

The three-dimensional system of differential equations is given as:

$$\dot{k}_t = \left(\frac{q_t - P_t}{P_t b} - (\delta + n + \hat{A}_t) \right) k_t \quad (i)$$

$$\dot{q}_t = (r + \delta)q_t - PV_t(1 - \alpha)k_t^{-\alpha} - \frac{(q_t - P_t)^2}{2bP_t} \quad (ii)$$

$$\hat{A}_t = \lambda(T_t) \left(1 - \frac{A_t}{A_{F,t}} \right) \quad (iii)$$

In the long run equilibrium capital per effective worker (k_t), the shadow price of capital (q_t) and relative productivity ($A_t/A_{F,t}$) are all constant:

$$\dot{k} = 0 \Rightarrow q_t = P_t \left(1 + b(\delta + n + \hat{A}_t) \right) \quad (iv)$$

$$\dot{q} = 0 \Rightarrow (q_t - P_t)^2 - 2bP_t(r + \delta)q_t + 2bP_tPV_t(1 - \alpha)k_t^{-\alpha} = 0 \quad (v)$$

$$\hat{A}_t = g \Rightarrow A_t = \frac{\lambda(T_t) - g}{\lambda(T_t)} \cdot A_{F,t} \quad (vi)$$

1. The slope of the $\dot{q} = 0$ curve

The $\dot{q} = 0$ curve is downward sloping. This can be verified through implicit derivation of equation (v) with respect to k_t :

$$\begin{aligned} 2(q_t - P_t) \frac{dq_t}{dk_t} - 2bP_t(r + \delta) \frac{dq_t}{dk_t} - \alpha 2bP_tPV_t(1 - \alpha)k_t^{-\alpha-1} &= 0 \\ \Rightarrow \frac{dq_t}{dk_t} = \frac{\alpha bP_tPV_t(1 - \alpha)k_t^{-\alpha-1}}{q_t - P_t(1 + b(r + \delta))} < 0 \end{aligned} \quad (vii)$$

From equation (iv) we know that in equilibrium $q_t = P_t \left(1 + b(\delta + n + \hat{A}_t) \right)$, and since $r > n + \hat{A}_t$ (follows from the Euler equation with positive rate of time preference) the denominator is negative, which gives the negative slope of the $\dot{q} = 0$ curve.

2. Movements of k_t and q_t outside of equilibrium

Equation (i) implies that $\dot{k} > 0$ when $q_t > P_t \left(1 + b(\delta + n + \hat{A}_t) \right)$ and $\dot{k} < 0$ when $q_t < P_t \left(1 + b(\delta + n + \hat{A}_t) \right)$. Since $\frac{\partial \dot{q}}{\partial k} > 0$ the shadow price of capital decreases to the left of the $\dot{q} = 0$ curve, while it increases to the right of the curve. These movements of k_t and q_t are illustrated by arrows in Figures 1 and 3 of the paper.

3. Implications of lower P_t for the $\dot{k} = 0$ and the $\dot{q} = 0$ curve

As seen from equation (iv), a reduction in the composite price of investment goods generates a downward shift in the $\dot{k} = 0$ curve. The implications for the $\dot{q} = 0$ curve involve an outward shift to a steeper curve, as documented below.

Based on equation (vii) the slope of the $\dot{q} = 0$ curve can be written as:

$$\frac{dq_t}{dk_t} = \frac{\alpha b P_t V_t (1 - \alpha) k_t^{-\alpha-1}}{\frac{q_t}{P_t} - (1 + b(r + \delta))}$$

It follows that $\frac{\partial (dq_t/dk_t)}{\partial P_t} > 0$. Lower P_t leads to a reduction in the negative slope of the curve, in other words, the curve becomes steeper.

To verify that the $\dot{q} = 0$ curve shifts outward for lower import tariffs, we calculate the effect of lower P_t on the value of capital per effective worker along the curve for a given value of q_t . By setting $q_t = 1$ in equation (v), the corresponding value of k_t is given by:

$$(1 - P_t)^2 - 2bP_t(r + \delta) + 2bP_tP_tV_t(1 - \alpha)k_t^{-\alpha} = 0$$

Solving for k_t gives:

$$k_t = \left(\frac{2bP_tP_tV_t(1 - \alpha)}{2bP_t(r + \delta) - (1 - P_t)^2} \right)^{1/\alpha}$$

The value of capital per effective worker is positive for all positive values of P_t . The denominator can be written as $2P_t(1 + b(r + \delta)) + P_t^2 - 1$, and since $P_t(1 + b(r + \delta)) > q_t = 1$ (same reasoning as for equation (vii)), the denominator and k_t are positive. The effect of lower P_t on the value of k_t on the $\dot{q} = 0$ curve for $q_t = 1$ follows as:

$$\frac{\partial k_t}{\partial P_t} = -\frac{1}{\alpha} \left(\frac{2bP_tP_tV_t(1 - \alpha)}{2bP_t(r + \delta) - (1 - P_t)^2} \right)^{1/\alpha-1} \frac{2bP_tV_t(1 - \alpha)(1 + P_t^2)}{(2bP_t(r + \delta) - (1 - P_t)^2)^2} < 0$$

This implies that for a given value of q_t , lower P_t generates a higher value of k_t , in other words, the $\dot{q} = 0$ curve shifts outwards.

Figure 1. Standard open economy Ramsey model and transitional and long-run effects of technology gap dynamics.

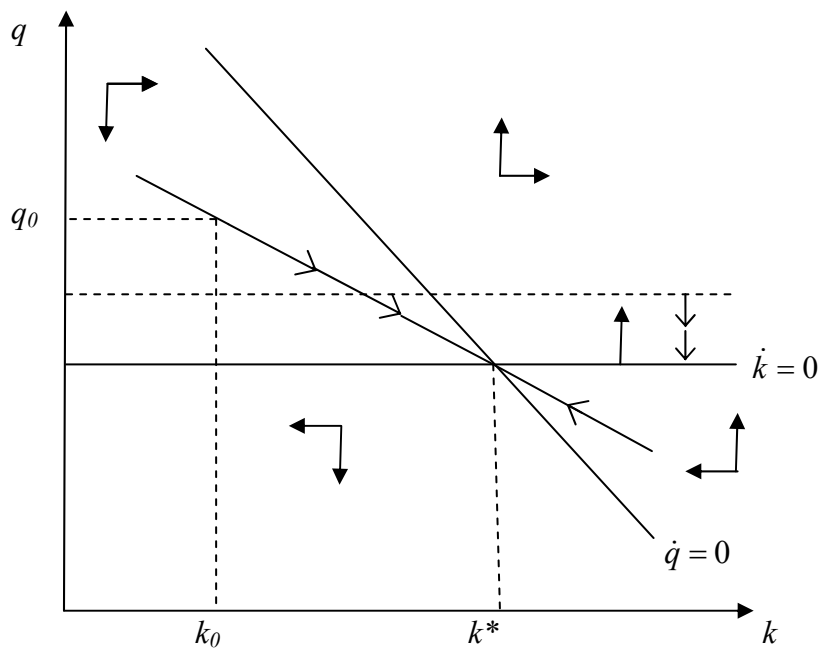


Figure 2. Dynamics of the technology gap: Transitional and long-run effects of increased trade share.

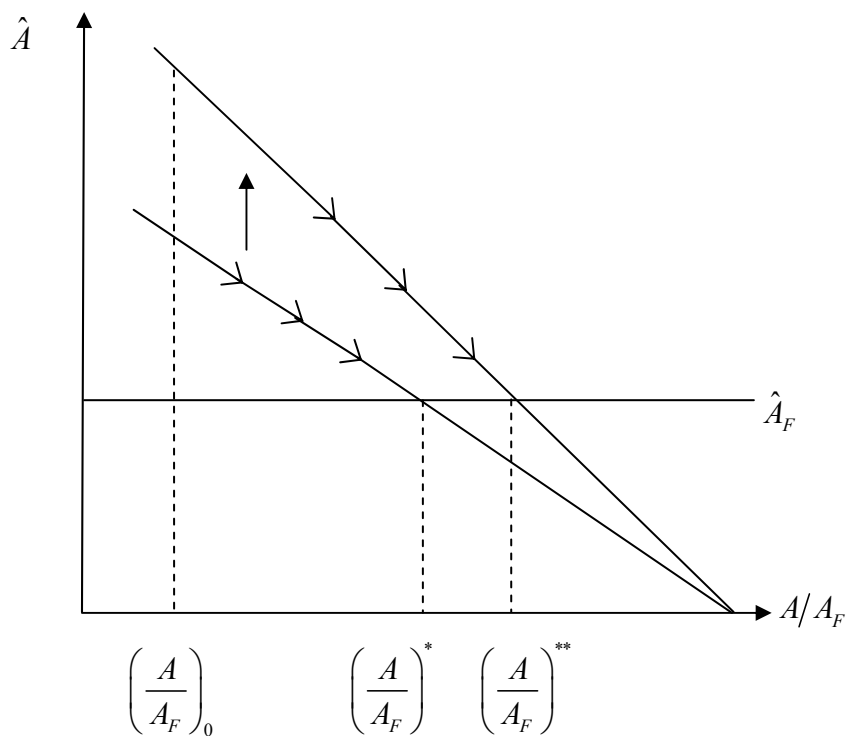


Figure 3. Ramsey model with technology gap dynamics: Transitional and long-run effects of increased trade share.

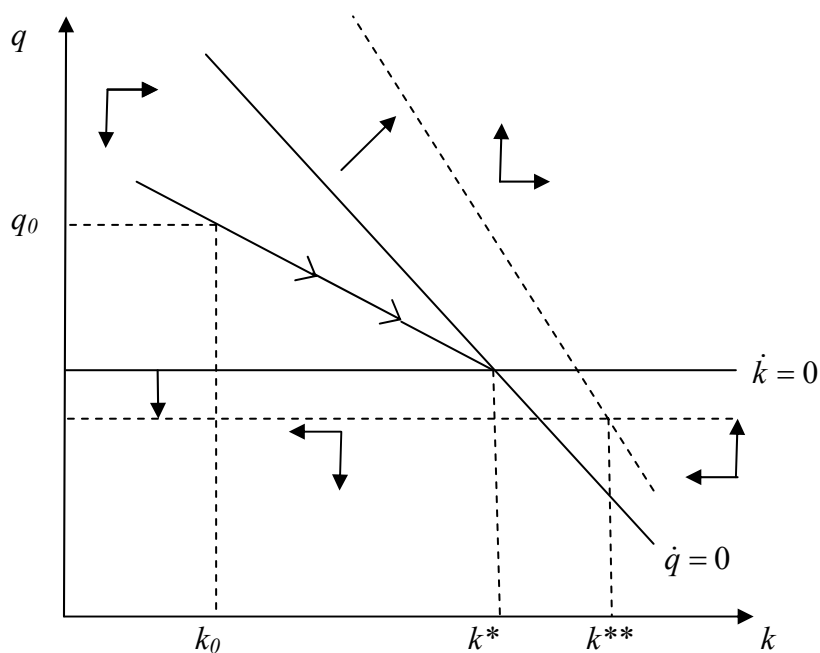


Figure 4. Total trade: Calibrated path of model versus actual path (given in Billions of 1995 rand)

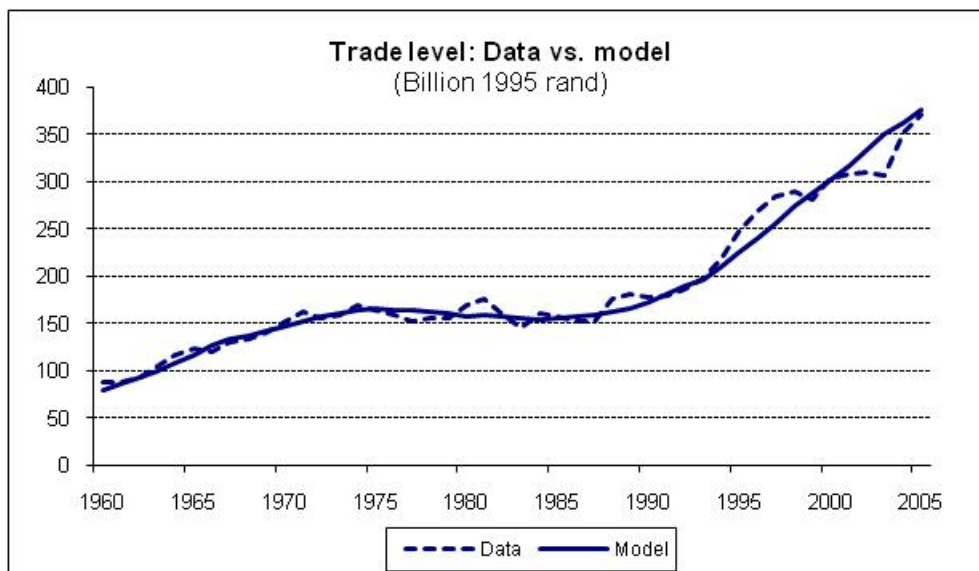


Figure 5. Calibrated openness indicator for South Africa 1960-2005 and counterfactual trade liberalization path. Indicator measured as import tax and export tax as share of total trade.

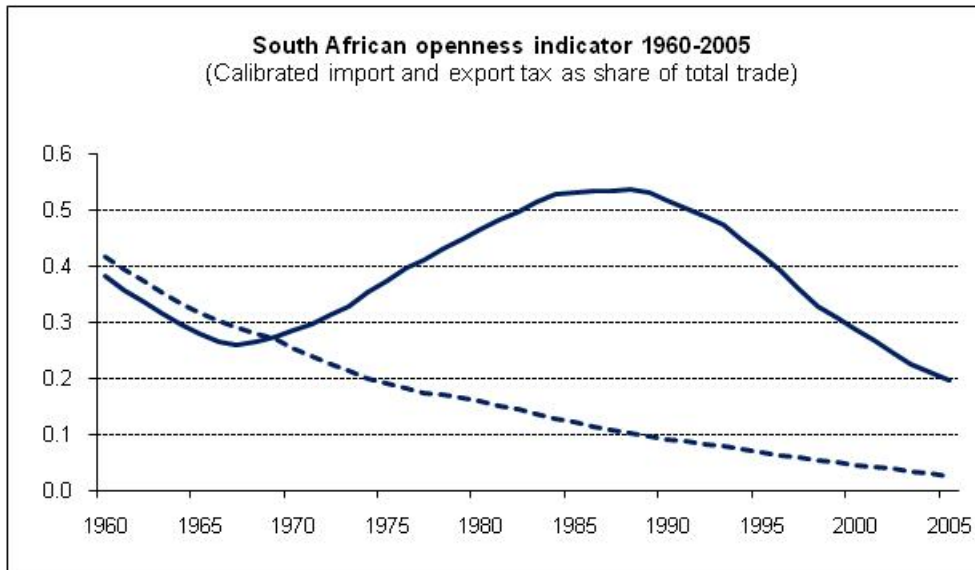


Figure 6. Real GDP growth rate: Calibrated path of model versus actual growth (measured as 3-year moving average)

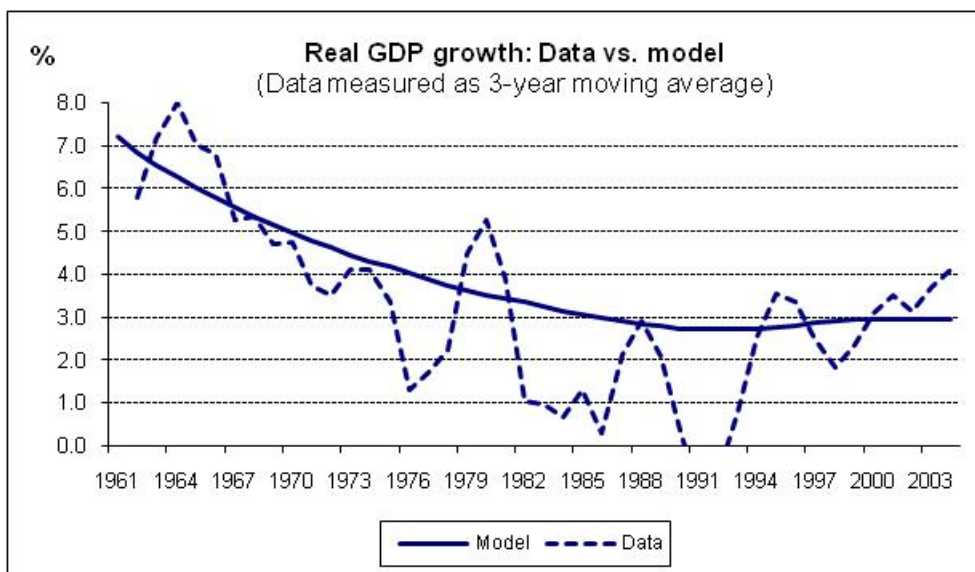


Figure 7. Real GDP growth: Calibrated path versus counterfactual path

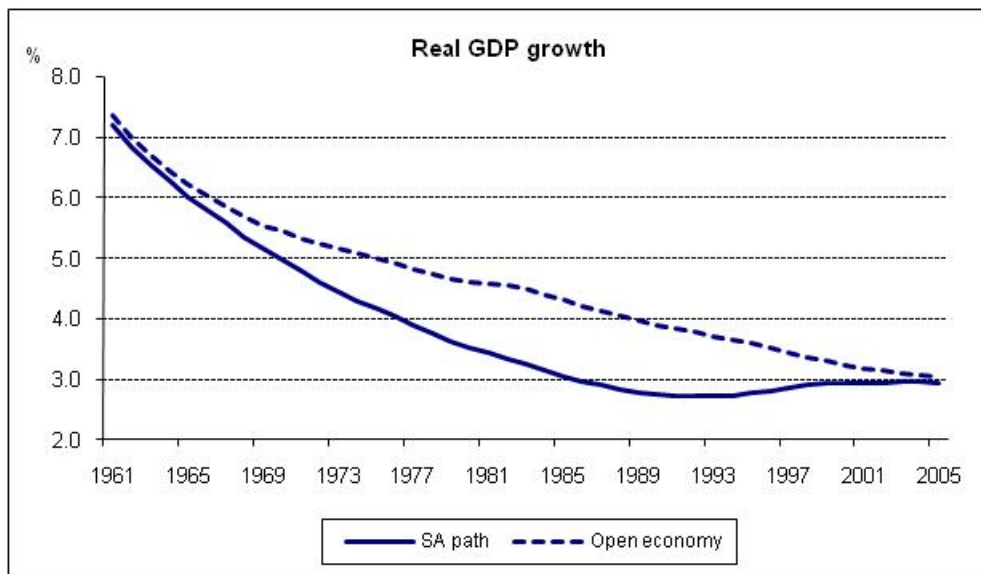


Figure 8. Domestic productivity level relative to the frontier: Calibrated path versus counterfactual path.

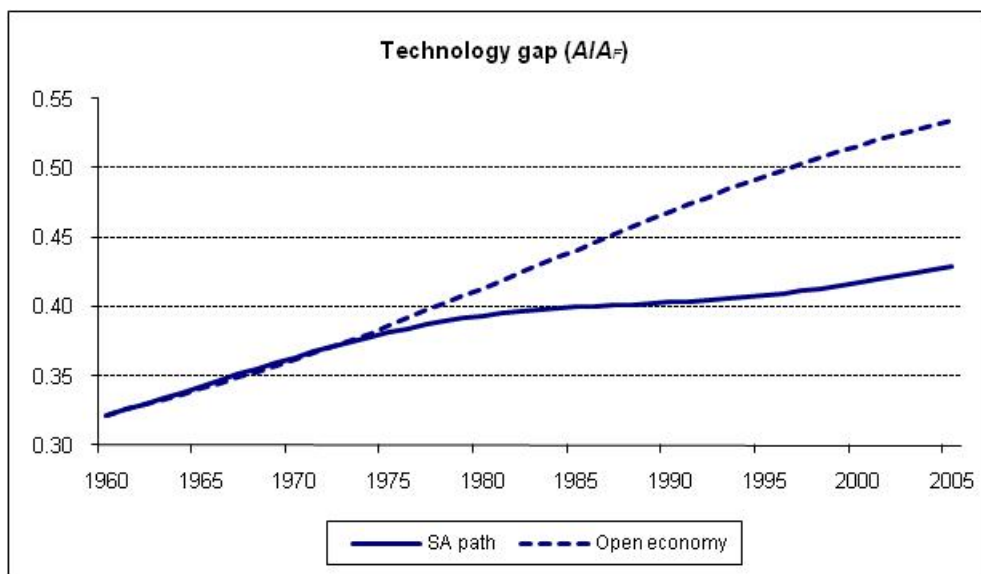


Table 1. The impact of eliminating the rise in the tariff equivalent on key macro variables:
The share of the effect working via increased productivity growth

	Exogenous productivity growth ¹	Endogenous productivity growth ¹	Share of reduced tariff effect working via increased productivity
Real GDP	10 % increase	35 % increase	71 %
Real investment	15 % increase	48 % increase	69 %
Trade/GDP	22 % points increase	25 % points increase	12 %

¹ The values give the impact of tariff reductions on the end of period (2005) level of GDP and investment, and on the average trade share during 1980-2005.

Table 2. Quantitative effects of trade barriers for different values of trade elasticities.

	Low elasticity $\sigma_m = 1.5, \sigma_e = 1.5$	Base run $\sigma_m = 3, \sigma_e = 2$	High elasticity $\sigma_m = 4.5, \sigma_e = 2.5$
Real GDP	22 %	35 %	45 %
A/A_F	5 % points	10 % points	14 % points
Real investment	32 %	48 %	60 %
Trade/GDP	15 % points	25 % points	30 % points
Implied GDP effect of 1% point increase in trade/GDP	1.5 %	1.4 %	1.5 %

Note: The values give the impact of tariff reductions on the end of period (2005) level of GDP, relative productivity and investment, and on the average trade share during 1980-2005. The bottom row gives the implied relationship between the trade share and GDP.

Table 3. Quantitative effects of trade barriers for different values of the elasticity of productivity growth with respect to the trade share.

	Low elasticity $\theta = 0.6$	Base run $\theta = 0.8$	High elasticity $\theta = 1.0$
Real GDP	28 %	35 %	42 %
A/A_F	8 % points	10 % points	13 % points
Real investment	40 %	48 %	56 %
Trade/GDP	24 % points	25 % points	25 % points
Implied GDP effect of 1% point increase in trade/GDP	1.1 %	1.4 %	1.7 %

Note: The values give the impact of tariff reductions on the end of period (2005) level of GDP, relative productivity and investment, and on the average trade share during 1980-2005. The bottom row gives the implied relationship between the trade share and GDP.