# R&D, Openness, and Growth

Pei-Pei Chen
University of Pretoria
Rangan Gupta
University of Pretoria
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Department of Economics
University of Pretoria
0002, Pretoria
South Africa
Tel: +27 12 420 2413
Fax: +27 12 362 5207
**http://www.up.ac.za/up/web/en/academic/economics/index.html**

# R&D, OPENNESS, AND GROWTH

**Pei-Pei Chen***
**and**
**Rangan Gupta****

## ABSTRACT

Recent studies have pointed out that trade liberalisation leads to technological spillovers, which, in turn, tend to improve the efficiency of the domestic Research and Development (R&D) sector, and ultimately boost economic growth. In this paper, we theoretically formalize the above mentioned relationship between trade openness and growth via technological and knowledge spill over in the R&D sector. We show that, under certain conditions, an increase in the degree of openness is not only growth enhancing, but also improves the standard of living. The study, thus, prescribe policies of developing and improving the domestic R&D sector in order to reap the full benefits of trade liberalisation.

***Contact Details**: Graduate Student, Department of Economics, University of Pretoria, Pretoria, 0002, Email: chenp@aforbes.co.za.

****To whom correspondences should be addressed. **Contact Details**: Dr. Rangan Gupta, Senior Lecturer, Department of Economics, University of Pretoria, Pretoria, 0002, Email: Rangan.Gupta@up.ac.za, Phone: +27 12 420 3460, Fax: +27 12 362 5207.

# 1    INTRODUCTION

The importance of the relationship between trade and economic growth has been realized ever since Adam Smith's and David Ricardo's theories of absolute and comparative advantages, respectively. Over the years, empirical research[1] has vindicated a strong and positive correlation between openness and economic growth, after controlling for other explanatory variables explaining economic growth. The result is robust across methodologies, model specifications, sample of countries and time frames. Openness can affect growth for various reasons[2], but, recent studies by Coe and Helpman (1995), Branstetter (1996), Keller (1996) and Nadiri and Kim (1996) have singled out role of technological spillovers, resulting from trade liberalization, that tend to improve the efficiency of the domestic Research and Development (R&D) sector, which ultimately boosts economic growth.

This paper theoretically formalizes the above mentioned relationship between trade openness and growth via technological and knowledge spill over in the R&D sector. We extend the R&D model of Romer (2006) by incorporating the role of openness and its impact on the domestic technological sector. We show that, under certain conditions, openness is growth enhancing and also improves the standard of living. The study, thus, stresses on the importance of policies directed towards developing and improving the domestic R&D sector in order to reap the full benefits of trade liberalization. The remaining of the paper is organized as follows: Besides the introduction and conclusions, Section 2 presents the theoretical model, while section 3 solves and discusses the basic results of the modified R&D model, following an increased degree of openness.

# 2    RESEARCH AND DEVELOPMENT FRAMEWORK

The theoretical model is based on Romer's (2006) Research and Development (R&D) Model. Essentially, it makes an attempt to endogenize the technological progress, which

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[1] For a detailed literature review on the theoretical and empirical relationship between openness and growth, see Chen and Gupta (2006).
[2] See Aghion and Howitt (1996) for further details.

otherwise have generally been treated as exogenous in the standard Solow-type models. The model involves four variables: labor ( $L$ ), capital ( $K$ ), technology ( $A$ ) and output ( $Y$ ). There are two sectors, a goods-producing sector (equation 2.1) where outputs are produced and a R&D sector (equation 2.2) where knowledge is accumulated. Fraction $a_l$ of the labour force is used in the R&D sector and fraction $1 - a_l$ is used in the goods-producing sector. Similarly $a_k$ of the capital stock is used in the R&D sector and the rest in goods production. Both $a_l$ and $a_k$ are exogenous and constant. Both sectors use the full stock of knowledge, $A$ since the usage of an idea does not prevent it from being used elsewhere.

The quantity of output produced at time $t$ is given by:

$$Y(t) = \left[(1 - a_k) K(t)\right]^\alpha \left[A(t)(1 - a_l) L(t)\right]^{1-\alpha}, \qquad 0 < \alpha < 1 \qquad (1)$$

Note $\alpha (1 - \alpha)$ is the output elasticity of capital (effective labour) used in the output sector. Equation (1) is a standard constant return to scale Cobb-Douglas production function in capital and labour. As shown in equation (2), the quantity of knowledge is produced via a generalised Cobb-Douglas type production function.

$$\dot{A} = B \left[a_k K(t)\right]^\beta \left[a_l L(t)\right]^\gamma \left[A(t)\right]^\theta, \qquad B>0, \qquad \beta \geq 0, \qquad \gamma \geq 0, \qquad (2)$$

where B is a shift parameter and $\beta$ and $\gamma$ are, respectively, the elasticity of new knowledge creation with respect to capital and labour.

Unlike, in the output sector, the production function for knowledge is not assumed to have constant returns to scale to labour and capital. As Romer (2006) points out, the standard argument that there must be at least constant returns, is based on a replication issue: if we double the inputs, with the new inputs doing exactly what the old inputs were doing, we would double the output. But in case of the knowledge production sector, exactly replicating what the existing inputs were doing would merely result in the same set of discoveries to be made twice, and, hence, keep $\dot{A}$ unchanged. Thus, it is possible

to have diminishing returns in the R&D sector. At the same time, fixed costs of set up, interaction among researchers and so on, may be important enough in the R&D sector to cause the doubling of capital and labour to more than double output. We, thus, also allow for the possibility of increasing returns. Moreover, there is no reason as to how we should restrict the increases in the existing stock of knowledge to affect the production of new knowledge, and hence, we place no restriction on $\theta$ to start off.

Our departure from Romer's (2006) model lies in our treatment of $\theta$. In our case $\theta$ is not exogenous, but a positive function of the degree of openness of the economy in concern. Such an assumption enables us to account for the advanced informational and technological spillovers that result from opening up to the global economy. However, the percentage change in the accumulation of new knowledge with respect to one percentage change in the existing stock of knowledge, via an increase in openness, increases at a decreasing rate. This implies that with unchanged capital and labour, openness causing better utilisation of the existing knowledge base, through spillovers, will have diminishing returns on new knowledge creation after a certain stage. Formally, we choose the following specification for $\theta$:

$$\theta = \underline{\theta} + c\lambda^{\vartheta}, \underline{\theta} > 0, c > 0, \lambda > 0, 0 < \vartheta < 1 \tag{3}$$

Note such a formulation implies that, as the degree of openness ($\lambda$) intensifies, one percentage increase in the current stock of knowledge, given capital and labour, would produce higher percentage increase in the creation of new knowledge. This is purely a result of better know-how of utilising the existing stock of knowledge resulting from the information spillovers following trade liberalization. However, the increase occurs at a decreasing rate, since $0 < \vartheta < 1$. Moreover, when the economy is closed, that is $\lambda = 0$, $\theta$ is at its lower limit of $\underline{\theta}$. Finally, note that c is a positive scalar which is chosen in a manner to ensure that equilibrium exists.[3]

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[3] See below for further details in equation (17).

Like in the Solow model, savings is equivalent to investments: $S = I$ ,with the the saving rate, $0<s<1$, being exogenous and constant. Thus, with the depreciation rate set equal to zero for simplicity, we have:

$$\dot{K} = sY(t) \tag{4}$$

The population grows at an exogenous rate of $n$, which implies:

$$\frac{\dot{L}}{L} = n \tag{5}$$

There are two endogenous stock variables, $A$ and $K$. Substituting the production function (1) into the expression for capital accumulation yields

$$\dot{K} = s\left[(1-a_k)K(t)\right]^{\alpha}\left[A(t)(1-a_l)L(t)\right]^{1-\alpha} \tag{6}$$

Dividing both sides by $k$ and defining $c_k = s[(1-a_l)^{1-\alpha}(1-a_k)^{\alpha}]$ gives an expression of

$$g_k = \frac{\dot{K}}{K} = s\left[\frac{A(t)L(t)}{K(t)}\right]^{1-\alpha}\left[(1-a_l)^{1-\alpha}(1-a_k)^{\alpha}\right] \tag{7}$$

$$= c_k\left[\frac{A(t)L(t)}{K(t)}\right]^{1-\alpha} \tag{8}$$

Taking logs of both sides of (8) and differentiating the same with respect to time yields, simultaneously:

$$\ln g_k = \ln c_k + (1-\alpha)\left[\ln A(t) + \ln L(t) - \ln K(t)\right] \tag{9}$$

$$\frac{\dot{g}_k}{g_k} = (1-\alpha)\left[g_A + n - g_k\right] \tag{10}$$

where $g_A = \dot{A}/A$. Note, from (10) $g_k$ is rising if $\left[g_A + n - g_k\right]$ is positive, and falling if this expression is negative, and constant if it is zero. The information is summarised in
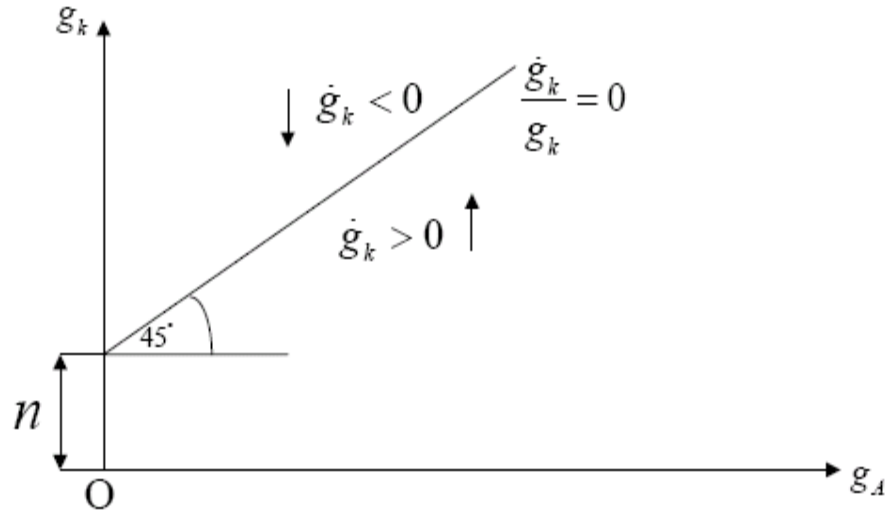
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Figure 1. In the ($g_A, g_k$) plane, the locus of points where $g_k$ is constant has an intercept of $n$ and a slope of 1. Since from (10) we have:

$$g_k = n + g_A \tag{11}$$

Moreover, starting from $\dfrac{\dot{g}_k}{g_k} = 0$, an increase (decrease) in $g_A$ makes causes $g_k$ to be positive (negative). Hence, above (below) the $\dfrac{\dot{g}_k}{g_k} = 0$ locus, $g_k$ is falling (rising).

**Figure 1 The Dynamics of the Growth Rate of Capital in the R&D Model**



Taking equation (2) and dividing both sides by $A$, yields

$$\frac{\dot{A}}{A} = g_A = B\left[a_k K(t)\right]^{\beta} \left[a_l L(t)\right]^{\gamma} [A(t)]^{\theta-1} \tag{12}$$

$$= c_A K(t)^{\beta} L(t)^{\gamma} A(t)^{\theta-1} \tag{13}$$

where $c_A = B a_k{}^{\beta} a_l{}^{\gamma}$.

As in the case of $g_k$, taking logs and the time derivative of (13) simultaneously, yields:

$$\ln g_A = \ln c_A + \beta \ln K(t) + \gamma \ln L(t) + (\theta-1)\ln A(t) \tag{14}$$

$$\frac{\dot{g}_A}{g_A} = \beta g_k + \gamma n + (\theta - 1) g_A \tag{15}$$

Note that $\frac{\dot{g}_A}{g_A} = 0$ in the ($g_A, g_k$) plane implies that

$$\beta g_k = -\gamma_n + (1 - \theta) g_A \tag{16}$$

Or, alternatively

$$g_k = -\frac{\gamma n}{\beta} + \left(\frac{1 - \theta}{\beta}\right) g_A \tag{17}$$

Firstly, in order to ensure that an equilibrium exists, which simply requires that $\frac{\dot{g}_k}{g_k} = 0 = \frac{\dot{g}_A}{g_A}$, that is the two curves of $\frac{\dot{g}_k}{g_k} = 0$ and $\frac{\dot{g}_A}{g_A} = 0$ intersects, the $\frac{\dot{g}_A}{g_A} = 0$ curve must be positively sloped, which, in turn, requires a necessary condition of $\theta < 1$. Secondly, the sufficiency condition, requires, in addition, that the $\frac{\dot{g}_A}{g_A} = 0$ locus must have a steeper slope than the $\frac{\dot{g}_k}{g_k} = 0$ curve, which implies that $\left(\frac{1 - \theta}{\beta}\right) > 1$ or $\beta + \theta < 1$. And given the specification of $\theta$ in (3), we require $c$ to be constrained by the following condition, given, $\beta, \underline{\theta}, \lambda$ and $\vartheta$:

$$0 < c < \frac{1 - \beta - \underline{\theta}}{\lambda^{\vartheta}} \tag{18}$$
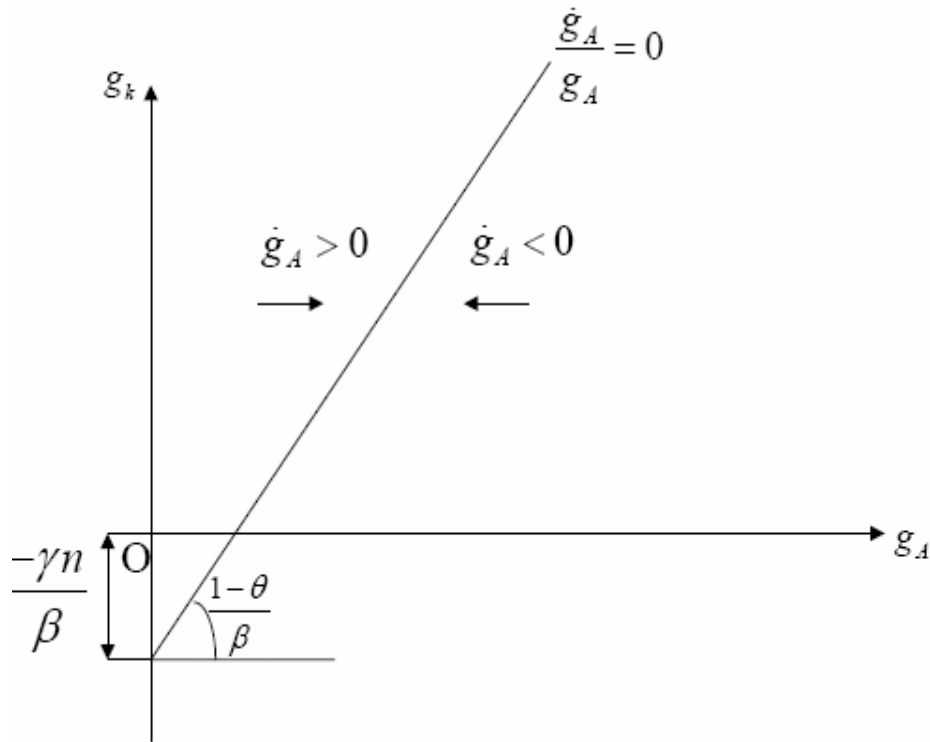
Now given that $\theta < 1$, the set of points where $g_A$ is constant, that is $\frac{\dot{g}_A}{g_A} = 0$, has an intercept of $-\gamma n / \beta$ and a slope of $\left(\frac{1 - \theta}{\beta}\right)$, as depicted in Figure 2. Note above the $\frac{\dot{g}_A}{g_A} = 0$, $g_A$ is rising, while it is falling below the locus. This is easy to see, since, starting from $\frac{\dot{g}_A}{g_A} = 0$, an increase (decrease) in $g_k$ makes $g_A > 0$ (<0).

**Figure 2    The Dynamics of the Growth Rate of Knowledge in the R&D Model**



As stated above for the steady-state equilibrium we require: $\dfrac{\dot{g}_k}{g_k}=0=\dfrac{\dot{g}_A}{g_A}$. Given that (17) holds, we have an unique equilibrium at point E. Moreover, given the behavior of $g_k$ and $g_A$ below and above the locii: $\dfrac{\dot{g}_k}{g_k}=0$ and $\dfrac{\dot{g}_A}{g_A}=0$, the equilibrium at E is also a stable one.[4] The information is summarised in Figure 3.

Note the corresponding equilibrium values of $g_k$ and $g_A$ at the equilibrium is denoted by $\hat{g}_k$ and $\hat{g}_A$ respectively. The values of $\hat{g}_k$ and $\hat{g}_A$, in turn, ensures that, at point E, equations (11) and (17) must hold simultaneously.

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[4] It is easy to see from figure 3.3 that if $\beta+\theta=1$ there is no equilibrium. However, if along with $\beta+\theta=1$, $n=0$, we have infinitely many stable steady state equilibria.

**Figure 3      The Dynamics of Growth Rates of Capital and Knowledge in Equilibrium**
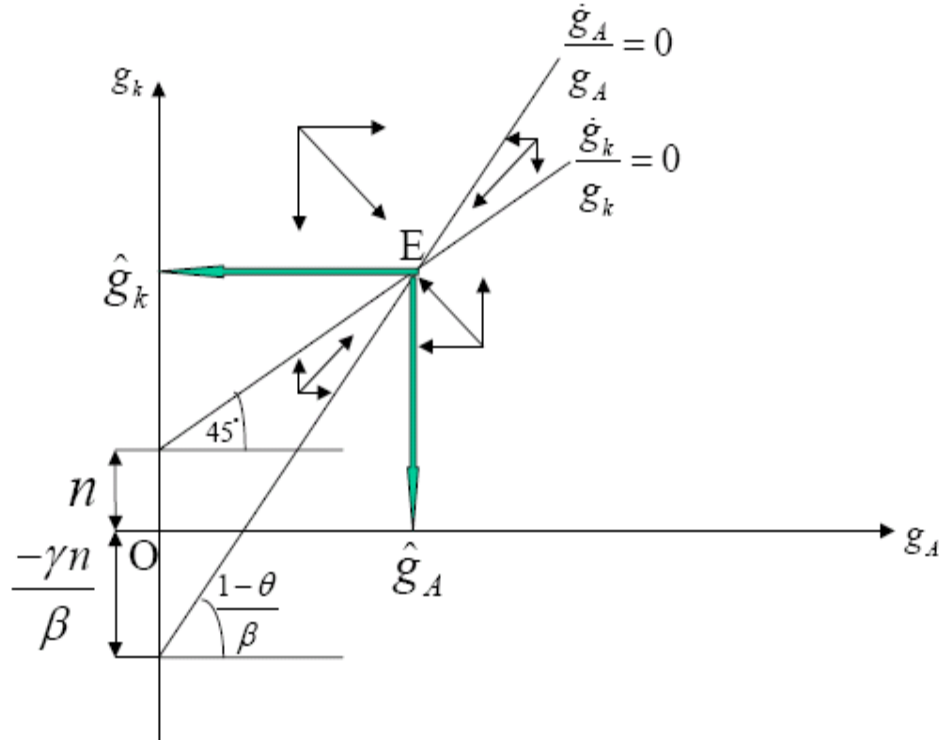


Therefore, at the equilibrium point E, equations (11) and (17) becomes

$$\hat{g}_k = \hat{g}_A + n \tag{19}$$

$$\hat{g}_k = -\frac{\gamma n}{\beta} + \left(\frac{1-\theta}{\beta}\right)\hat{g}_A \tag{20}$$

Substituting (19) into (20) yields

$$\hat{g}_A + n = -\frac{\gamma n}{\beta} + \left(\frac{1-\theta}{\beta}\right)\hat{g}_A \tag{21}$$

Collecting like terms and simplifying

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$$\hat{g}_A\left\{1 - \frac{1+\theta}{\beta}\right\} = -\frac{\gamma m}{\beta} - n$$

$$\hat{g}_A\{\beta + \theta - 1\} = -n(\gamma + \beta)$$

$$\hat{g}_A = \frac{n(\gamma + \beta)}{1 - (\beta + \theta)} \tag{22}$$

And when equation (17) is substituted into (19)

$$\hat{g}_k = \frac{n(\gamma + \beta)}{1 - (\beta + \theta)} + n \tag{23}$$

The equation is further simplified

$$\hat{g}_k = \frac{n\gamma + n\beta + n - n\beta - n\theta}{1 - (\beta + \theta)}$$

$$\hat{g}_k = \frac{n + n(\gamma - \theta)}{1 - (\beta + \theta)} = \frac{n[1 + (\gamma - \theta)]}{1 - (\beta + \theta)} \tag{24}$$

Moreover, taking logs and the time derivative of the production function for output, equation (1), we obtain the growth rate of output as follows:

$$\frac{\dot{Y}}{Y} = g_y = \alpha g_k + (1 - \alpha)\{g_A + n\} \tag{25}$$

And, on substituting equation (11) into (25) we have:

$$\frac{\dot{Y}}{Y} = \hat{g}_y = \alpha \hat{g}_k + (1 - \alpha)\hat{g}_k = \hat{g}_k$$

$$\frac{\dot{Y}}{Y} = \hat{g}_y = \hat{g}_k \tag{26}$$

Finally, we can obtain the growth rate for the standard of living or income per capita, $y = Y/L$, by subtracting the growth rate of labour from the growth rate of output. Using equations (11), (26) and (22), we have the following expression:

$$\frac{\dot{y}}{y} = \hat{g}_{yl} = \frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \hat{g}_k - n = \hat{g}_A = \frac{\beta + \gamma}{1 - (\theta + \beta)} n \tag{27}$$

# 3        THE EFFECT OF OPENNESS ON ECONOMIC GROWTH

After having characterized the equilibrium in Section 2, we are now ready to analyse the impact of an increase in the degree of openness ($\lambda$) on the steady-state growth rate ($\hat{g}_y$) and the steady-state standard of living ($\hat{g}_{yl}$). Given equation (3), that is $\theta = \underline{\theta} + c\lambda^{\vartheta}$, as the degree of openness intensifies, the elasticity of the creation of new knowledge with respect to the existing stock of knowledge ($\theta$) increases. Given equation (22) and the fact that a steady-state equilibrium exists ($0 < c < \dfrac{1 - \beta - \underline{\theta}}{\lambda^{\vartheta}}$), an increase in $\theta$ causes the steady-state growth rate of knowledge ($\hat{g}_A$) to increase. With $\hat{g}_k = \hat{g}_A + n$, the steady-state growth rate of physical capital ($\hat{g}_k$) rises following an increase in $\hat{g}_A$ and given $n$. The increase in $\hat{g}_k$ implies an increase also in the growth rate of output since $\hat{g}_y = \hat{g}_k$. Finally, given that $\hat{g}_{yl} = \hat{g}_A$, an increase in the degree of openness also improves the steady-state growth rate of the standard of living of the economy.

Figure 4 summarizes the effect of the intensification of the degree of openness on the steady-state growth rate of capital and knowledge, given that an unique and stable equilibrium exists. Starting from an initial equilibrium at $E$, an increase in $\theta$ to $\theta_1$ due to a rise in the measure of openness from $\lambda$ to $\lambda_1$, causes the $\dfrac{\dot{g}_A}{g_A} = 0$, locus to swing to the right, due to a fall in the slope of the curve. Note $\left(\dfrac{1 - \theta_1}{\beta}\right) < \left(\dfrac{1 - \theta}{\beta}\right)$. As a result of this movement the new equilibrium of the economy moves to $E_1$ causing the steady-state levels of the growth rate of capital and knowledge, respectively, to rise to $\hat{g}_{k1}$ and $\hat{g}_{A1}$ from their initial corresponding values of $\hat{g}_k$ and $\hat{g}_A$.

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**Figure 4**      **Effect of an Increase in the degree of Openness on the Steady-State Growth Rate of Capital and Knowledge**
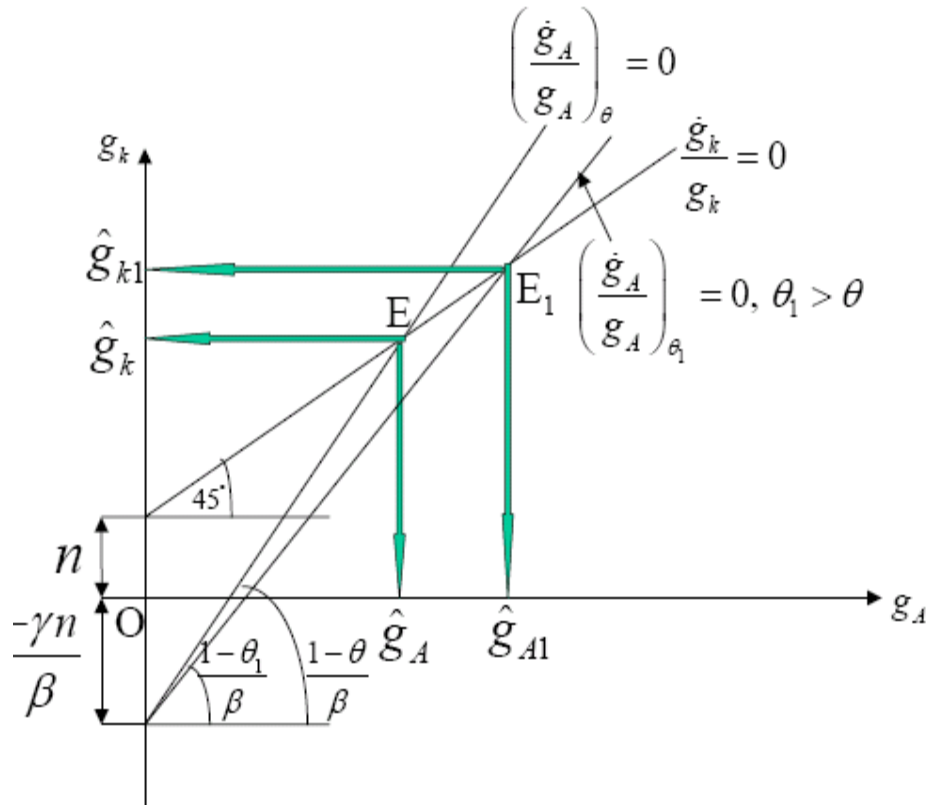


## 4      CONCLUSIONS

Recent studies by Coe and Helpman (1995), Branstetter (1996), Keller (1996) and Nadiri and Kim (1996) have pointed out that trade liberalisation leads to technological spillovers, which, in turn, tend to improve the efficiency of the domestic Research and Development (R&D) sector, and ultimately boost economic growth. In this paper, we theoretically formalize the above mentioned relationship between trade openness and growth via technological and knowledge spill over in the R&D sector. We show that, under certain conditions, an increase in the degree of openness is not only growth enhancing, but also improves the standard of living. The study, thus, prescribe policies of

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