Technical Progress Effects on Productivity and Growth in the Commonwealth of Nations (1993-2009)*

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Abstract

The productivity generated by capital goods is not uniform along the time. When there exist conventional physical capital goods the productivity obtained is minor that one generated by quality capital goods. For this reason it can be interesting to develop a special analysis on the investment in capital goods in order to identify what are the differences between the productivity derived from physical capital and from quality capital. It seems that the differences between both kinds of capital stems from the fact that the vintage or quality capital is affected by an additional form of technical progress. Solow (1960) called this form of capital as capital jelly. The main aim of this paper is to analyze what fraction of the labour productivity is independent with respect to the capital accumulation, and what fraction is related to the massive investment processes in quality technologies. We also want to analyze which are the effects of the two forms of technical progress, neutral or directly embodied while capital is accumulated, on the economic growth. Due to the difficulties embodied in the construction of hedonic prices indices and in the elaboration of the micro-level data sets, the application for the purpose above mentioned has been made following a vintage capital model. This model has been applied across the countries that have quarterly data belonging to the Commonwealth of Nations: Canada, UK, Australia, New Zealand, South Africa, Cyprus, Malaysia, and India. The time period choose for this application is 1993-2009 using quarterly data. To estimate the percentages of responsibility of the embodied and disembodied technical progress on the labor productivity we use multivariate time series and cointegration techniques, specially vector autoregressive and ARDL models.

Keywords: Quality capital, Endogenous technical progress, Vintage capital, Investment-specific technological change, Neutral technical progress, Growth. JEL Class: O47, O57.

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1 Introduction

An important part of the pioneer studies on the sources of the economic growth, such as in Solow (1956) or Jorgenson (1966) supposed that a great part of the technical progress was not incorporated into the process of capital accumulation. From this point of view, technological change was linked to a certain number of factors such as improvements in education, a progressive higher development and to a better resources market organization. This type of analysis emphasizes that technical progress is neutral, or capital disembodied, that is, the output per hour and the capital per hour are determined independently from the process of capital accumulation. Moreover, some empirical and recent evidences contradict partly several of the stylized facts of Kaldor (1961), and it cannot be explained by means of the original framework of the neoclassical growth model. Solow (1960) pointed out that this last hypothesis was in contradiction with a simple observation: the bigger part of technological innovations, that is, the bigger part of the technological progress embodied in the investment in capital goods generates effects over the efficiency and productivity of the economy. This minds that the bigger part of the technological progress came from the fact of to be embodied by the firms, by means of the capital accumulation process. Yet, from the 1980 decade, became more and more evident that the quality of the goods, in particular of the durable goods, increases. The more high efficiency in the production of these goods suggests that an important part of the technical progress is already incorporated in the new capital goods. This new type of technical progress is then so-called embodied technical progress. Denison (1964) already outlined that the embodiment of the technical progress in the new capital goods (the embodiment question) could be certainly relevant if the age of the capital play a crucial role in the correct determination of the GDP growth rate. After the above considerations, there are two possible forms to understand technical progress. The classical one, generally considered as a Hicks neutral technical progress that affects to all production factors, or alternatively this new class of technical progress, so-called endogenous, which only affects the capital factor. A purpose of the present work is to evaluate in which manner this new type of technical progress, caused by new technologies, can impact on the economic growth and productivity across several economies belonging to the Commonwealth of Nations. The precursory works in the present research have found in Solow (1960) and Johansen (1959). To obtain a correct measure of growth in presence of embodied technical progress there exist three schools: first, the traditional growth accounting school appears due to the limitations existing in to measure the quality of the real investment in efficiency units, because the investment is not really comparable along the time. The analysis carried out by this school is based in to adjust the quality or productivity of the investment goods constructing hedonic prices indices. Still now only has been elaborated this prices indices for the U.S. economy. This school is represented among others by Hulten (1992), Jovanovic and Nyarko (1996), Bartelsman and Dhrymes (1998), and Gordon (1999). The second school analyzes the productivity using longitudinal micro-level data sets which follow large numbers of establishments or firms over the time. Still today only a few developed countries have longitudinal research databases: Norway, US, Canada, France, Denmark, Sweden, the Netherlands, and Israel. The most important contributions from this school are Griliches and Ringstad (1971), Olley and Pakes (1996), Caves (1998), McGuckin and Stiroh (1999), and Tybout (2000) among others. The third school is the equilibrium growth accounting school, which measures the balanced growth by means of vintage capital models, being represented by Greenwood, Hercowitz and Krusell (1997), Campbell (1998), Hobijn (2000), and Comin (2002), among others. The results obtained by Hobijn (2000) applying a vintage capital model to U.S. quarterly data in the period 1973-2000 indicate that at least two thirds of growth of U.S. real GDP per capita is due to quality improvements of capital goods in this period. The issue of this debate is to know what part of the investment processes in capital goods and new technologies determines technical progress. That minds to analyze which are the effects of the two form of technical progress, neutral or embodied directly by capital, on the economic growth, and productivity. One application to carry out the purpose above mentioned has been made into this paper following the vintage capital model school. The model has been applied across eight countries belonging to the Commonwealth of Nations. The time period choose for this application coincides with the last period of the third wave of Globalisation (1990-2009), where the new technologies affect the total factor productivity. The application of the vintage capital model has been made by taking quarterly data from the National Accounts of each country, coming from the Main Economic Indicators of the OECD Statistics and the International Financial Statistics (International Monetary Fund). The data are collected at constant and current prices for the GDP, gross fixed capital formation, and private final consumption expenditure. In some cases we have applied consumer prices indices. The sequence of this work is the following: section 2 study the hedonic prices system. Section 3 formalize a vintage capital model. Section 4 analyzes the impacts of the embodied and disembodied technical progress on the economic growth rate. In section 5 are collected the data and the empirical results, and the concluding remarks are in section 6.

2 The hedonic prices system

During the development of this research a first difficulty arise when we try to determine how to measure the quality of the capital investment. A possibility is to measure, in efficiency units, the quality of real investment. A limitation of this approach is that the results of these measures indicate that the investment is not really comparable along the time. The explanation of that seems to be found in that most recent generations of investment flows allow a greater production per capital factor unit than those carried out in the past. Consequently, to make these both flows comparable, it would be necessary to adjust the quality or productivity of the investment goods. Under this approach it is necessary to measure the quality in a form related with some relative price indices. This would require to control all quality changes. Gordon (1999) and Bartelsman and Dhrymes (1998) builded a series of production price indices adjusted by quality, based in National Accounts investment data. From the National Accounts we can obtain the data on investment in nominal terms and also the number of units of investment goods installed. One problem presented is that this form to measure the investment in real terms is not really comparable along the time.The reason is that the current vintages of capital investment have a greater productivity than vintages coming from capital in the past.We would need then to measure real investment in terms of quality units, which are already comparable along the time. To make comparable these investment goods it is necessary then to adjust the measure by the changes in productivity. It could be interesting to have some information about the path of the quality improvements of the capital goods, measuring the evolution of quality and productivity for the several capital goods. That will allow us to obtain a prices index to the investment, $P_{i,t}$, so-called hedonic price indices, which can satisfy the following nominal investment ($I_{N,t}$) equation

$$\frac{I_{N,t}}{P_{i,t}} = I_t \cdot Q_t \tag{1}$$

Where Q_t is a parameter which reflects a certain quality degree. This index allows to measure real investment ($I_t \cdot Q_t$) in constant quality units. We really don't know what exactly one unit of capital good means, and hence it maybe convenient to define I_t in units of consumption goods. Under this approach Q_t reflects the opportunity cost of investment goods measured in units of consumption goods terms. In that case the price $P_{i,t}$ appears as the relative price of a quality unit of investment good in terms of the consumption good. That is, $P_{i,t} = P_{c,t}/Q_t$, where $P_{c,t}$ is a consumption price index. This allows that Q_t can be written as

$$Q_t = \frac{P_{c,t}}{P_{i,t}} \tag{2}$$

Now a new problem appears because the elaboration of $P_{i,t}$ requires to have control over the changes in quality: Q_t must be measured considering the path of the relative price index of investment relative to consumption, but the construction of this price index itself requires a measurement of Q_t. Alternatively we could measure the quality dimensions of several investment goods, and then estimate which percentage of the oscilations in the relative price of the investment goods can be attributed to the fluctuations in these quality indices. In other words we can identify the contribution that the accumulation in capital goods could have on technical progress. This maybe done through some regressions that allow to compute these hedonic prices. Gordon (1999) and Jovanovic and Nyarko (1996) use this methodology, that is, once quantified Q then to construct the price index $P_{i,t}$. The resulting price index of investment goods then appears adjusted by quality. The problem is that it requires to measure different dimensions of quality improvements, which may lead an spurious measurement of the embodied technical change. That is, if some of the quality dimensions that have actual effect are not included, then the embodied technological change can be underestimated. With this current identification strategy is very difficult to obtain a precise adjustment in quality changes. The situation became worse due to the degree of detail used in the National Accounts price indices and the availability of the aggregation level. For these reasons stated, it could be more interesting consider other methods that allow a measurement of Q_t without using the hedonic prices. Then, given the difficulties outlined, some authors follow a different strategy. Most part of they decided to analyze how technical progress affect output avoiding the need of building hedonic prices of investment goods. In section three we will use a strategy based in a structural approach which contains a vintage capital growth model.

3 Vintage capital growth theoretical model

To evaluate the impact of the quality investments on the economic growth and productivity we will follow an approach based in the use of the maximum information available, already used by Hobijn (2000), Campbell (1998) and Comín (2002). This strategy applies the information supplied by variables such as investment, output level, or the population growth rate, using a Cobb-Douglas production function and a utility function. The objective is to capture the evolution followed by the technical progress which arise endogenously when investment in capital goods are carried out. In this way it maybe possible to show the implicit evolution of the quality by determining the impact of quality fluctuations on the economic growth process. The starting point of the model is in the conventional literature of capital accumulation theory, where, calling by δ the depreciation of the physical capital being K_t the aggregate capital stock

$$K_{t+1} = (1-\delta)K_t + I_t \tag{3}$$

Where I_t represents the investment at period t. However a great part of economic growth seems to be due to new capital goods, which are more productive than old ones. This vintage, coming from current investment, embodies an additional productivity equal to Q_{t+1}, because investment has been made in the t period. In these conditions, the effective aggregate capital stock is bigger than K_t, and Solow (1960) called it as jelly capital (J_t). Assuming the value of the additional productivity as Q_{t+1}, the relations-ship between physical capital (K_t) and jelly capital (J_t) are

$$J_t = K_t \cdot Q_{t+1} \tag{4}$$

$$J_{t+1} = K_{t+1} \cdot Q_{t+2} = K_{t+1} \cdot (Q_{t+1} + \Delta Q_{t+1}) \tag{5}$$

Substituting these last equations in (3), we can obtain[1]:

$$J_{t+1} = (1 - \delta^*) J_t + I_t \cdot Q_{t+1} \tag{6}$$

where I_t is the current investment and δ^* mind the depreciation rate including the depreciation of both physical and vintage capital. From this last expression we can isolate I_t

$$I_t = \frac{J_{t+1}}{Q_{t+1}} - (1 - \delta^*) \left(\frac{J_t}{Q_t} \right) \left(\frac{Q_t}{Q_{t+1}} \right) \tag{7}$$

We now will assume that the behaviour of $Q_{t+1}$is a random walk: $Q_{t+1} = (1 + \gamma) Q_t + \varepsilon_t$ where considering that $Q_{t+1} = Q_t + \Delta Q_t$, the value of γ will be the growth rate of the additional productivity: $\gamma = \frac{\Delta Q_t}{Q_t}$, being ε_t an $iid(Gumbel)$ error. On the supply side, we assume that the aggregate real output Y_t can be produced by means of the following production function

$$Y_t = Z_t \cdot J_t^{\alpha} \cdot L_t^{(1-\alpha)} \tag{8}$$

where L_t is the labor supply, J_t is the jelly capital affected by the specific vintage Q_t, and Z_t is the level of a Hicks neutral disembodied technological progress. We will assume that the labor supply is inelastic and grows at a constant rate $n = \frac{\Delta L_t}{L_t}$. Normalizing the labor supply in period zero to one ($L_0 = 1$), this implies that the total labor supply equals $L_t = (1 + n)^t$. Then, the production function can be written as $Y_t = Z_t \cdot J_t^{\alpha} \cdot (1 + n)^{(1-\alpha)t}$. We also assume that the main objective for an optimum amount of investment must be the maximization of the consumtion per capita in each time period, once normalized labour

[1]See Apendix 1

$$MAX\left[\frac{C_t}{(1+n)^t}\right]=MAX\left[\frac{(Y_t-I_t)}{(1+n)^t}\right] \tag{9}$$

Where C is consumption, Y real income , and I investment. In each period the amount of investment must fulfil the consumption golden rule[2]:

$$Y'_K=n+g+\delta^*+\alpha\gamma=Y'_J\cdot J'_K=\left[\alpha Z_t J_t^{-(1-\alpha)}(1+n)^{(1-\alpha)t}\right]\cdot Q_t(1+\gamma) \tag{10}$$

Where g is the exogenous growth rate of the neutral technological progress Z. Rearranging the expression (10)

$$\left[\frac{\alpha(1+\gamma)}{n+g+\delta^*+\alpha\gamma}\right]Z_t\cdot J_t^{-(1-\alpha)}\cdot Q_t(1+n)^{(1-\alpha)t}=1 \tag{11}$$

And so-calling the term $\left[\frac{\alpha(1+\gamma)}{n+g+\delta^*+\alpha\gamma}\right]$ as Φ, we have[3]

$$J_t^{1-\alpha}=\Phi\cdot Z_t\cdot Q_t\cdot(1+n)^{(1-\alpha)t} \tag{12}$$

By dividing now the equation (12) into (8), that is, dividing $J_t^{1-\alpha}$ into Y_t , we have

$$\frac{J_t^{1-\alpha}}{Y_t}=\frac{\Phi\cdot Q_t}{J_t^{\alpha}} \tag{13}$$

And hence

$$\Phi=\frac{J_t}{Q_t\cdot Y_t},\forall t \tag{14}$$

From the equation (12) we can derive the optimal investment-specific policy rule:

[2] See Apendix 2

[3] If we suppose that the representative household in this economie chooses a sequence of investment levels $\{I_t\}_{t=0}^{\infty}$ in order to maximize the expected present discounted value of the stream of per capita consumption levels, then the maximization problem will be

$Max\ E_0\left[\sum_{t=0}^{t=\infty}\left(\frac{\rho}{1+n}\right)^t(Y_t-I_t)\right]$, being ρ the intertemporal discount rate. Following Benhabib and Rustichini (1993) and Hobijn (2000) the dynamic optimality condition resulting from this maximization requires that in every period the marginal des-utility from saving should be equal the expected present discounted value of the future marginal product of the investment. In this particular case, the value for Φ will be then:

$\Phi=\frac{\rho}{1+n}\left(\frac{1}{1-\left(\frac{\rho}{1+n}\right)\left(\frac{1-\delta^*}{1+\gamma}\right)}\right)$

$$J_t = \Phi^{[1/(1-\alpha)]} \cdot Z_t^{[1/(1-\alpha)]} \cdot Q_t^{[1/(1-\alpha)]} \cdot (1+n)^t \tag{15}$$

In the other hand, rearranging now the equation (7), we have

$$\frac{I_t}{Y_t} = \frac{J_{t+1} \cdot Y_{t+1}}{Q_{t+1} \cdot Y_{t+1} \cdot Y_t} - (1-\delta^*)\left(\frac{J_t}{Q_t \cdot Y_t}\right)\left(\frac{Q_t}{Q_{t+1}}\right) \tag{16}$$

and:

$$\frac{I_t}{Y_t} = \Phi \frac{Y_{t+1}}{Y_t} - \left[\Phi \cdot \left(\frac{Q_t}{Q_{t+1}}\right)\right](1-\delta^*) \tag{17}$$

Regressing this equation 17 taking the term $\frac{I_t}{Y_t}$ as the endogenous variable and $\frac{Y_{t+1}}{Y_t}$ as the explanatory variable, the last term of the equation appears as an independent term because still now we do not known δ^*. Once regressed this equation we can estimate Φ as $\widehat{\Phi}$, and we can express the embodied technical progress growth rate as follows

$$\frac{\Delta Q_t}{Q_t} = \frac{Q_{t+1}}{Q_t} - 1 = \frac{1-\delta^*}{\frac{Y_{t+1}}{Y_t} - \frac{1}{\widehat{\Phi}}\left(\frac{I_t}{Y_t}\right)} - 1 \tag{18}$$

Notwithstanding, an important identification issue that remains from the above equation, is that we cannot identify separately Q_t and δ^*, but we can identify separately Q_t and δ because this last determines only the physical deterioration of the capital good. Under a sample of technological leader countries, with an investment composed by physical and, about all, vintage capital, we can take δ as a proxy of δ^*. In our particular case we will take by simplicity δ as the depreciation rate. To obtain this we will rearrange the equation 3

$$(1-\delta^*) = \frac{K_{t+1}}{K_t} - \frac{I_t}{K_t} \tag{19}$$

where for I_t we use the real fixed private non-residential investment. Substituting this last result (19) into the equation 18, we can approximately isolate the path of the endogenous technical progress Q_t growth rate

$$\frac{\Delta Q_t}{Q_t} = \frac{Q_{t+1}}{Q_t} - 1 = \frac{\frac{K_{t+1}-I_t}{K_t}}{\frac{Y_{t+1}}{Y_t} - \frac{1}{\widehat{\Phi}}\left(\frac{I_t}{Y_t}\right)} - 1 \tag{20}$$

It seems important to compare the path of the endogenous technical progress Q_t growth rate with the path of the exogenous technical progress Z_t growth rate, which affects directly the production function. In this sense, and considering the production function (8), we can express $Y_{t+1} = Z_{t+1} \cdot J_{t+1}^{\alpha} \cdot L_{t+1}^{(1-\alpha)}$. Dividing this last expression between (8), we have

$$\frac{Y_{t+1}}{Y_t} = \frac{Z_{t+1} \cdot J_{t+1}^{\alpha} \cdot L_{t+1}^{(1-\alpha)}}{Z_t \cdot J_t^{\alpha} \cdot L_t^{(1-\alpha)}} \tag{21}$$

Tath is

$$\frac{Y_{t+1}}{Y_t} = \frac{Z_{t+1}}{Z_t} \left(\frac{Q_{t+1}}{Q_t}\right)^{\alpha} \left(\frac{Y_{t+1}}{Y_t}\right)^{\alpha} (1+n)^{(1-\alpha)} \tag{22}$$

Taking Neper logarithms in this expression we have

$$\ln \frac{Y_{t+1}}{(1+n)Y_t} = \left[\frac{1}{1-\alpha} \cdot \ln\left(\frac{Z_{t+1}}{Z_t}\right)\right] + \frac{\alpha}{1-\alpha} \cdot \ln\left(\frac{Q_{t+1}}{Q_t}\right) \tag{23}$$

Like the series $\left(\frac{Q_{t+1}}{Q_t}\right)$is know by means of (20), regressing this equation (23) considering the series $\ln\left(\frac{Q_{t+1}}{Q_t}\right)$ as the explanatory variable we can estimate the parameter α as $\widehat{\alpha}$. Substituting this value in 22 we can isolate the disembody factor productivity growth rate

$$\frac{\Delta Z_t}{Z_t} = \left(\frac{Y_{t+1}}{Y_t}\right)^{(1-\widehat{\alpha})} \left(\frac{Q_t}{Q_{t+1}}\right)^{\widehat{\alpha}} \left(\frac{1}{1+n}\right)^{(1-\widehat{\alpha})} - 1 \tag{24}$$

Alternatively, using the Appendix 2, we can also deduce the path of the growth rate for the disembody factor productivity, from the Solow residual

$$\frac{\Delta Z_t}{Z_t} = \frac{\Delta Y_t}{Y_t} - \widehat{\alpha}\left(\frac{\Delta Q_t}{Q_t} + \frac{\Delta K_t}{K_t}\right) - (1-\widehat{\alpha})\, n \tag{25}$$

Comparing expressions 20 and 24 or 25 we can see the two different growth paths of the technical progress, embodied (20) and disembodied (24 and 25). In the following paragraphs and figures we will compare empirically this trajectories join the paths of other relevant macroeconomic variables, to observe the macroeconomics effects of the quality investment in the analyzed countries.

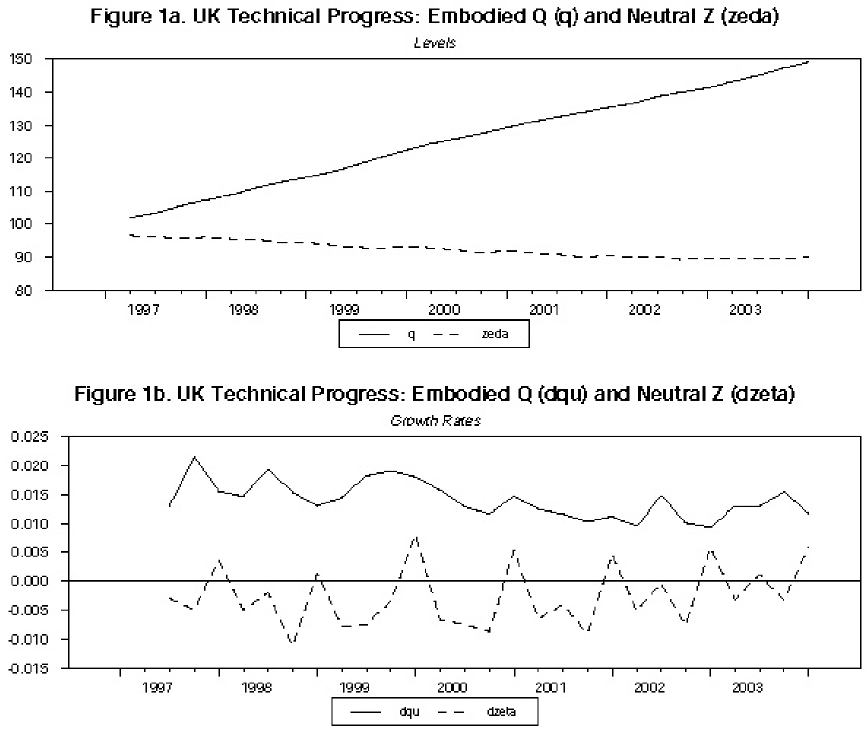

Figure 1. U.K. Technical Progress Evolution 1997-2004

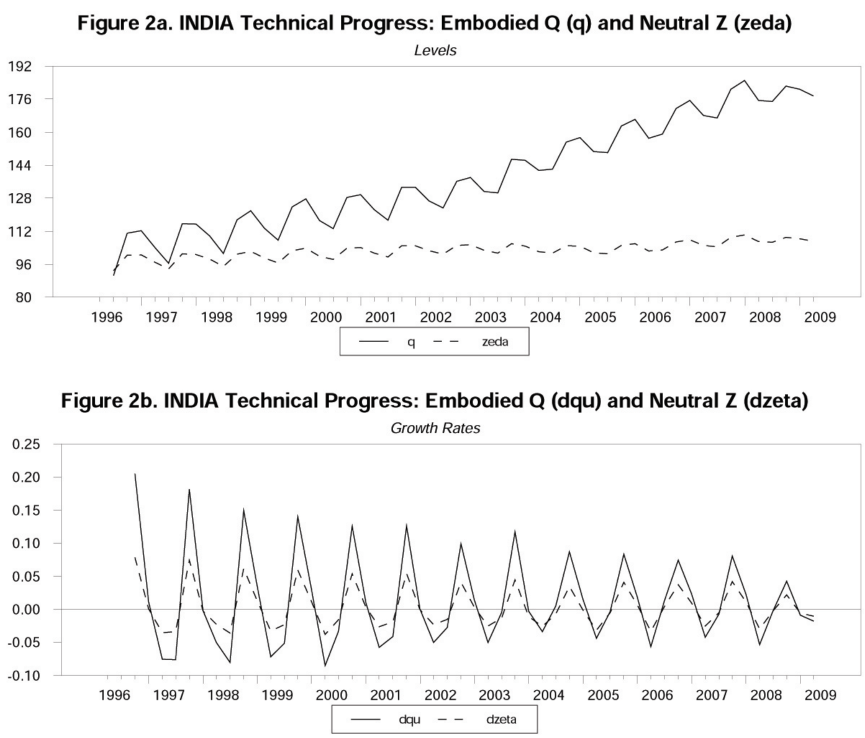

Figure 2. INDIA Technical Progress Evolution 1996-2009

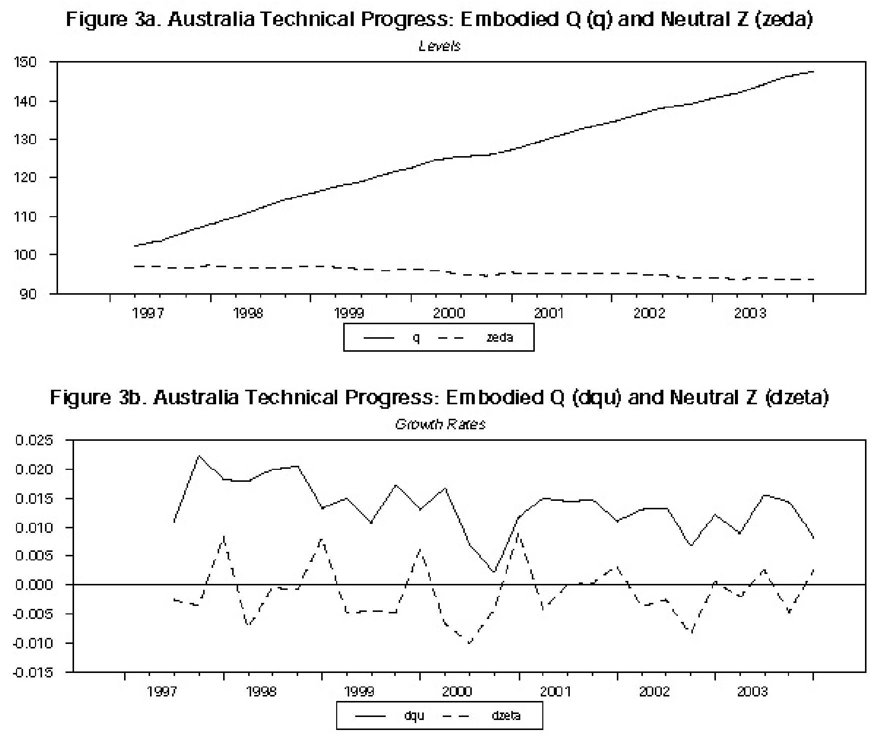

Figure 3. AUSTRALIA Technical Progress Evolution 1997-2004

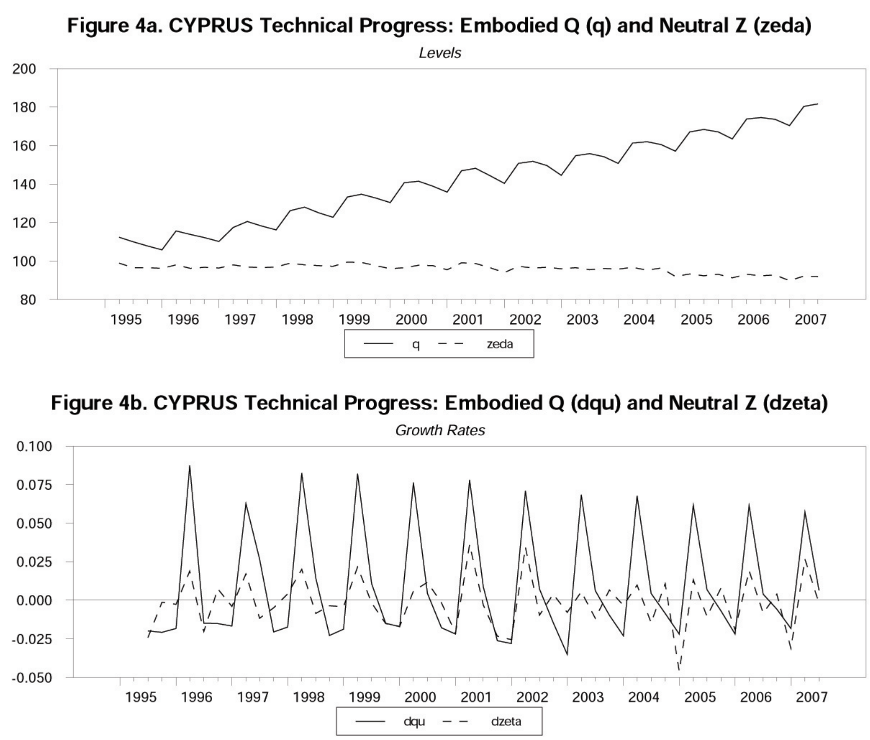

Figure 4. CYPRUS Technical Progress Evolution 1995-2007

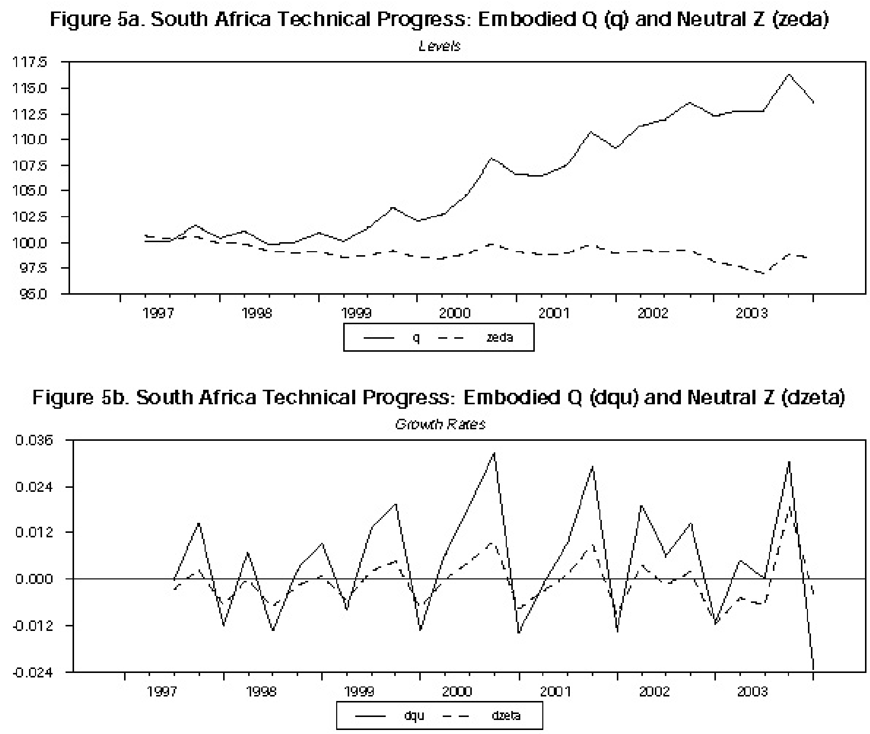

Figure 5. S. AFRICA Technical Progress Evolution 1997-2004

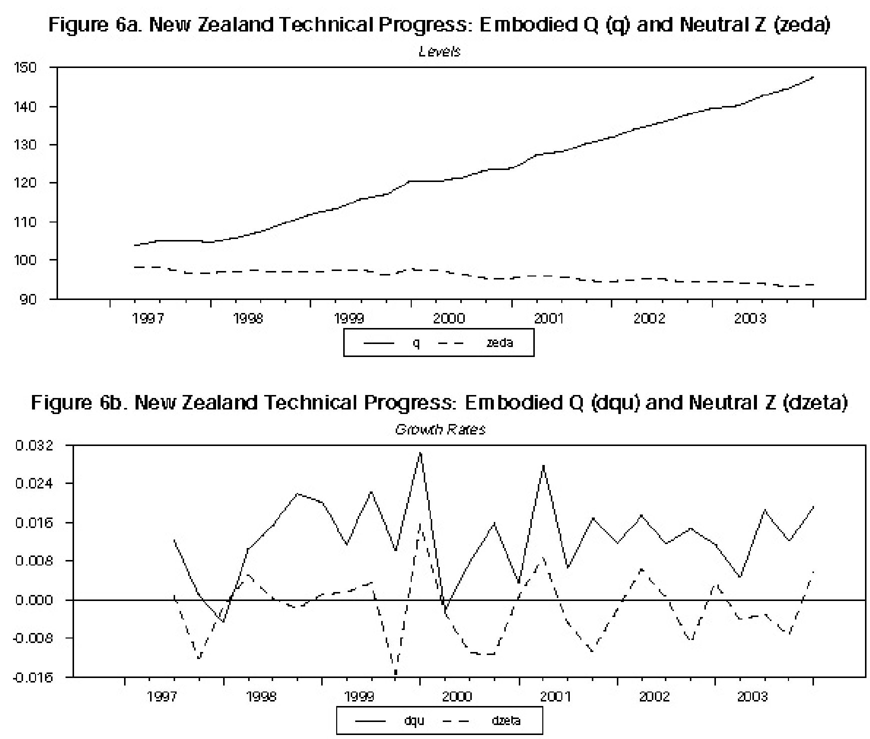

Figure 6. N.ZEALAND Technical Progress Evolution 1997-2004

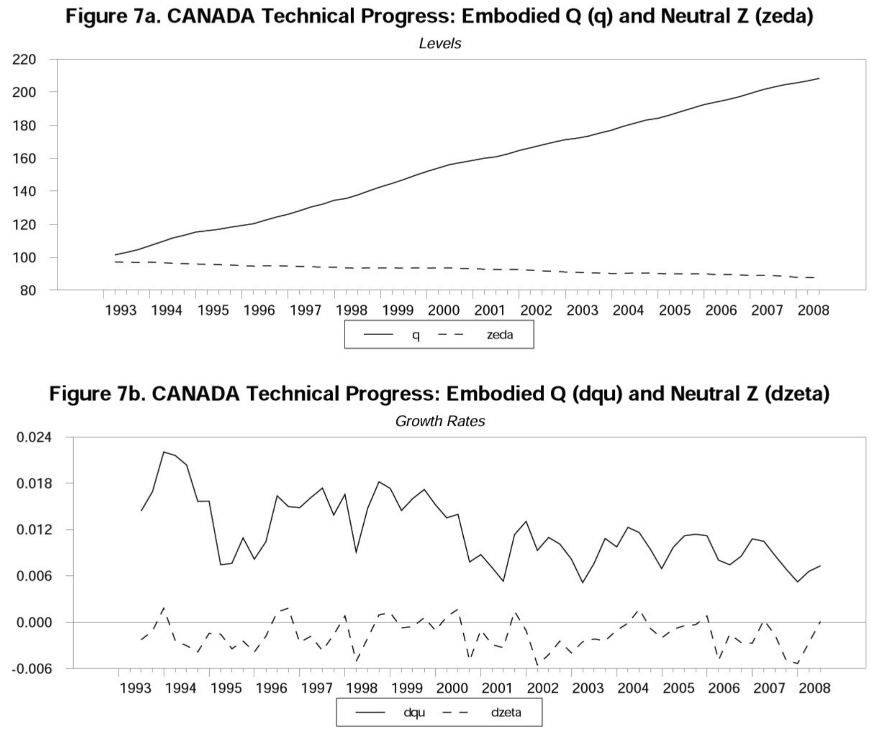

Figure 7. CANADA Technical Progress Evolution 1993-2008

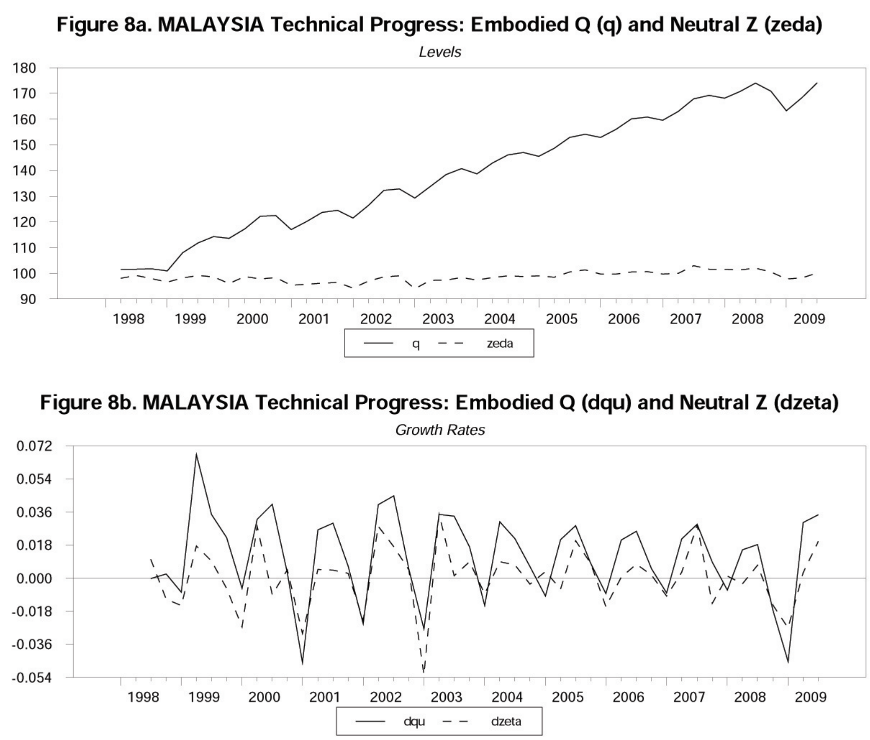

Figure 8. MALAYSIA Technical Progress Evolution 1998-2009

4 The contribution of Z and Q to the labour productivity growth rate

There is a relation-ship between the growth rates concerning to the embodied (Q) and disembodied (Z) technical progresses, obtained by means of expressions (20) and (24 or 25) respectively, which relates both rates with the average labour productivity. To observe that, it is necessary to relate the production function (8) with the optimality condition (14). Additionally we assume that labour (L) must be measured in number of hours worked. Under these conditions, substituting the expression (14) into (8), and so-calling Y/L as Yn, we will have

$$Yn_t = Z_t^{\frac{1}{1-\alpha}} \cdot (\Phi \cdot Q_t)^{\frac{\alpha}{1-\alpha}} \tag{26}$$

Where Yn_t represent the average labour productivity. Taking Neper logarithms in this expression we have

$$\ln(Yn_t) = \frac{\alpha}{1-\alpha}\ln\Phi + \frac{1}{1-\alpha}\ln Z_t + \frac{\alpha}{1-\alpha}\ln Q_t \tag{27}$$

Differentiating this expression, we obtain

$$d[\ln(Yn_t)] = \frac{1}{1-\alpha}d[\ln Z_t] + \frac{\alpha}{1-\alpha}d[\ln Q_t] \tag{28}$$

That is

$$\frac{d(Yn_t)}{Yn_t} = \frac{1}{1-\alpha}\cdot\frac{d(Z_t)}{Z_t} + \frac{\alpha}{1-\alpha}\cdot\frac{d(Q_t)}{Q_t} \tag{29}$$

This is the relation-ship among the growth rates, which allow us to obtain the weights of Z and Q in the labour productivity growth rate.

5 Data, empirical model and results

The theoretical model has been applied on eight countries belonging to the Commonwealth of Nations: Canada, UK, Australia, New Zealand, South Africa, Cyprus, Malaysia and India. The data has been collected from the International Financial Statistics for Cyprus and Malaysia, and from the OECD data base for the other countries. The analysis has been applied from January 1993 to December 2009, with quarterly data.

The main purpose of this application is to control in which manner labour productivity growth rate, and the economic growth rate could be affected by the two forms of technological progress. That is, which percentage of the economic growth and which percentage of the labour productivity growth are induced by Q and Z respectively. To obtain a truth measure of the impact of Z and Q it is necessary to arrange the equation (29) by dividing its both members by (dYn_t/Yn_t):

$$1 = \frac{1}{1-\alpha} \cdot \frac{d(Z_t)/Z_t}{d(Yn_t)/Yn_t} + \frac{\alpha}{1-\alpha} \cdot \frac{d(Q_t)/Q_t}{d(Yn_t)/Yn_t} \tag{30}$$

Calling the first term of the second member of the equation as $\theta_1$and the second as θ_2, we will have then: $1 = \theta_1 + \theta_2$, where $\theta_1$is the part of the productivity due to the disembodied technical progress Z, and θ_2 the part due to the embodied technical progress Q. At the same time from the equation (29) we can write the following expression

$$\frac{\alpha}{1-\alpha} = \frac{d\left(\frac{dYn_t}{Yn_t}\right)}{d\left(\frac{dQ_t}{Q_t}\right)} = \frac{\frac{d^2Yn_t}{Yn_t} - \left(\frac{dYn_t}{Yn_t}\right)^2}{\frac{d^2Q_t}{Q_t} - \left(\frac{dQ_t}{Q_t}\right)^2} \simeq \frac{d^2Yn_t}{d^2Q_t} \cdot \frac{Q_t}{Yn_t} \tag{31}$$

Substituting this expression (31) into (30), we can obtain the value of θ_2:

$$\theta_2 = \frac{\frac{d[d(Yn_t)]}{d(Yn_t)}}{\frac{d[d(Q_t)]}{d(Q_t)}} = \frac{d[\ln d(Yn_t)]}{d[\ln d(Q_t)]} \tag{32}$$

In the same form, we obtain the value for θ_1:

$$\theta_1 = \frac{d[\ln d(Yn_t)]}{d[\ln d(Z_t)]} \tag{33}$$

Considerig both equations (32) and (33), we can estimate the weigths θ_1 and θ_2 by regressing the following relation-ship

$$\ln[d(Yn_t)] = \theta_0 + \theta_1 \cdot \ln[d(Z_t)] + \theta_2 \cdot \ln[d(Q_t)] \tag{34}$$

Where θ_0 is a constant. To avoid imaginary values in this equation, by using some logarithms properties we multiply into two the both members of the equation, and the coefficients θ_1 and θ_2 do not change

$$\ln[d(Yn_t)]^2 = 2\theta_0 + \theta_1 \cdot \ln[d(Z_t)]^2 + \theta_2 \cdot \ln[d(Q_t)]^2 \tag{35}$$

This is the final form of the equation to be estimated for obtaining the percentages θ_1 and θ_2, which reflect the impacts coming from Z and Q on the labour productivity growth rate. After testing stationarity with the ADF tests and cointegration using the test of Johansen and Juselius (1989), the estimation of the equation (35) has been made by means of VAR techniques, like in Michelacci and Lopez-Salido (2002), for Denmark and Norway, and by the ARDL (Auto Regressive Distributed Lags) technique, from Pesaran and

Shin (1999), for the rest of the countries. Gregory-Hansen (1996) tests have been used to detect break points and to contrast cointegration in presence of structural changes, and CUSUM and CUSUMQ tests, based on the recursive regression of the residuals, have been employed to verify that the regression's coefficients are stable. While the specification VAR requires stationarity for all variables, the ARDL method can be used when it is not known with certainly whether the regressors are purely I(0), purely I(1) or mutually cointegrated. The autoregressive distributed lag model of order p and n, ARDL(p,n) is defined for a scalar variable y_t as:

$$y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \cdot y_{t-i} + \sum_{i=0}^{n} c_i' \cdot x_{t-i} + \varepsilon_t \tag{36}$$

where ε_t is a scalar zero mean error term being vectors x_t and y_{t-i}.

The total estimation results for the impacts on labour productivity are collected in the Tables 1 and 2.

In other hand, to obtain the impacts of Z and Q on the total economic growth rate, we must multiply the both members of the equation (30) into $\frac{d(Yn_t)}{Yn_t}$

$$\frac{d(Y_t)}{Y_t} = d[\ln(L_t)] + \theta_1 \cdot \frac{d(Yn_t)}{Yn_t} + \theta_2 \cdot \frac{d(Yn_t)}{Yn_t} \tag{37}$$

Dividing now the both members of this last equation by the first member we obtain

$$1 = \frac{d[\ln(L_t)]}{d[\ln(Y_t)]} + \theta_1 \cdot \frac{d[\ln(Yn_t)]}{d[\ln(Y_t)]} + \theta_2 \cdot \frac{d[\ln(Yn_t)]}{d[\ln(Y_t)]} \tag{38}$$

and so-calling by ε the elasticity labour productivity-real income, and by $\pi_1$and π_2 the participation of Z and Q respectively in the real income growth rate, we have finally that $\pi_1 = \theta_1 \cdot \varepsilon$, and $\pi_2 = \theta_2 \cdot \varepsilon$. The elasticity coefficients between real income and labour productivity (ε) were estimated by Least Squares, correcting the autocorrelation by means of first order autoregressive processes (AR1). The results of these regressions are collected in Table 3, and the results of the contribution of Z and Q on labor productivity and real income growth rates are collected respectively in the Tables 4 and 5.

Table 1. Z an Q effects on the labour productivity growth rate

Country:	**UNITED KINGDOM**	**INDIA**	**AUSTRALIA**	**CYPRUS**
Period:	1997-2004	1996-2009	1997-2004	1995-2007
Method:	VAR (3)	ARDL	VAR (5)	ARDL
Endogenous: $\text{Ln}(\text{dYn})^2$				
Explanatory:				
$\text{Ln}(\text{dYn})^2(1)$	-0.132	-	0.1309	0.0246
	(-0.49)	-	(0.30)	(0.11)
$\text{Ln}(\text{dZ})^2$	Lag 3	Lag 8	Lag 4	Lag 0
	0.2220	**0.4532**	**0.1719**	**0.5186**
	(0.71)	(3.84)	(0.91)	(1.64)
$\text{Ln}(\text{dQ})^2$	Lag 3	Lag 3	Lag 1	Lag 1
	0.5195	**0.2608**	**0.4460**	**0.3941**
	(1.65)	(2.00)	(2.19)	(1.32)
Tests				
DW	1.83	2.01	1.87	2.05
R^2 *adjusted*	0.66	0.81	0.80	0.76

Note: *t-ratios in brackets*

Table 2. Z an Q effects on the labour productivity growth rate

Country:	**SOUTH AFRICA**	**NEW ZEALAND**	**CANADA**	**MALAYSIA**
Period:	1997-2004	1997-2004	1993-2008	1995-2004
Method:	VAR (5)	VAR (5)	ARDL	ARDL
Endogenous: $\text{Ln}(\text{dYn})^2$				
Explanatory:				
$\text{Ln}(\text{dYn})^2(1)$	0.985	-0.207	0.0854	-0.609
	(1.05)	(-0.36)	(0.47)	(-2.71)
$\text{Ln}(\text{dZ})^2$	Lag 3	Lag 3	Lag 4	Lag 0
	0.250	**0.281**	**0.2867**	**0.4940**
	(0.22)	(0.35)	(1.09)	(2.01)
$\text{Ln}(\text{dQ})^2$	Lag 3	Lag 3	Lag 1	Lag 5
	0.425	**0.550**	**0.6633**	**0.3487**
	(1.09)	(1.09)	(3.40)	(0.83)
Tests				
DW	1.59	2.12	2.01	2.21
R^2 *adjusted*	0.89	0.43	0.81	0.49

Note: *t-ratios in brackets*

Table 3. Elasticity between labour productivity and real income

Country:	UNITED KINGDOM	INDIA	AUSTRALIA	CYPRUS
OLSQ-AR1				
Endogenous: Ln(Yn)				
Ln(Y)	**1.174**	**0.6655**	**0.817**	**0.7325**
(Explanatory)	(7.33)	(38.7)	(4.87)	(13.2)
Tests				
DW	2.25	1.45	2.34	2.12
$R^2 adjusted$	0.99	0.99	0.99	0.99
Country:	**SOUTH AFRICA**	NEW ZEALAND	**CANADA**	**MALAYSIA**
Ln(Y)	**0.973**	**0.845**	**0.968**	**1.031**
(Explanatory)	(30.4)	(8.03)	(5.49)	(7.87)
Tests				
DW	1.20	2.18	1.85	2.12
$R^2 adjusted$	0.99	0.99	0.99	0.99

Note: *t-ratios in brackets*

Table 4. Percentage of total labour productivity explained by Q and Z

Country	Period	Total Labour Productivity	Explained by Q	Explained by Z	Explained by other inputs
UNITED KINGDOM	1997:1-2004:1	100 %	52 %	22 %	26 %
INDIA	1996:2-2009:2	100 %	26 %	45 %	29 %
AUSTRALIA	1997:1-2004:1	100 %	45 %	17 %	38 %
CYPRUS	1995:1-2007:4	100 %	39 %	52 %	9 %
SOUTH AFRICA	1997:1-2004:1	100 %	42 %	25 %	33 %
NEW ZEALAND	1997:1-2004:1	100 %	55 %	28 %	17 %
CANADA	1993:1-2008:3	100 %	66 %	29 %	5 %
MALAYSIA	1998:1-2009:3	100 %	35 %	49 %	16 %

Table 5. Percentage of total growth explained by Q and Z

Country	Period	Total Growth	Explained by Q	Explained by Z	Explained by labour and others
UNITED KINGDOM	1997-2004	100 %	61 %	26 %	13 %
INDIA	1996-2009	100 %	17 %	30 %	53 %
AUSTRALIA	1997-2004	100 %	37 %	14 %	49 %
CYPRUS	1995-2008	100 %	29 %	38 %	33 %
SOUTH AFRICA	1997-2004	100 %	41 %	24 %	35 %
NEW ZEALAND	1997-2004	100 %	46 %	24 %	30 %
CANADA	1993-2008	100 %	64 %	28 %	8 %
MALAYSIA	1998-2009	100 %	36 %	51 %	13 %

Concluding remarks

Looking Figures 1 to 8, we can observe that in all countries between 1990 and 2007 the level of the endogenous technical progress, coming from new technologies, is rising, whereas the neutral technical progress is in general decreasing in near all countries, as it is mentioned by Hobijn (2000) for the USA data, with the exceptions of India where the disembodied technical progress does not diminishe, and in Malaysia during the period 2002-2007. After 2007 we can observe in some figures how decrease the labour productivity and Q. In other hand, during the considered period (Gobalisation wave) in the more developed economies, UK, Australia, New Zealand and Canada, the embodied technical progress (Q) growth rate is always more high than the disembodied technical progress (Z). A great part of the total growth is explained by the endogenous technical progress Q in all countries of the sample, with the exceptions of Cyprus and India. The impact of Q on labour productivity is similar than in total growth.

The empirical results coming from the econometric model indicate that the embodied technological progress (Q), that is, the investment in quality capital, is responsible of the total labour productivity growth rate during the considered period in the following manner: In United Kingdom 52 %, India 26 %, Australia 45 %, Cyprus 39 %, South Africa 42 %, New Zealand 55 %, Canada 66 %, and Malaysia 35 %. The participation of the disembodied technological progress (Z), coming from the old technologies, on the labour productivity, in the same period is in the United Kingdom 22 %, India 45 %, Australia 17 %, Cyprus 52 %, Soth Africa 25 %, New Zealand 28 %, Canada 29% and Malaysia 49 %. In the other hand, with respect to the total economic growth rate, Q is responsible of the 61 % in the United Kingdom, 17 % in India, 37 % in Australia, 29 % in Cyprus, 41 % in South Africa, 46 % in New Zealand, 64 % in Canada, and 36 % in Malaysia. The participation of the disembodied technological progress (Z) in the same period on total economic growth rate was 26 % in the United Kingdom, 30 % in India, 14 % in Australia, 38 % in Cyprus, 24 % in South Africa, 24 % in New Zealand, 28 % in Canada, and 51 % in Malaysia. The participation of the labor (L) and the other no technological production factors in the total economic growth rate was 13 % in the United Kingdom, 53 % in India, 49 % in Australia, 33 % in Cyprus, 35 % in South Africa, 30 % in New Zealand, 8 % in Canada, and 13 % in Malaysia, during the considered periods.

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Appendix 1: Jelly capital accumulation

Defining $J_t = K_t \cdot Q_{t+1}$ and $J_{t+1} = K_{t+1} \cdot Q_{t+2} = K_{t+1} \cdot (Q_{t+1} + \Delta Q_{t+1})$, and considering the main equation of physical capital accumulation: $K_{t+1} = (1-\delta)K_t + I_t$, if we multiply both members of this last equation by Q_{t+1}, we can obtain

$$K_{t+1} \cdot Q_{t+1} = (1-\delta)K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{39}$$

and hence:

$$J_{t+1} - K_{t+1} \cdot \Delta Q_{t+1} = (1-\delta) K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{40}$$

but we can write $K_{t+1} = K_t + \Delta K_t$, being $K_t = \sum_{t=1}^{t} (\Delta K_t) = \vartheta \cdot \Delta K_t$ for $\vartheta > 1$. Then, the value of ΔK_t will be: $\Delta K_t = K_t/\vartheta = \Psi K_t$, where $\Psi = 1/\vartheta$, for $0 < \Psi < 1$. Therefore we have that: $K_{t+1} = K_t + \Psi K_t = (1+\Psi)K_t$ and hence $K_{t+1} = \eta K_t$ where $\eta = 1 + \Psi$. In the same sense, we have that $Q_{t+1} = \sum_{t=1}^{t} (\Delta Q_{t+1}) = \nu \cdot \Delta Q_{t+1}$ for $\nu > 1$, and therefore we will have $\Delta Q_{t+1} = \rho Q_{t+1}$, for $\rho = 1/\nu$. Substituting these results in the equation 17, we have

$$J_{t+1} - \eta\rho K_t \cdot Q_{t+1} = (1-\delta) K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{41}$$

and hence

$$J_{t+1} = [1 - (\delta - \eta\rho)] K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{42}$$

Calling now $\delta - \eta\rho$ as δ^*, and considering that $J_t = K_t \cdot Q_{t+1}$, we can write now

$$J_{t+1} = (1-\delta^*) J_t + I_t \cdot Q_{t+1} \tag{43}$$

where δ^* denotes the depreciation rate concerning to both types of capital: jelly and physical.

Appendix 2: Golden rule and vintage capital

Considering the expression [4], normalizing labour, and knowing that $Q_{t+1} = (1+\gamma)Q_t + \varepsilon_t$, we can express the production function [8] as follows

$$Y_t = Z_t \cdot J_t^{\alpha} \cdot L_t^{(1-\alpha)} = [(1+\gamma)^{\alpha} \cdot Q_t^{\alpha} \cdot Z_t] \cdot K_t^{\alpha} \cdot L_t^{(1-\alpha)} \tag{44}$$

that is, the production function can be expressed as a neoclassical Cobb-Douglas: $Y_t = A_t \cdot K_t^{\alpha} \cdot L_t^{(1-\alpha)}$, where now the total factor productivity is A_t, which embodies both technical progresses: neutral (Z_t) and embodied (Q_t):

$$A_t = (1+\gamma)^{\alpha} \cdot Q_t^{\alpha} \cdot Z_t \tag{45}$$

Following the neoclassical growth model for a closed economy where there exist technical progress, the equation of the steady-state equilibrium can be written as

$$s \cdot Y_t = (n + \delta^* + \frac{dA}{A}) \cdot K_t \tag{46}$$

where s is the saving rate. From expression [45] we can deduce the growth rate of A_t:

$$\frac{dA_t}{A_t} = \frac{dZ_t}{Z_t} + \alpha \frac{dQ_t}{Q_t} \tag{47}$$

but knowing that $\frac{dQ_t}{Q_t} = \gamma$, and so-calling $\frac{dZ_t}{Z_t}$ as g, the equation for the steady-state in this particular case could be expressed as

$$s \cdot Y_t = (n + \delta^* + g + \alpha\gamma) \cdot K_t \tag{48}$$