VINTAGE CAPITAL AND ECONOMIC GROWTH*

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Abstract. The productivity generated by capital goods is not uniform, especially across the time, because productivity obtained from physical goods is minor than one generated by new capital goods, or quality capital goods. It seems that the difference between both kinds of capital stems from the fact that vintage capital is affected by an additional form of technical progress. When capital is affected by this kind of technical progress is so-called, from Solow (1960), as capital jelly. There are, hence, two possible forms to understand technical progress: the classical one or, alternatively, this new class of technical progress that affects only to capital. Both kinds of technical progress affect the economic growth in two separated ways, and for this reason it is interesting to develop a special analysis on the investment in capital goods in order to identify the difference between productivity derived from physical and from vintage capital. The main aim of this paper is to analyze how two types of technical progress can affect the real income growth rate in countries belonging to three world areas: The Eueopean Union with 15 members, the Pacific Rim, and North-America. Keywords: Growth, Quality capital, Endogenous technical progress, World economic areas, Investment, Neutral technical progress.

1 Introduction

The productivity generated by capital goods is not uniform, specially over the time. With physical capital goods the productivity obtained is minor that the one generated by "new" capital goods or quality capital goods. For this reason can be interesting to develop a special analysis on the investment in capital goods in order to identify what is the difference between the productivity derived from physical capital and from vintage capital. It seems that the difference between both kinds of capital stems from the fact that vintage capital is affected by an additional form of technical progress. From Solow (1990), when capital is affected by this kind of technical progress, it is so-called capital jelly. From that point of view, there are two possible forms of understand technical progress. The classical one, assuming generally a Hicks neutral technical progress, which affect all production factors, or alternatively this new class of technical progress, that could be called endogenous, and that affects only to capital. In this sense, the main purpose of the present

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work is to evaluate how this new type of technical progress can impact on economic growth and productivity.

Precursory works of the present research have found, in one hand, in Solow (1956), (1960) and Johansen (1959), (1966). By the other hand, more recent discussions have been cause of new basic references such as Hulten (1992), Greenwood, Hercowitz and Krusell (1997), Gordon (1999) and Hobijn (2000). Solow(1956) and Jorgenson (1966) assumed that the bigger part of technological change is not embodied in the capital accumulation process. 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 better resources market organization at an entrepreneur level. 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.

However, Solow (1960) pointed out that this hypothesis was in contradiction with a simple observation: the bigger part of technological innovations, that is, the bigger part of technological progress embodied in the investment in capital goods, generates effects over the efficiency and the productivity of the economy. This mind that the bigger part of technological progress came from the fact of to be embodied by the firms by means of the acquisition or capital accumulation.

As it has been pointed out the study, the quality embodied in economic growth came associated to the analysis and identification of what fraction of the increase in labor productivity is neutral or independent of the accumulation process and what fraction is tied to the massive investment processes in quality technologies. The issue of this debate is to know what part of the investment processes in capital goods and new technologies determines technical progress. That carries along to analyze which are the effects of the two form of technical progress, neutral or the embodied directly when capital is accumulated, on economic growth and on other relevant macroeconomic variables.

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 measure results indicate that investment is not really comparable over time. A reason seems to be 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 them comparable, it would be necessary to adjust the quality or productivity of the investment goods. Under this approach it would be necessary to measure the quality in a form related with some relative price indices, that is, as hedonic price indices. This would require to control all quality changes. Gordon (1990), (1999) and Herman (2000) builded a series of production price indices adjusted by quality, based in National Accounts investment data. From National Accounts we have data on investment in nominal terms and also about the number of units of investment goods installed. A problem presented is that this form to measure investment en real terms is not really comparable over time.The reason is that 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 over time. To make comparable those investment goods is necessary then to adjust the measure by this change in the productivity.We would like to have information about the path of the quality improvements of capital goods, measuring the evolution of quality and productivity of the several capital goods. That will allow us to obtain an investment price index, $P_{i,t}$, which satisfies 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, and hence this index allows to measure real investment ($I_t \cdot Q_t$) in constant quality units. How we really don't know what exactly one unit of capital good means, it is convenient to define I_t in units of consumption good terms. 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, which allows that Q_t can be written as

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

A new problem appears because the elaboration of $P_{i,t}$ requires to have control over changes in quality. Hence, 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 quality dimensions of various investment goods and then estimate how much relative price fluctuations of investment goods can be attributed to the fluctuations in these quality indices. In other words we could identify the contribution that the accumulation of capital goods have on technical progress. This could be done through regressions that allows to compute the hedonic prices. Gordon (1990) and Cummins and Violante (2002) 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 measuring different dimensions of quality improvements which may lead an spurious measurement of the embodied technical change. On the other hand, if some of the quality dimensions that have actual effect are not included, this might lead that 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 availability of the aggregation level. For the reasons stated it could be more interesting consider methods that allow a measurement of Q_t without using 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 two we will use a strategy based in a structural approach which contains a vintage capital growth model. Section three contains the results of the application of this model on a sample which contains data concerning to the nine most important OECD countries. Main conclusions are in the last section.

2 A vintage capital growth model

To evaluate the impact of the quality of investment we will follow then 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 will be 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 capital and the aggregate capital stock by K_t, we can have

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

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 it is called from Solow (1960) as jelly capital (J_t). Assuming the value of the additional productivity such 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 (1), we can obtain[a]:

[a]See Apendix 1

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

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

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

In other sense, following Benhabib and Rustichini (1993), the dynamic optimality condition requires that in every period the marginal disutility from saving should be equal the expected present discounted value of the future marginal products of the investment. As a consequence of this optimization we have that

$$\Phi = \frac{J_t}{Q_t \cdot Y_t}, \forall t \quad (8)$$

being Φ a parameter related with the real interest rate and the intertemporal discount rate. Substituting this in the above formulation and dividing it by the GDP at period t (Y_t) and *t+1*, (Y_{t+1}), once known the depreciation rate of capital (δ), we have

$$\frac{I_t}{Y_t} = \frac{J_{t+1} \cdot Y_{t+1}}{Q_{t+1} \cdot Y_{t+1} \cdot Y_t} - (1-\delta^*)\left(\frac{J_t}{Q_t \cdot Y_t}\right)\left(\frac{Q_t}{Q_{t+1}}\right) \quad (9)$$

and hence

$$\frac{I_t}{Y_t} = \Phi\frac{Y_{t+1}}{Y_t} - \left[\Phi \cdot \left(\frac{Q_t}{Q_{t+1}}\right)\right](1-\delta^*) \quad (10)$$

where in this relation-ship the term $\frac{I_t}{Y_t}$ appears as an endogenous variable and $\frac{Y_{t+1}}{Y_t}$ is an explanatory variable. Last term of equation appears as an independent term because still we do not known δ^*. Regressing then this equation, we can estimate Φ as $\widehat{\Phi}$, and hence, we can isolate the vintage technical progress growth rate series

$$\frac{\Delta Q_t}{Q_t} = \frac{Q_{t+1}}{Q_t} - 1 = \frac{1-\delta^*}{\frac{Y_{t+1}}{Y_t} - \frac{1}{\widehat{\Phi}}\left(\frac{I_t}{Y_t}\right)} - 1 \tag{11}$$

Notwithstanding, an important identification issue that remains from the above equation, is that we cannot separately identify 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, the countries of the sample are the main OECD countries and hence, we will take δ as the depreciation rate. To obtain this we will rearrange the equation 1

$$(1-\delta^*) = \frac{K_{t+1}}{K_t} - \frac{I_t}{K_t} \tag{12}$$

where for I_t we use is real fixed private non-residential investment. Substituting this last result into the equation 11, we can approximately isolate the path of the endogenous technical progress Q_t growth rate

$$\frac{\Delta Q_t}{Q_t} = \frac{Q_{t+1}}{Q_t} - 1 = \frac{\frac{K_{t+1}-I_t}{K_t}}{\frac{Y_{t+1}}{Y_t} - \frac{1}{\widehat{\Phi}}\left(\frac{I_t}{Y_t}\right)} - 1 \tag{13}$$

and also

$$\frac{Q_t}{Q_{t+1}} = \frac{\frac{Y_{t+1}}{Y_t} - \frac{1}{\widehat{\Phi}}\left(\frac{I_t}{Y_t}\right)}{\frac{K_{t+1}-I_t}{K_t}} \tag{14}$$

It seems important to compare the path of the endogenous technical progress Q_t growth rate with the path of the exogenous technical progress A_t growth rate, which affects directly the production function. In this sense, we assume that the aggregate real output Y_t can be produced by means of the following process

$$Y_t = A_t \cdot J_t^{\alpha} \cdot L_t^{(1-\alpha)} \tag{15}$$

Figure 1a. E-15 Technical Progress: Embodied Q (q) and Neutral Z (zeda)

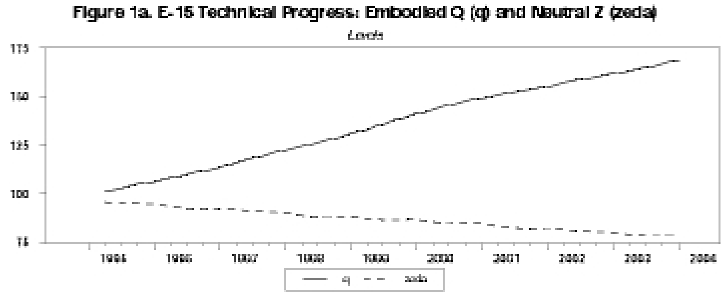
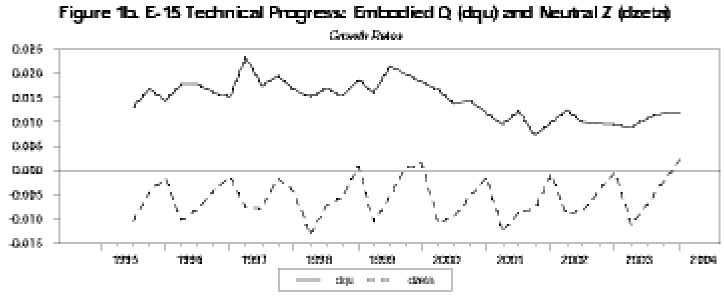


Figure 1b. E-15 Technical Progress: Embodied Q (dqu) and Neutral Z (dzeta)



where L_t is the labor supply, J_t is the jelly capital affected by a vintage specific Q_t, and A_t is the level of a Hicks neutral disembodied technological progress. At the same time we can express $Y_{t+1} = A_{t+1} \cdot J_{t+1}^{\alpha} \cdot L_{t+1}^{(1-\alpha)}$. Dividing this last expression between 15, we have

$$\frac{Y_{t+1}}{Y_t} = \frac{A_{t+1} \cdot J_{t+1}^{\alpha} \cdot L_{t+1}^{(1-\alpha)}}{A_t \cdot J_t^{\alpha} \cdot L_t^{(1-\alpha)}} \tag{16}$$

We will assume that the labor supply is inelastic and grows at a constant rate n. Normalizing the labor supply in period zero to one, this implies that the total labor supply equals $L_t = (1+n)^t$. Substituting this result into the equation 16, and considering the equation 8, we can obtain

$$\frac{Y_{t+1}}{Y_t} = \frac{A_{t+1}}{A_t} \left(\frac{Q_{t+1}}{Q_t} \right)^{\alpha} \left(\frac{Y_{t+1}}{Y_t} \right)^{\alpha} (1+n)^{(1-\alpha)} \tag{17}$$

Taking Neperian logarithms in this expression we have

$$\ln \frac{Y_{t+1}}{(1+n)Y_t} = \left[\frac{1}{1-\alpha} \cdot \ln \left(\frac{A_{t+1}}{A_t} \right) \right] + \frac{\alpha}{1-\alpha} \cdot \ln \left(\frac{Q_{t+1}}{Q_t} \right) \tag{18}$$

Figure 2a. Japan Technical Progress: Embodied Q (q) and Neutral Z (zeda)

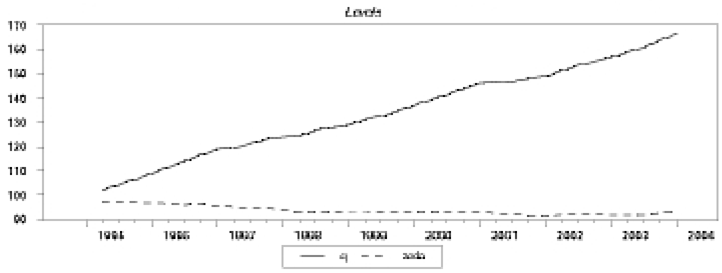


Figure 2b. Japan Technical Progress: Embodied Q (dqu) and Neutral Z (dzeta)

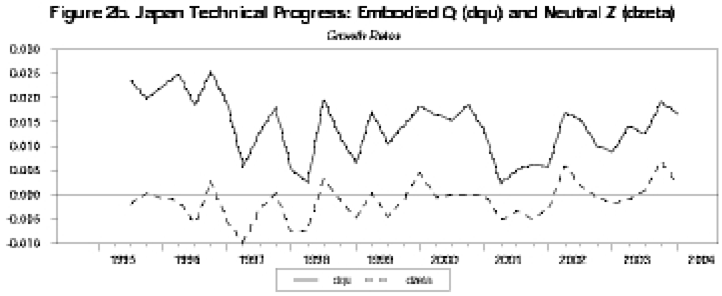


Figure 3a. Australia Technical Progress: Embodied Q (q) and Neutral Z (zeda)

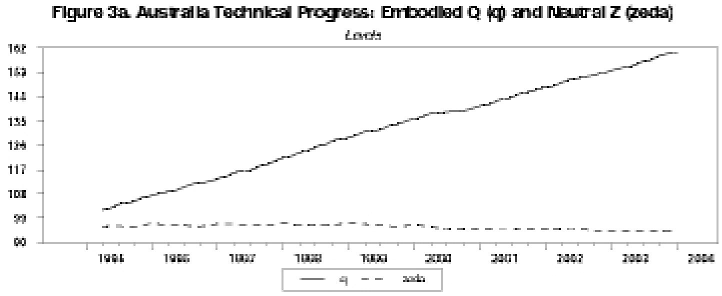
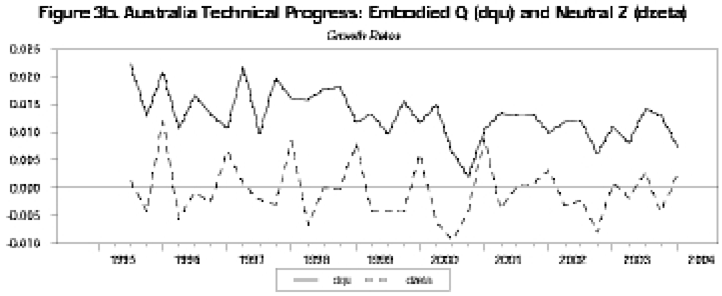


Figure 3b. Australia Technical Progress: Embodied Q (dqu) and Neutral Z (dzeta)



and regressing this equation, we can estimate the parameter α as $\widehat{\alpha}$. Substituting this value in 17 we can isolate the disembody factor productivity growth rate

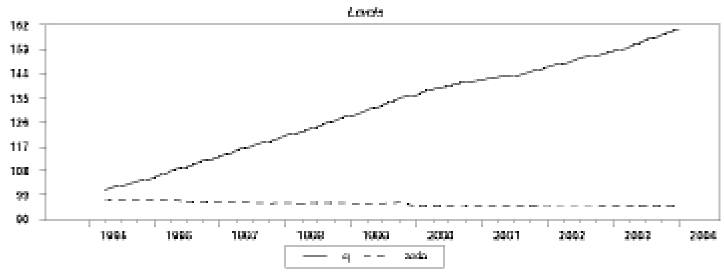


Figure 4a. USA Technical Progress: Embodied Q (q) and Neutral Z (zeda)

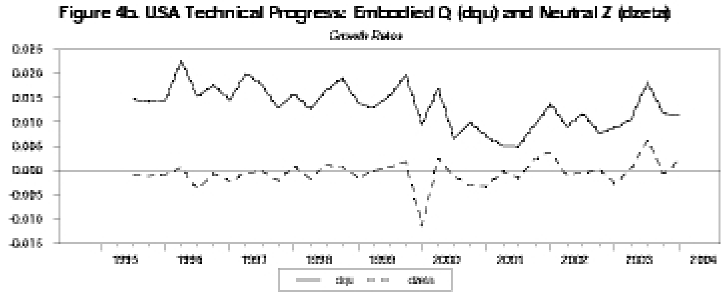


Figure 4b. USA Technical Progress: Embodied Q (dqu) and Neutral Z (dzeta)

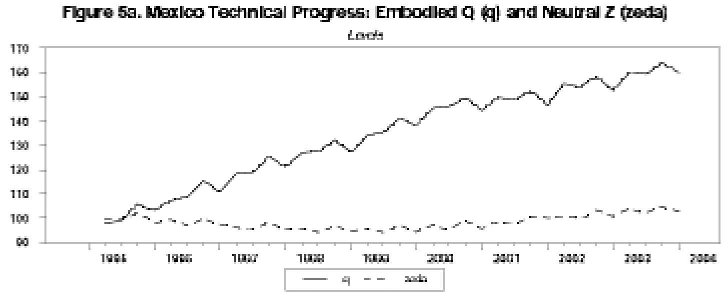


Figure 5a. Mexico Technical Progress: Embodied Q (q) and Neutral Z (zeda)

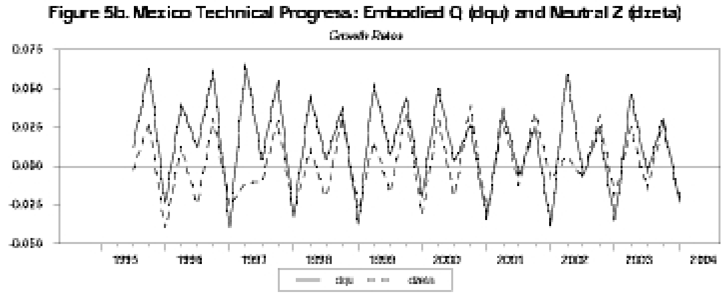


Figure 5b. Mexico Technical Progress: Embodied Q (dqu) and Neutral Z (dzeta)

$$\frac{\Delta A_t}{A_t} = \left(\frac{Y_{t+1}}{Y_t}\right)^{(1-\widehat{\alpha})} \left(\frac{Q_t}{Q_{t+1}}\right)^{\widehat{\alpha}} \left(\frac{1}{1+n}\right)^{(1-\widehat{\alpha})} - 1 \qquad (19)$$

Comparing expressions 13 and 19 we can see the two different growth paths of the technical progress, embodied (13) and disembodied (19). In the following paragraphs we will compare empirically this trajectories join the paths of other relevant macroeconomic variables, in special employment, to observe the macroeconomics effects of the quality investment.

3 Data and empirical results

This theoretical model has been applied across the 19 OECD countries, which reflect three world areas: The European Union with 15 countries, the Pacific Rim with two representative countries (Japan and Australia), and North America represented by two countries (USA and Mexico). In total is represented near of the 95% of the total GDP of OECD. The analysis has been made with data come from OECD statistics, and it has been applied from 1995 to 2004, with monthly data.

After apply VAR techniques, the main results indicate that in those countries between 72% to 74% of the economic growth is explained by the endogenous technical progress (Q), an also with the same ratio is explained the real per capita income growth rate, whereas the neutral technical progress (A) only explain between 26% to 27% of the economic growth in each country.

Concluding remarks

Looking the Tables 1, 2, 3, 4 and 5, we can observe that in all countries between 1995 and 2004 the endogenous technical progress, coming from new technologies, is rising, whereas the neutral technical progress is always decreasing in all countries, with the only exception of Mexico. This can be caused because Mexico, although member of the OECD, is an emerging country. However, in all these countries a great part of growth is explained by the endogenous technical progress: 73.9% in E-15, 73,0% in Japan, 72.7% in Australia, 72.7% in USA, and 72.5% in Mexico.

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Appendix

We can insert an appendix here and place equations so that they are given numbers such as Eq. (20).

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

$$K_{t+1} \cdot Q_{t+1} = (1-\delta)K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{20}$$

and hence:

$$J_{t+1} - K_{t+1} \cdot \Delta Q_{t+1} = (1-\delta)K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{21}$$

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

$$J_{t+1} - \eta\rho K_t \cdot Q_{t+1} = (1-\delta)K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{22}$$

and hence

$$J_{t+1} = [1 - (\delta - \eta\rho)]K_t \cdot Q_{t+1} + I_t \cdot Q_{t+1} \tag{23}$$

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

$$J_{t+1} = (1-\delta^*)J_t + I_t \cdot Q_{t+1} \tag{24}$$

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