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GROWTH AND TECHNOLOGY

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ÖZET

BÜYÜME VE TEKNOLOJİ

Son yıllara kadar büyüme teorilerinde teknolojik ilerleme, dışarıdan verili ve maliyeti olmayan önemli bir faktör olarak ele alınmaktaydı. Yeni büyüme teorilerinin gelişmesiyle neoklasik büyüme teorisinin uzun süren üstünlüğü sona erdi. Yeni büyüme teorilerinde, üretkenliğin ve sermaye başına gelirin büyüme oranı içsel olarak açıklanmaktadır. Bu teorinin neoklasik büyüme teorilerine yönelik temel eleştirisi, neoklasik teoride büyüme oranının dışsal belirleyicilere bağlanmasıdır. Aslında ampirik çalışmalar teknolojinin organizasyonlara, bilgiye, firmalar ve çevresi arasındaki ilişkiye, ülkeye özel faktörlere ve toplumsal özelliklere bağlı olduğunu göstermiştir. Bu çalışma, büyüme teorilerinin teknolojiye bakış açılarını dikkate alan bir literatür taramasından ve Avrupa birliğine üye 10 ülkeden oluşan bir örneklem için büyüme muhasebesi uygulamasından oluşmaktadır. Büyüme muhasebesini kullanarak yapılan statik panel veri tahmininin sonuçları, ortalama olarak gayri safi yurt içi hasıladaki artışın %75'inin teknolojik ilerlemeden kaynaklanmakta olduğunu göstermektedir.. Teknolojik değişimi ekonomik büyümenin ana belirleyicisi olarak bulan büyüme muhasebesinin temel başarısı, neoklasik büyümenin teorik zayıflıklarını göstermesidir. Ampirik analizlerin bir çok soru işareti oluşturmasına rağmen, endojen büyüme modelleri, neoklasik büyüme modellerine göre daha zengin bir çalışma alanı sağlamaktadır ve şimdi eski yıllara göre büyümenin faktörleri hakkında daha fazla bilgiye sahibiz.

GENERAL KNOWLEDGE

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ABSTRACT

GROWTH AND TECHNOLOGY

Until recently in the growth theory, technological progress had been treated as something given from the outside and as an important factor which has no cost. With the rise of the new growth theory, the long dominance of neoclassical growth theory has been ended. Within the framework of new growth theories, the rates of growth of productivity and per capita income are endogenously explained. Their main criticism of neoclassical growth theory is attributing growth rates to exogenous determinants. In fact, many empirical works has shown that technology depends on organizations, tacit and cumulative knowledge, interaction between firms and environments, country specific factors and social capabilities. This study consists of a literature review of growth theories in terms of the technological view and a growth accounting application for the sample of 10 of the EU15 countries. By using growth accounting method, the static panel data estimation results indicate that on average 75 percent of the rise in gross domestic product can be attributable to technical progress. The major merit of the growth accounting approach which found the main determinant of economic growth as technological change is showing the theoretical weaknesses of the neoclassical growth theory. Even though empirical analyses open many questions, endogenous growth models provide a richer framework for the growth theory than the neoclassical model and we have much more knowledge about the factors of growth than before.

ACKNOWLEDGEMENTS

It is apparent that some countries have faster growth rates than the others. From the classical economists to the new growth economists, understanding the process of economic growth was the main aim and the role of technological change has been always crucial to explain this process. This study reviews the growth literature in the view of technology and requires panel data estimation for growth accounting approach.

Some people helped me in different contexts for this study. Needless to say, the most important of them is my supervisor, Professor Fatma Doğruel who helped me in almost every aspects of the material produced in this study. Also Professor Suut Doğruel from Marmara University helped me during the process of panel data estimation. They discussed with me almost all aspects of this thesis. I would like to express my thanks both of them for their helps. Finally, I want to express my special thanks to my husband who supported me in every step of this study.

İstanbul, 2004 Fatma Didin

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INTRODUCTION

From the classical economists to the new growth economists, understanding the process of economic growth was the main aim. The question "What determines the rate of growth?" has always been central to the economists. It is apparent that some countries have faster growth rates than others. The role of technological change has been always crucial to explain these differences in growth rates.

Classical economists, such as Adam Smith, David Ricardo and Karl Marx provided many of the basic concepts that are used in modern theories of economic growth. For instance; competitive behavior, diminishing returns and its relation to the accumulation of capital, per capita income and the growth rate of population are the basic approaches which are used by classical economists. They have discussed differences in growth rates across the countries extensively but their main focus was not on the technology. In the classical growth theories, the effects of technological change are in the forms of discoveries of new goods, innovation in production methods and increase in specialization of labor.

Smith (1776) used a supply side driven model of growth. Output growth is a function of population growth, investment growth, land growth and overall productivity. According to him improvements in machinery are the main source of specialization which improves growth. Ricardo (1817) modified the Smith growth model by using diminishing returns to land. He believed that diminishing returns can be eliminated by technological improvements and specialization. The other famous classical economist, Marx, argued that technological progresses in the form of machinery or division of labor are not beneficial ways of improving growth. It creates the technological unemployment and wages will decline. Also technological improvement is a way of alienation of the working class.

After the classical models, Harrod (1939) and Domar (1946) attempted to analyze the elements of economic growth by using Keynesian model and they did not focus on technology. They argued that the capitalist system is inherently unstable. Harrod and Domar advocated that the only stable growth path is where the real growth rate is equal to warranted growth rate permanently. Any shock that will lead to deviate from this path will cause moving further away from it. Thus "knife-edge" means that the steady-state growth path is unstable.

In contrast to Keynesian growth theory, the neoclassical growth model developed by Solow (1956) and Swan (1956) generated a simple general equilibrium model of the economy. They argued that in the long-run all the equilibrium variables such as gross domestic product, the capital stock and the labor grow at the same exogenously determined rate. The technological progress which allows the long-run growth in GDP per capita is an exogenous variable.

The recent empirical studies indicate that technological change is not exogenous and there are some country specific factors which affect this variable. Arrow (1962) and some other authors developed vintage models by changing Solow assumptions. This is one of the first attempts to provide endogenized technological progress. Uzawa (1965) introduced the technology producing sector and according to him technical advance comes from a sector which produces new ideas and innovation.

After the 1980s, there were some works in which the long-run growth rate are determined within the model and they are called as endogenous growth models. These new growth models beginning with the work of Romer (1986) and Lucas (1988) built on the work of Arrow (1962) and Uzawa (1965). The theory of endogenous growth helps to explain the existence of technological progress which the neoclassical growth model takes as given. Also it provides more realistic R&D description.

Also in 1980s some models are developed to explain the importance of technology for the international competitiveness. Fagerberg (1988a) suggested that international competitiveness and growth are mainly affected by technological competitiveness and ability. Many empirical studies have proved this positive relation.

After the review of all growth theories in terms of the technological view, I analyzed the some European countries by using static panel data model to measure the effects of technology on growth rate of gross domestic product. I found that on average, 75 percent of the increase in growth rate of GDP is attributable to technical progress.

The aim of this paper is to review the growth literature in terms of the technological view and it is outlined as follows. Section 1 includes the basic neoclassical growth model and convergence hypothesis. Also in this section growth accounting and vintage models are discussed and the criticisms of the neoclassical growth model are represented. Section 2 outlines the theoretical model of international competitiveness and its empirical studies. Section 3 has a model of endogenous growth and the shortcomings of this theory. Additionally this section includes a brief summary of relationship between R&D, patent and technological change. Section 4 examines the European growth performance and technological change, and I conducted a growth accounting analysis for some European countries. Finally the conclusion is presented in Section 5.

1. THE NEOCLASSICAL GROWTH MODEL

In the Harrod-Domar growth model, steady state growth was unstable. However, Solow (1956) and Swan (1956) claimed that the capital output ratio of Harrod-Domar model is not exogenous. This model is called "Solow-Swan" or simply neoclassical growth model. The macroeconomic equilibrium condition is:

$$i = sy \tag{1.1}$$

where $i = I/L$ and $y = Y/L$. I is the investment, L is the labor, Y is aggregate supply.

Also the general form of the production function is:

$$Y = F(K, L) \tag{1.2}$$

By using the assumption of constant returns to scale, we can rewrite this equation as:

$$Y/L = F(K/L, 1) = f(k) \tag{1.3}$$

As a result, the macroeconomic equilibrium condition is:

$$i = sf(k) \tag{1.4}$$

At any k, we can derive investment per person, i, output per person, y.

Figure 1 demonstrates the intensive production function $y = f(k)$ and the actual investment function, $i = sf(k)$. Unlike the Harrod-Domar model, capital-output ratio is not exogenously fixed in the Solow model. Changing k will change the capital-output ratio (v).

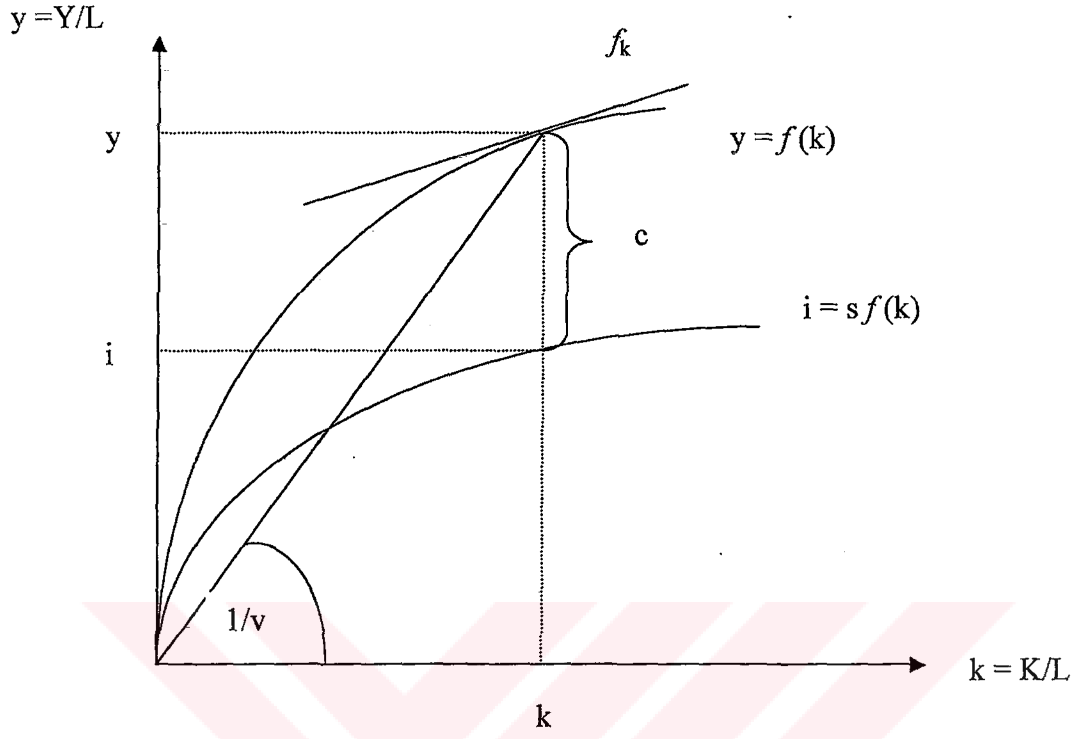

Figure 1 - Intensive Production Function

In the Solow model, population grows exogenously, at the rate n:

$$g_L = (dL/dt)/L = n \qquad (1.5)$$

To keep capital-labor ratio, $k = K/L$, steady, capital must grow at the rate n:

$$g_K^r = (dK/dt)/K = n \qquad (1.6)$$

where g_K^r is called the required growth rate of capital.

If investment is defined as $I = dK/dt$, we can rewrite this as follows:

$$I^r = nK \qquad (1.7)$$

Dividing through by labor we can obtain,

$$i^r = nk \qquad (1.8)$$

where i^r is the required investment per person to maintain a steady k.

Figure 2 depicts the stable capital-labor ratio, k^*. This is also called the steady-state capital-labor ratio. Only at k^*, actual investment is equal to required investment, $i = i^r$.

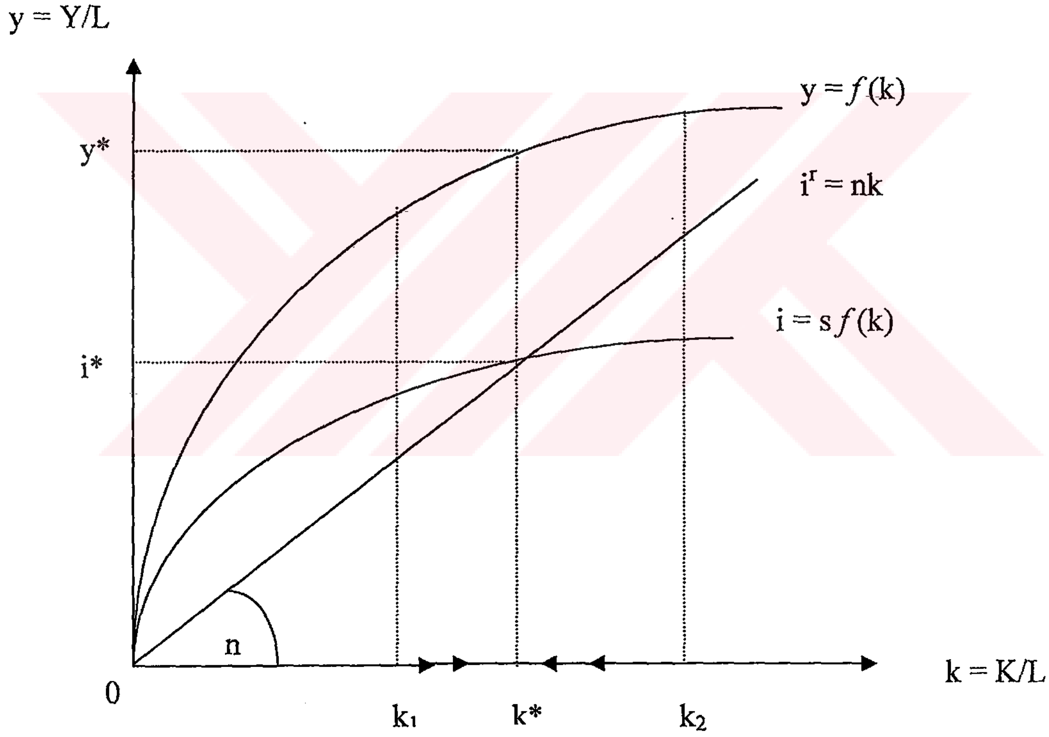

Figure 2 - Steady-State Growth

In terms of the differential equations:

$$dk / dt = i - i^r \qquad (1.9)$$

$$dk / dt = sf(k) - nk \qquad (1.10)$$

If we insert depreciation into the model we see that the macroeconomic condition (1.4) is same but required rate of investment is different. So in order to keep k as constant, capital must grow not only to cover population growth but also to cover the depreciation of old capital:

$$i^r = (n+\delta)k \qquad (1.11)$$

So the fundamental Solowian differential equation illustrated in figure 3 can be rewritten as:

$$dk/dt = sf(k) - (n+\delta)k \qquad (1.12)$$

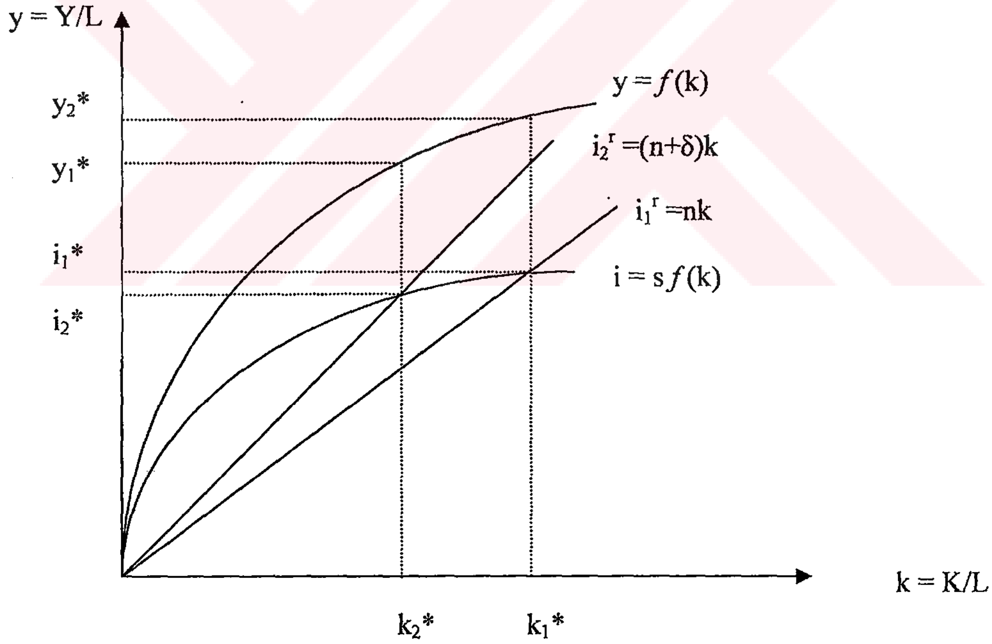

Figure 3 - Steady-State Growth with Depreciation

1.1 Technological Progress and Solow–Swan Growth Model

According to Solow-Swan growth model, capital-labor ratio, output per person and consumption per person remain constant. But the capital-labor and output–labor ratios have been rising over time. To allow for this growth, Solow added an exogenous term which is called "technological progress".

The growth of output can be explained by changes in capital (K), changes in labor (L) and changes in productivity growth which is called technical progress (F (.)). If technical progress has been raised repeatedly over time, capital-labor ratio will continue to rise.

There are various types of "technical progress" in a production function. One of them is Harrod-neutral or labor-augmenting technical progress. Only Harrod-neutral technical progress keeps the capital-output ratio, v, constant over time. By using effective labor ($A(t)L$), Solow-Swan growth model can be converted to the Harrod-neutral model:

$$Y = F\left(K, A(t)L\right) \tag{1.13}$$

We can rewrite this equation as:

$$Y / AL = F\left(K / AL, 1\right) \tag{1.14}$$

In intensive form:

$$y^e = f\left(k^e\right) \tag{1.15}$$

where y^e is the output-effective labor ratio and k^e is the capital-effective labor ratio.

Also the macroeconomic condition $\left(I = sY\right)$ can be written as follows:

$$I / AL = sY / AL \Rightarrow i^e = sy^e = sf\left(k^e\right) \tag{1.16}$$

where i^e is the investment-effective labor ratio.

If the population growth rate is n and labor-augmenting technical shift factor A grows at the rate θ, effective labor growth rate will be:

$$g_{AL} = g_A + g_L = \theta + n \tag{1.17}$$

For steady-state growth, capital must grow at this rate. Thus we have

$$I^r = dK / dt = (\theta + n) K \tag{1.18}$$

where I^r is the required investment level. Dividing through by AL we can obtain,

$$i^{re} = (\theta + n) k^e \tag{1.19}$$

where i^{re} is the required rate of investment per unit of effective labor.

In differential terms we can write as follows:

$$dk^e / dt = i^e - i^{re} \tag{1.20}$$

If we substitute (1.16) and (1.19) into (1.20) we obtain,

$$dk^e / dt = sf(k^e) - (n + \theta) k^e \tag{1.21}$$

At the steady-state $dk^e / dt = 0$. Also output, consumption and capital grow at the rate "$n+\theta$". Population grows at the rate n, but other variables grow at the rate "$n+\theta$". Thus, output per person and consumption per person grows at the rate of technical progress.

1.2 Convergence Hypotheses

There are two types of convergence hypotheses of the Solow-Swan model. Both two hypotheses suggest the same growth rates for all countries but in the conditional convergence hypothesis it is not necessary to be at the same steady state capital-labor ratio.

1.2.1 Absolute Convergence

If countries which have the same technology, same population and the same saving propensity differ in terms of their initial capital-labor ratio, they will converge to the same steady-state capital-labor ratio, and same growth rate[1]. (Barro and Sala-i-Martin, 2003)

Since the marginal product of capital relative to labor is higher in the poor nations then in the rich ones, the poor nations will accumulate more capital and grow at a faster rate than the rich nations. As a result, the poor country will grow relatively fast while the rich nation will grow slowly. Hence, the gaps in income level between rich and poor countries are expected to be disappearing. But this holds unrealistic assumptions. Actually countries may have very different saving propensities, technological possibilities and population growth rates.

So the neoclassical model of economic growth argued that in the long run, for all countries GDP per capita will grow at the same exogenously determined rate of technological progress.

1.2.2 Conditional Convergence

Conditional convergence hypothesis argued that the countries which have the same technology and population growth rates, even if they have different savings propensities and initial capital-labor ratio, should converge to the same growth rate. It is important to point that in this type of convergence, it is not necessary to converge at the same capital-labor ratio. (Barro and Sala-i-Martin, 2003)

If a rich economy has a higher saving rate than a poor economy, the rich economy may be proportionately further from its steady-state. Thus the rich economy grows faster per capita than the poor economy. In this case absolute convergence will

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[1] Figure 2 illustrates this type of convergence.

not hold. Figure 4 illustrates the convergence speed of two different economies which have the different saving rates. In this figure the rich economy has a higher saving rate, then $\left(\dot{k}/k\right)_{poor} < \left(\dot{k}/k\right)_{rich}$.

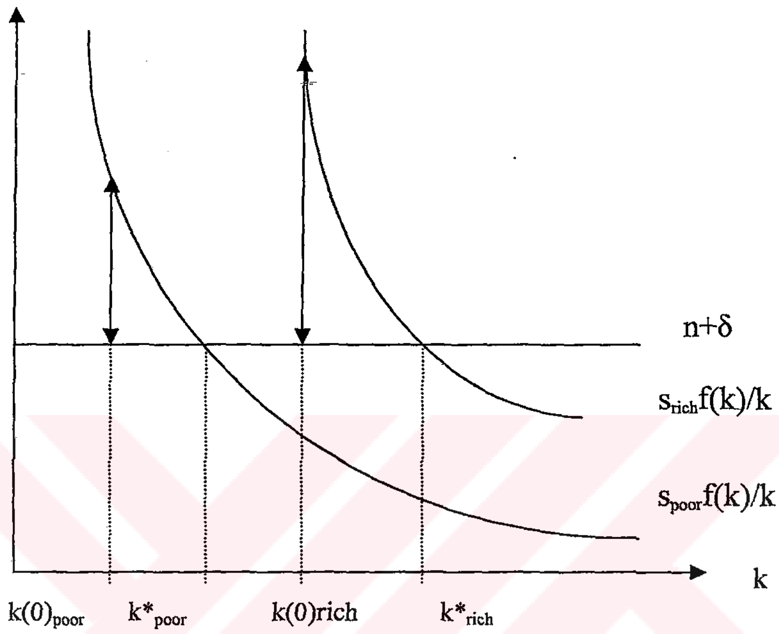

Figure 4-Conditional Convergence I
Source: Barro and Sala-i-Martin (2003, pp.48)

The neoclassical growth model predicts that each economy converges to its own steady-state and the convergence speed depends on distance from the steady-state. The speed of the convergence is negatively related to distance. Figure 5 illustrates that two different economy may have different steady-state in the conditional convergence hypothesis.

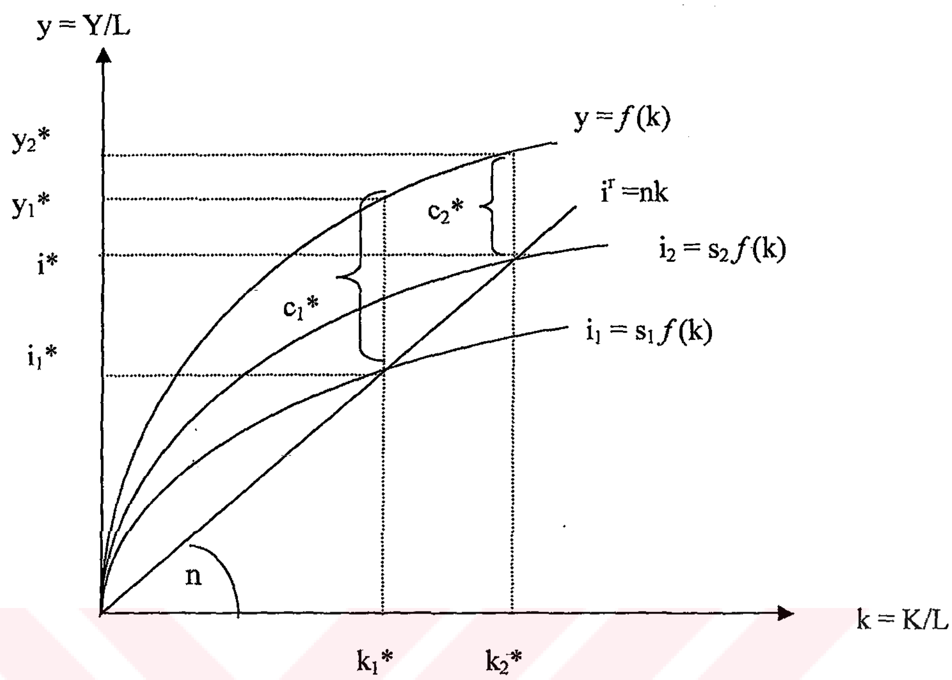

Figure 5- Conditional Convergence II

1.3 Vintage Models

Solow included the "technology" into the growth model as a free good which is accessible for everybody and he did not discuss the implications of this for a multi-country world. So the neoclassical model of economic growth predicts that GDP per capita in all countries will grow at the same, exogenously determined rate of technological progress.

There were some economists who had changed the assumptions of Solow growth model. For instance; Johansen (1959) argued that new production techniques can be introduced only by means of new capital equipment. This argument expanded the embodiment hypothesis and called vintage models.

The amount of capital, which is available at any point in time, is:

$$K(t) = I(t) + (1-\delta) I(t-1) + \ldots + (1-\delta)^t I(0) \qquad (1.22)$$

Where $I(t)$ is the vintage investment at time t, δ is rate of depreciation. So $K(t)$ is the number of new machine equivalents implied by the stream of past investment.

Fisher (1965) developed the vintage model, and he measured the investment in technological efficiency units, $H(t)$:

$$H(t)=\phi(t)I(t) \tag{1.23}$$

where $\phi(t)$ is the best practice level of technology in year t (an index of technical efficiency), $I(t)$ is the amount of investment good. So under the model of Fischer the total amount of capital at time t can be written as:

$$J(t)=H(t)+(1-\delta)H(t-1)+...+(1-\delta)^t H(0) \tag{1.24}$$

So the average embodied technical efficiency

$$\Psi(t)=\frac{I(t)}{K(t)}\phi(t)+\frac{(1-\delta)I(t-1)}{K(t)}\phi(t-1)+... \tag{1.25}$$

As a result, the average productivity of a collection of investment goods depends both on the relative efficiency of each vintage and on the relative amount of unadjusted investment in each vintage.

Burmeister and Dobell (1970, pp.90-92) explained that the process of embodied technical change which was originally formulated by Solow (1960) is an autonomous process which means that the increased efficiency of new capital goods is seen as increasing the quantity of capital input which is measured in efficiency units but no resources are expanded to achieve this increase. Thus, the output of investment goods is not adjusted for quality improvement. In contrast, the variant of the embodiment model developed by Domar (1963) and Jorgenson (1966) adjusts both investment output and capital input for improvements in technical quality.

Embodiment models show that output growth is affected by two ways. Firstly, an increase in the technical efficiency $\phi(t)$ will lead to an increase in the growth rate of quality adjusted investment, $H(t)$, and this increases the growth rate of quality adjusted output. Secondly, an increase in $\phi(t)$ raises the productivity of new capital and thus leads to increase in average embodied technical efficiency, $\Psi(t)$.

The assumption of new technology which is embodied in new capital goods increased the importance of capital accumulation to explain the raise in long run equilibrium. But if the other assumptions of the Solow model are left unchanged, long run productivity growth will be zero when there is no exogenous technological progress. This is the same conclusion for both Solow growth model and vintage models.

Kaldor and Mirrlees (1962) and Arrow (1962) presented another vintage model. Kaldor and Mirrlees developed a "Keynesian" model of economic growth which is a varied version. In their model, technical progress is inserted into the economy via the creation of new equipment. Also they argued that there are continuous technical progress and obsolescence. This model shows that technical progress is not only the main source of economic growth, it affects the share of profits, lifetime of equipment, the rate of obsolescence and the relationship between investment and potential output. This model does not require a clear relationship between capital, labor and output in traditional sense. They claimed that if the existing capital stock is created recently, output will be greater.

Arrow (1962) model of learning by doing takes the technical progress as a function of cumulative investment. This is the most extreme model of the embodiment hypothesis. In this model, learning is a function of cumulative gross investment rather than cumulative output. He emphasized that new machines are the vehicles of technical progress. Arrow analyzed a model in which improvement in techniques depends on the experience within production process. He argued that the higher the investment causes the greater opportunity for learning and the faster rate of technical progress and thus the level of production. Arrow claimed that knowledge is common to all firms and it arises from past cumulative investment of all firms.

If the production function is as the following:

$$Y_i = A_i K_i^a L_i^{1-a} \tag{1.26}$$

where A_i is the technical augmentation factor. Arrow assumed that the technical augmentation factor is related to the aggregate capital in an economy. Thus the experience of an individual firm depends on stock of total capital, G;

$$A_i = G^z \tag{1.27}$$

where $z \rangle 0$. Since in the aggregate, $K = G$, we can rewrite the aggregate production function as the following:

$$Y = K^{a+z} L^{1-a} \tag{1.28}$$

In his paper Arrow (1962) assumed that $a + z \langle 1$. This means that increasing only capital does not lead to increasing returns. Since $a + z + (1 - a) = 1 + z$, capital and labor must be increased to obtain increasing returns to scale.

Until the mid 1960s the flow of technological innovations had been treated as something given from the outside with no cost. None of the models did not take into account "technology sector" or "research sector" until the model of Uzawa (1965). He assumed that various activities which provide improvement in labor efficiency are put together as one sector. He described a growth model in which intangible human capital and physical capital can be produced. Also he considered the case of constant returns to scale with linear production of human capital and in this case asymptotically, output and both types of capital grow at the same constant rate. Also, Phelps (1966) argued that the level of technology at any particular point of time depends on past research, and he found an expression for the rate of steady growth of the income-labor ratio in the sector producing material commodities and services.

1.4 Growth Accounting

The Solow growth model presents a theoretical framework for understanding the sources of economic growth and the consequences of changes in the economic environment for long-run growth. From the late 1950s, economists have started to examine economic growth in a freer framework. In order to conduct a less theory bound analysis, economists have built up "growth accounting". Growth accounting is an empirical methodology that allows to find the components of GDP growth.

Solow (1956) theoretical article was addressed to the pessimism about full employment growth. He argued that with flexible factor coefficients the capital labor ratio could adjust so that demand for labor and supply of labor could grow at the same rate for any saving rate. In that model he admitted the possibility of technological advance which shifted the production function.

According to the neoclassical growth theory firms transform inputs into outputs due to the production function. The production function which is determined by the technology defines the maximum available output with any given quantity of inputs. Technological knowledge is assumed to be public. Firms are profit maximizers and generally these markets are assumed to be perfectly competitive.

1.4.1 Solow Residual

Since the factor price can be adjusted, the model is consistent with full employment. Output grows as inputs increase and as technology advances. Proportional output growth equals the sum of share weighted proportional input growths. If there is a residual, it is a technological advance.

If technological progress is eliminated, the Solow model predicts that GDP growth g_y is the weighted sum of the growth rate of the capital (g_k) and the growth rate of the labor force (n):

$$g_y = s_K g_k + s_L n \qquad (1.29)$$

where s_K and s_L denote the share of capital and labor in national income.

If technological progress is inserted into the neoclassical production function:

$$Y = F(A, K, L) \tag{1.30}$$

where A is the level of technology, K is the capital stock, and L is the quantity of labor. So output can grow only if these components grow.

If we take the logarithms of equation (1.30) and derivatives with respect to time we can get:

$$\dot{Y}/Y = g + \left(\frac{F_K K}{Y}\right).\left(\dot{K}/K\right) + \left(\frac{F_L L}{Y}\right).\left(\dot{L}/L\right) \tag{1.31}$$

where F_K, F_L marginal products of capital and labor respectively, and g is the growth due to technological change:

$$g \equiv \left(\frac{F_T T}{Y}\right).\left(\dot{A}/A\right) \tag{1.32}$$

The contribution of technological progress to growth can be calculated as follows:

$$g = \dot{Y}/Y - \left(\frac{F_K K}{Y}\right).\left(\dot{K}/K\right) - \left(\frac{F_L L}{Y}\right).\left(\dot{L}/L\right) \tag{1.33}$$

If the factors are paid due to their marginal products:

$$F_K = R \tag{1.34}$$

$$F_L = w \tag{1.35}$$

If $\frac{F_K K}{Y} = \frac{RK}{Y} = s_K$ and $\frac{F_L L}{Y} = \frac{wL}{Y} = s_L$, we can rewrite the equation (1.33) as the following:

$$g = \dot{Y}/Y - s_K.\left(\dot{K}/K\right) - s_L.\left(\dot{L}/L\right) \qquad (1.36)$$

where s_K and s_L denote the fraction of GDP used to rent capital and wages respectively.

The value of g is often described as Solow residual and its value is often described as an estimate (primal estimate) of total factor productivity (TFP).

1.4.2 Dual Approach to Growth Accounting

The dual approach consists of using data on factor prices to calculate growth rates of TFP. This idea goes back to Jorgenson and Griliches (1967).

Simply, the dual approach can be derived from the equality between output and factor incomes:

$$Y = RK + wL \qquad (1.37)$$

If we take the logarithms and derivatives (with respect to the time) of both sides of the equation (1.37), we can get:

$$\dot{Y}/Y = s_K.\left(\dot{R}/R + \dot{K}/K\right) + s_L.\left(\dot{w}/w + \dot{L}/L\right) \qquad (1.38)$$

Then the estimated TFP growth rate can be measured by:

$$\hat{g} = \dot{Y}/Y - s_K.\left(\dot{K}/K\right) - s_L.\left(\dot{L}/L\right) = s_K.\left(\dot{R}/R\right) + s_L\left(\dot{w}/w\right) \qquad (1.39)$$

So the estimation of TFP depends on share weighted of factor price growth rather than quantities. Because of this reason it is called the dual or price based estimate of TFP growth.

It is inevitable that If the assumption of $Y = RK + wL$ holds, the primal and dual estimates of TFP growth coincide.

1.4.3 Empirical Evidence for Growth Accounting

One of the first analyses about the reasons of growth was made by Abramovitz (1956). He found that a great portion of the growth of output could not be explained by increases in input. So there must be some form of technical progress to account of this growth Abramovitz's interpretation was:

"This result is surprising in the lopsided importance which it appears to give to productivity increase, and it should be, in a sense, sobering, if not discouraging, to students of economic growth. Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth in the US and some sort of indication of where we need to concentrate our attention." (Abramovitz, 1956)

Also Solow (1957) found a similar conclusion. He applied his theoretical function to the US economy for the period 1909-1949. After some manipulation of Solow's function, measure of technical change can be rewritten as:

$$\left(\dot{A}/A\right)=\left(\dot{q}/q\right)-w_K\left(\dot{k}/k\right) \qquad (1.40)$$

where q denotes output per man hour;

k denotes capital per man hour;

w_K denotes capital's share of total income;

and (.)represents derivatives with respect to time.

The result is that 87 ½ percent of the rise in gross output per man hours appears to be attributable to technical progress.

Jorgenson and Griliches (1967) examined the hypothesis that if quantities of output and input are measured correctly, growth in total input largely explains the growth in total output. Jorgenson and Griliches emphasized four main sources of measurement error. First of them is the errors of aggregation in combining investment and consumption goods and labor and capital services. Second one is the errors of measurement in the prices of investment goods. This arises from the use of prices for inputs into the investment goods sector rather than the use of prices of outputs from this sector. Third one is the error from assuming that the flow of labor and capital services is proportional to the stock of labor and capital. Finally, errors are resulting from the aggregation of investment goods and capital services on the one hand and labor services on the other. Jorgenson and Griliches removed these errors from data on output and inputs for the US between 1945-1965 and they found that before the correction of data only 52.4 percent of the rate of output growth could be explained by the rate of input growth but after elimination of the errors, the rate of input growth explains 96.7 percent of the rate of output growth. So the role of technical progress was demoted.

Nishimizu and Hulten (1978) examined the sources of Japan's postwar economic growth. He found that the average annual growth rate of aggregate real product is 11.45%, and the contributions of capital, labor and TFP to this growth are 58%, 17% and 25% respectively.

Barro and Sala-i-Martin (2003) discussed papers which are written by Jorgenson and Yip (2001) and Christensen et al (1980). These papers consist of the growth accounting application for the same OECD countries but for the different period. Jorgenson and Yip found that generally TFP growth rates in the later period (1960-1995) are lower than the early period (1947-1973) which is used by Christensen, Cummings, and Jorgenson.

The main contribution of the growth accountants was to show that neoclassical theory had very little explanatory power for "why growth rates differ" across countries. The growth accountants introduced additional factors other than inputs like technological catch-up, structural change and economies of scale.

1.5 The Technology Gap Approach to Economic Growth

Since the technology is assumed to be a public good, the traditional neoclassical growth theory does not see technology as a source of differences in GDP across countries. But technology gap approach explains these differences by technological variation.

The technology-gap approach to economic growth points to technological differences across countries as the major cause of differences in per capita income levels (Fagerberg, 1988b). From a theoretical perspective the main difference between the technology-gap theory and that of neoclassical exogenous growth is the way in which technology is conceived. In the neoclassical approach, technology is a public good which is accessible to all countries, and therefore it cannot be the cause of differences in economic development of the countries. On the other hand, the technology-gap approach though that technology has some of the features of a public good, also this approach emphasized the country-specific character of technical change and the difficulties of transferring technological capabilities across countries. These difficulties depend on the tacit and cumulative character of knowledge that is seen to be embedded within firms and organizations.

Many writers have accepted that each country has distinct national characteristics which affect the process of technological change.

In order to explain why Europe was not able to catch-up with the United States before World War II, Abramovitz (1986, 1993) and Nelson and Wright (1992) refer to two classes of constraints: technological congruence and social capability. The first constraint depends on the fact that natural resources and other factors of production, different degrees of economies of scale, and some requirements for different technical abilities determine the technological progress so that for the countries that are behind the technological frontier it is difficult to catch up with the leader if they do not have the characteristics that conform with the prevalent technology. The second constraint, social capability, refers to education, financial institutions, infrastructures, the political and social environment, and all elements that can favor or limit the ability of countries to exploit their growth potential. As Abramovitz (1986) points out, the problem with social capability has been that "no one knows just what it means or how to measure it." [2]

In this sense Abramovitz (1993) described the phenomenon of convergence among OECD countries as an event that has a precise historical collocation. He argued

[2] Temple and Johnson (1998) suggested that it is relevant to use Adelman-Morris Index (Adelman and Morris, 1967) to measure social capability.

that West European countries and Japan were not able to exploit the productivity gap with the US in the preceding period, because the dominant technology required a more intensive use of mineral resources and tangible capital and the exploitation of economies of scale. In the third quarter of the present century, technology had become intangible capital using technology and this allowed the West European countries and Japan to exploit this gap.

Ames and Rosenberg (1963) saw the technological variation as a main source for the differences in GDP per capita across countries. They examined the three theses about the technological differences across the countries; weak, moderate and strong theses. They explained the rate of growth by using these three theses. The weak thesis claimed that late comers can grow more rapidly than early starters, because they don't repeat the past mistakes of early starters. The moderate thesis asserted that obsolescence of skills and plant creates retardation which does not affect late comers. Thus, late comers can reach higher level of growth than early starters can reach. Finally, since the late comers will cease developing the strong thesis alleged that late comers will be superior.

Nelson and Wright (1992) argued that technology is not a public good and it differentiates due to the some features of the countries. They emphasized the concept of a "national technology" which means that country specific factors are crucial in the process of technological change. Technological advances require more complex and different kinds of inputs and organizational structures. Because of different social and political progress which affects the education, communication and regulatory tools of government, technological capability differentiates from one country to another.

Nelson and Wright (1992) also argued that the technological leadership of the US was linked to the abundance of natural resources, and to the size of the domestic market, and these elements are the main forces to the mass-production in US. At the same time the high technological efforts and the large investments in education provided technological leadership in high-technology industry. In this sense the catching-up process after World War II can be explained by the erosion of both advantages in mass-production and in high technology US leadership. Catching-up countries were able to reduce their gap with the leading country. Because they have started to invest in human and physical capital (social capability).

Also Nelson (1981) advocated that technology is not a public good in traditional sense. Firm structures, decision making style, labor-management relations, and managerial and worker skills are the important variables which influence the technological progress. Nelson (1981) stressed on the determinants of the technological change as follows:

"...information about new technology is not costless to acquire and may require considerable sophistication, and luck, to evaluate properly. More, the technology chosen by a firm in many cases is not determined by management preference alone. The choice may be constrained by legal restrictions to buy from nationals or by other forms of governmental influence. In many cases, technological change is the subject of labor-management bargaining."(Nelson, 1981)

At the level of the firms, technological benefits and transformation are mainly based on "how to do things" and "how to improve them" which are embodied in organizational structures and routines. Dosi (1988) stressed on these firm specific factors and environment related factors. He argued that technological limitations, opportunities, experiences and skills are determined by organization and country specific factors.

Technology-gap approach has shown that domestic capability is the key factor to explain growth rate differentials across the countries. Because it determines the ability to absorb knowledge spillovers from abroad. Fagerberg (1988b) argued that adoption of a new technology requires investment in capital equipment, infrastructure, and domestic capabilities. If a country has not a sufficient level of such investment, it can not be able to benefit from backwardness. Thus the economic growth may be seen as the outcome of the innovation activities in the country, the potential for exploiting technologies and some factors which affect the diffusion of technology. Generally, population density, industrial structure, physical infrastructure and long-term unemployment are the factors which affect the diffusion of technology.

Boyer (2002) developed a "regulation theory" which does not accept either economic or technological determinism. In this approach the economic system is seen as something "regulated" by economic, technological, social and institutional issues which allow the system to work. The relationships between these issues are crucial for the growth of the system. Institutional forms can have different and alternative features and they offer a framework for technical progress and economic growth. If a good match occurs between institutional forms and technological opportunities, a "mode" of regulation which leads the economic growth is established.

In the work of Ohkawa and Rosovsky (1973) the "social capability" to import technology is offered as a key component in their explanation of swings and trend acceleration. Inkster (2001) used their works to explain Japanese industrial economy in his book:

"Ohkawa and Rosovsky note that only a well functioning 'socio-political infrastructure' can close the gap between advanced imported technologies and their efficient absorption, and that 'Japanese economic history shows both the significance of a rapid absorption of imported technology and also the development of specific institutions that facilitated the entire process' **(Ohkawa and Rosovsky 1973: 219)."**(Inkster 2001, pp. 25)

In the political economy of industrialization, Gerschenkron (1962) asserted that the state traditionally played a strong and directive role over the market. Industrialization occurred under a strong autonomous state. According to him, to industrialize, the state must divert national income from consumption to investment.

Internationalization of the technology development activities which has reduced the importance of the national borders has very important role for technological progress. Since the 1960s, companies have been performing some sort of research and development (R&D) activities. In a study, Cantwell (1998) found that in the early 1930s, about the 7 percent of total R&D of the largest European and American companies was performed outside their home countries. But, in the past, the magnitude, nature and scope of the overseas R&D were limited. Much of such R&D was undertaken to obtain technology transfer by adapting the parent's technology to local conditions (Reddy, 2000, pp.1). In the 1990s, globalization of corporate R&D has attracted greater attention from economists and policy-makers mainly due to its changing characteristic features and its potential implications.

Several studies have shown the increasing trend of globalization of corporate R&D. Among them, Kuemmerle (1999) analysis of thirty-two transnational corporations showed that these transnational corporations carried out 6.2 per cent of their R&D outside their home countries in 1965, whereas in 1995, this figure had risen to 25.8 per cent. Also it has been estimated that 86 percent of France's technological progress is purchased from abroad, the remainder is generated locally. (Eaton and Kortum, 1999)

1.6 Criticism of the Neoclassical Growth Theory

In the empirical studies which have used a neoclassical growth model have revealed the importance of technical progress measured as the residual. Residual could not be explained by the increase in the two factors of production. Furthermore, other empirical investigations have tested the convergence hypothesis and it has been found that convergence is a phenomenon that holds only for particular countries over particular periods. In this sense neoclassical growth theory has been criticized both on theoretical and empirical grounds. The main theoretical weakness of neoclassical model is attributing long-run growth to exogenous technical progress, this is not satisfactory. Also from an empirical perspective there is little evidence of convergence and in spite of the decreasing marginal product of capital, some countries experience non-decreasing rates of growth for long periods.

Nelson (1981) argued that growth accounting exercises do not explain why growth rates differ across countries. According to him its failure is to explain the relation between the various 'explanatory' factors. Nelson also pointed out the lack of any attempt, within the growth accounting exercises, for a direct measuring of the contribution of increase in knowledge to economic growth. These are the results of the theoretical weaknesses of the neoclassical growth.

Solow (1957) found that less than 20 per cent of the increase in output per hour worked in the US between 1909 and 1949 could be attributed to the growth in the capital–labor ratio, while over 80 per cent had to be attributed to technical change. This result was somewhat disappointing for neoclassical growth theory which treated technical change as an exogenous factor.

A second way to evaluate the neoclassical growth theory has been to test for convergence in countries' rates of growth. The neoclassical growth theory has been tested for convergence in countries' rates of growth. In the Neoclassical model, considering two countries with the same value of the some parameters (the saving rate, the growth rate of labor force and the rate of technical change), the country which has a higher level of per capita GDP must have a lower productivity of capital and therefore it can grow at a lower rate than the country which has a lower level of per capita GDP. When countries are allowed to differ in the parameters, convergence can still exist after controlling for these differences; this second case is known as conditional convergence.

Convergence is the result of poor countries which have grown at a higher rate than rich countries, and can be tested by regressing the rate of growth of per capita income on the initial level of per capita income. A negative relation between the development level and the growth rate supports the hypothesis of convergence. (Baumol, 1986; De Long, 1988; Barro and Sala-i-Martin, 1991, 1992). Also convergence can be seen as a decrease in the differences in income levels and it can be measured by the standard deviation or the coefficient of variation of the logarithm of per capita income. (Baumol, 1986; Dowrick and Nguyen, 1989; Barro and Sala-I-Martin, 1991, 1992)

Baumol (1986), using Maddison's 1870– 1979 data[3], ran a regression of growth rate of GDP on the level of GDP per work hour at the beginning of the period (considered as a proxy for the level of development). Using the sample which consists of industrialized countries he obtained a highly significant negative relation between the two variables. Thus this result confirms the convergence hypothesis. But De Long (1988) argued that convergence hypothesis can hold only for particular countries and particular periods. He repeated similar exercises on the sample consisting of countries which have the different development levels and he obtained different results. Also he claimed that if the data are enlarged, the convergence hypothesis is not relevant.

[3] Maddison (1982) requires these data.

2. INTERNATIONAL COMPETITIVENESS

It is important to find the direction of causality in particular the relationship between favourable elasticities, balanced trade and economic growth. In a neoclassical framework, it is argued that higher rates of growth which is explained by the rate of growth of labor, capital and exogenous technical change stimulates higher income elasticities of demand and current account surpluses. On the other hand, in a post-Keynesian framework, demand can determine supply as in export-led and balance-of-payments-constrained growth models. But this approach can not explain why some countries have a better trade performance and favourable income elasticities of exports and imports. The post-Keynesian approach has not given enough importance to technical change as one of the key factors affecting the combination of export performance, favourable income elasticities of demand and economic growth. There have been numerous empirical studies that have introduced technological variables into trade equations. (Fagerberg, 1988a; Greenhalgh, 1990; Zhao and Li, 1997).

2.1 The Theoretical Model

Several contributions have linked the technological account of international competitiveness with the post-Keynesian balance-of-payments-constrained growth theories. One of the famous contributors, Fagerberg (1988a), introduced technological competition into export and import equations within a model where actual growth adjusts to the balance-of-trade equilibrium growth rate. This is the fact that technological factors affect international competitiveness which allows an indirect effect of technical change on countries' rates of growth. He developed a model of international competitiveness and he stressed that the factors related to the technology and capacity play a more advanced role than commonly assumed.

He used the following symbols in his model;

Y = GDP (volume)

X = Exports (volume)

M = Imports (volume)

W = World demand (volume)

P = Price per nationally produced product (dollar)

P_w = World Market price (dollar)

Fagerberg used three factors to explain economic growth; technological competitiveness of a country $\left(\frac{T}{T_w}\right)$, price competitiveness $\left(\frac{P}{P_w}\right)$ and capacity C.

He defined the market share for exports $\left(S(X) = X/W\right)$ as the following equation:

$$S(X) = AC^v\left(\frac{T}{T_w}\right)^e\left(\frac{P}{P_w}\right)^{-a} \qquad (2.1)$$

where A, v, e, a are positive constants. If we differentiate the equation (2.1), we can obtain:

$$\frac{dS(X)}{S(X)} = v\left(\frac{dC}{C}\right) + e\left(\frac{dT}{T} - \frac{dT_w}{T_w}\right) - a\left(\frac{dP}{P} - \frac{dP_w}{P_w}\right) \qquad (2.2)$$

Also he explained the capacity growth (the growth in the ability to meet demand) by the following equation:

$$\frac{dC}{C} = z\left(\frac{dQ}{Q}\right) + r\left(\frac{dK}{K}\right) - l\left(\frac{dW}{W}\right) \qquad (2.3)$$

Where z, r, l are positive constants and *(dQ/Q)*, *(dK/K)* and *(dW/W)* are the growth in technological capability and know-how, the growth in physical production equipment, buildings, transport equipment and infrastructure, and the rate of growth of demand respectively.

Fagerberg used the customary assumption on the diffusion, so the growth in free knowledge can be written as:

$$dQ = f - f\left(\frac{Q}{Q^*}\right) \qquad (2.4)$$

In this figure $(Q/Q^*)$is the ratio between country's own technological development level and the world innovation frontier level, also f is a positive constant. So we can rearrange equation (2.2):

$$\frac{dS(X)}{S(X)} = vzf - vzf\frac{Q}{Q^*} + vr\frac{dK}{K} - vl\frac{dW}{W} + e\left(\frac{dT}{T} - \frac{dT_w}{T_w}\right) - a\left(\frac{dP}{P} - \frac{dP_w}{P_w}\right) \qquad (2.5)$$

If we applied same logic to the import share, we can obtain the import share $\left(S(M) = M/Y\right)$:

$$\frac{dS(M)}{S(M)} - vzf + vzf\frac{Q}{Q^*} - vr\frac{dK}{K} + vl\frac{dW}{W} - e\left(\frac{dT}{T} - \frac{dT_w}{T_w}\right) + a\left(\frac{dP}{P} - \frac{dP_w}{P_w}\right) \qquad (2.6)$$

So equations (2.5-2.6) show that the growth in the market share for exports and imports depends on technological factors, capacity, relative prices and demand.

Under the assumption of the balanced trade, we can write:

$$XP = MP_w \qquad (2.7)$$

Since the $S(X) = X/W$ and $M(X) = M/Y$, we can rewrite this equality as follows:

$$S(X).W.P = S(M).Y.P_w \qquad (2.8)$$

Differentiating equation (2.8) with respect to time can be written:

$$\frac{dS(X)}{S(X)} + \frac{dW}{W} + \frac{dP}{P} = \frac{dS(M)}{S(M)} + \frac{dY}{Y} + \frac{dP_w}{P_w} \qquad (2.9)$$

If we leave *(dY/Y)* alone, we can obtain:

$$\frac{dY}{Y}=\frac{dS(X)}{S(X)}-\frac{dS(M)}{S(M)}+\left(\frac{dP}{P}-\frac{dP_w}{P_w}\right)+\frac{dW}{W} \tag{2.10}$$

In this model, investment in physical production depends largely on other resources which assist the R&D activities. Since these resources are scarce, governmental activities, especially military governmental expenditures, reduce the investment.

$$\frac{dK}{K}=-g\,MIL-h\,WELF+\frac{dY}{Y} \tag{2.11}$$

where the *MIL* and *WELF* denote the shares of the military and non-military governmental expenditures in total output respectively.

Another assumption is about the prices determined by unit labor costs.

$$dP_i/P_i=dU_i/U_i \tag{2.12}$$

where i = (home, world)

2.2 Working of the Model

The model consists of five equations:

$$\frac{dY}{Y}=\frac{dS(X)}{S(X)}-\frac{dS(M)}{S(M)}+\left(\frac{dP}{P}-\frac{dP_w}{P_w}\right)+\frac{dW}{W} \tag{2.10}$$

$$\frac{dS(X)}{S(X)}=vzf-vzf\frac{Q}{Q^*}+vr\frac{dK}{K}-vl\frac{dW}{W}+e\left(\frac{dT}{T}-\frac{dT_w}{T_w}\right)-a\left(\frac{dP}{P}-\frac{dP_w}{P_w}\right) \tag{2.5}$$

$$\frac{dS(M)}{S(M)}-vzf+vzf\frac{Q}{Q^*}-vr\frac{dK}{K}+vl\frac{dW}{W}-e\left(\frac{dT}{T}-\frac{dT_w}{T_w}\right)+a\left(\frac{dP}{P}-\frac{dP_w}{P_w}\right) \tag{2.6}$$

$$\frac{dK}{K}=-g\,MIL-h\,WELF+\frac{dY}{Y} \tag{2.11}$$

$$dP_i/P_i=dU_i/U_i \qquad i=(\text{ home, world}) \tag{2.12}$$

There are three factors which explain the equilibrium growth rate[4]; the growth in market shares, the growth in relative prices and the growth of the world demand. The first factor, market shares, is determined by technological factors, growth in physical production and demand, growth in relative prices determined by the growth in relative unit labor costs. Unit labor cost is assumed to be determined outside the model.

2.3 Testing the Model

The empirical test of the model gives support to the view that non-price competition (measured by a composite index of patents and R& D expenditures) affects exports (positively) and imports (negatively). Moreover there appears to be a close relationship between the balance-of-payment equilibrium growth rate and the actual growth rate, and a one-to-one correlation between deviations in the two rates of growth. The results of Fagerberg's study support the model of technology-driven and balance-of-payment-constrained growth.

He tested his model by applying cross country analysis with time series data for the period 1960-1983 and he used the following variables:

GDP_i : Growth rate of gross domestic product for country i,

ME_i : Growth rate of export market share for country i,

MI_i : Growth rate of import market share for country i,

$TERMS_i$: Growth in terms of trade for country i,

$RULC_i$: Growth in relative unit labor costs for country i,

W : Growth of world trade at constant price,

TL_i : Technological level of country i relative to the most advanced country of the sample.

[4] The balance of trade equilibrium growth rate is the warranted growth rate which actual growth rate has to adjust in the long run.

TG_i : Growth in technological competitiveness for country i,

$WELF_i$: Non-military governmental expenditure as percentage of GDP in country i,

MIL_i : Military expenditures as a percentage of GDP in country i,

INV_i : Country i's gross fixed investment as a percentage of GDP.

The empirical model consists of six equations:

$$GDP = a_{10} + a_{11}\, BAL \qquad (2.13)$$

$$BAL = ME - MI + TERMS + W \qquad (2.14)$$

$$TERMS = a_{31}\, RULC - a_{32}\, POST_{73} + DUMMIES \qquad (2.15)$$

$$ME = a_{40} - a_{41}\, TL + a_{42}\, INV - a_{43}\, W + a_{44}\, TG - a_{45}\, RULC \qquad (2.16)$$

$$MI = a_{50} + a_{51}\, TL - a_{52}\, INV + a_{53}\, GDP - a_{54}\, TG + a_{55}\, RULC \qquad (2.17)$$

$$INV = a_{60} - a_{61}\, MIL - a_{62}\, WELF + a_{63}\, GDP \qquad (2.18)$$

where *DUMMIES* and the $POST_{73}$ are dummy variables used to reflect the country's specific factors and the oil price shocks.

In the table 1 there are some results of the estimation of the model. The results of the estimation (2.13) do not support the assumption of equality between actual growth rate and balance of trade equilibrium growth rate, but there is a strong relationship between them. Estimation (2.16) and (2.17) show that technological factors affect the market shares for export and import which determine the growth of GDP.

Table 1 Some results of the estimation of the Fagerberg's model

(13) 2SLS *GDP = 0.96 + 0.67 BAL* *(2.13) (6.43)*	$R^2 = 0.31\ (0.30)$ *SER = 1.76* *DW(g) = 1.62* *DF = 58*
(16) 2SLS *ME = -2.03 - 2.70TL + 0.24INV – 0.35W + 0.27TG – 0.29RULC* *(-1.16) (-2.31) (3.56) (-4.56) (4.49) (-3.14)*	$R^2 = 0.55\ (0.51)$ *SER = 1.81* *DW(g) = 2.09* *DF = 54*
(16) 2SLS-WLS *ME = -3.25 – 2.64TL + 0.30INV – 0.36W + 0.25TG – 0.34RULC* *(-2.25) (-2.98) (-5.01) (-5.42) (4.68) (-4.59)*	$R^2 = 0.67\ (0.63))$ *SER = 1.10* *DW(g) = 1.97* *DF = 54*
(17) 2SLS *MI = 2.65 + 3.47TL – 0.27INV + 1.22GDP – 0.17TG + 0.23RULC* *(1.47) (2.75) (-3.39) (7.20) (-2.55) (2.45)*	$R^2 = 0.47\ (0.42)$ *SER = 1.85* *DW(g) = 1.85* *DF = 54*
(17) 2SLS-Random effects method *MI = 0.88 + 3.46TL – 0.23INV + 1.25GDP – 0.21TG + 0.21RULC* *(0.62) (1.84) (-2.00) (7.72) (-2.34) (2.38)*	$R^2 = 0.47\ (0.42)$ *SER = 1.85* *DW(g) = 1.85* *DF = 54*

Sources: Fagerberg (1988, pp. 368)

*R^2 in brackets = R^2 adjusted for degrees of freedom.

**SER = Standard error of regression.

***DW = Durbin-Watson statistics adjusted for gaps.

****DF = Degrees of freedom.

*****The numbers in brackets below the estimates are t-statistics.

Thus we can conclude that in his model Fagerberg took into account both the balance of payments and the endogeneity of the income elasticities of exports and imports. In this model non-price competition is used. Export and import equations depend on price and non-price competitiveness, and the actual rate of growth adjusts in order to maintain equilibrium in the current account of the balance of payments.

2.4 Other Empirical Results for International Competitiveness

In general, technology has proved to be an important determinant of trade flows and its role has been found to differ across industries. As a result of all these empirical works, technological competitiveness, in the form of higher R&D expenditures, higher patenting activity and a higher rate of capital accumulation, has proved to be an important factor in international competitiveness; moreover its importance has been found to differ across sectors.

Greenhalgh (1990) used a model of demand for net exports which is a function of prices, income and innovation and he estimated this model for 31 industry groups. He found that generally industries with high level of innovation are net exporters and non-innovation industries are more likely to be net importers.

Zhao and Li (1997) analyzed the role of R&D to explain export propensity and export growth. They used a large data set of manufacturing firms in China. In this analysis, one percent increase in R&D spending lead to an 11% increase in export growth. Thus contribution of R&D spending of firms to the export growth was found to be significant. R&D is considered as an important means to gain market share in global competition.

Also Sterlacchini (1999) analyzed the impact of the innovation on the export performance. He used the amount of expenditure on design, engineering and pre-production developments as indicators of innovation. He stressed on these indicators and he argued that if innovation is measured by only R&D expenditures, the impact of technological change on the export performance is underestimated. He found that export share has positively affected by these indicators.

In another research, a sample of 213 manufacturing firms was analyzed by Guan and Ma (2003). They defined seven innovation capability dimensions; learning, R&D, manufacturing, marketing, organizational, resource allocating and strategic planning. They argued that the majority of the studies used mainly the intensity of R&D to measure innovation and other factors related to innovation capability of firm are ignored. They concluded that with the exception of manufacturing capability other six capability dimensions are positively correlated with the export.

The study carried out by Basile (2001) was based on a sample of more than 4000 Italian firms with more than 10 employees. The results showed that innovation is a very important competitive factor and it explains the heterogeneity in export behaviour among the firms in Italy. But he concluded that the large exchange rate shocks which allow the non-innovating firms to enter foreign markets can reduce the importance of technological competitiveness in export behaviour.

3. ENDOGENOUS GROWTH THEORY

The endogenous growth theory was developed in the mid 1980's. This theory was developed in response to criticisms of the neoclassical growth model. In the neoclassical growth model, the rate of growth is determined outside the model and it is independent of preferences, most aspects of the production function and policies. In fact different countries have different growth rates[5] and these rates are related to various national features.

This is the fact that standard neoclassical growth model is unsatisfactory to explore the determinants of long run growth. Simply, the basic idea behind the neoclassical growth theory is that the output depends on two main inputs: capital and labor. When the amount of labor is fixed, using more units of capital leads to diminishing marginal product of capital. Also the neoclassical production function exhibits constant return to scale and to double the outputs inputs should be doubled.

The conceptual difficulties forced to researchers to find a new model which allows the endogenous technological progress. One of the first attempts to present technological progress as an endogenous variable in the growth model was Arrow (1962) which I have discussed in section 2.3. In his paper he used the learning by doing model and he argued that the level of knowledge depends on the past level of investment. It is assumed that productivity of a firm is an increasing function of cumulative aggregate investment for the industry.

Uzawa (1965), Lucas (1988) and Romer (1990) developed some theoretical model to explain technological change as an endogenous variable[6]. The main feature of these models is the existence of a sector that produces new ideas. These models emphasize on the importance of human capital which is the most crucial determinant of growth process.

[5] In the endogenous growth model determinants of growth include physical and human capital accumulation (Lucas, 1988; Rebelo, 1991), private externalities (Romer, 1986), public externalities (Barro, 1990), R&D (Aghion and Howitt, 1992; Romer,1987; 1990)
[6] Also the important contributions to this literature include Grossman and Helpman (1991a, 1991b, 1991c) and Aghion and Howitt (1992)

3.1 The Romer Version of Endogenous Growth

The main property of endogenous growth model is the absence of diminishing returns to inputs (Romer, 1986). Romer (1990) provided the first formal application to the modeling of endogenous growth. Romer's analysis is a generalization of Arrow (1962) learning by doing model. As I said before, in the Arrow's model of growth we can conclude that long run rate of growth can not be positive unless the rate of growth of labor is positive and this rate can not be affected by policy. Romer produced results which is sharply different from these conclusions. It must be noted that both Arrow and Romer used the assumption of the externality so that there are constant returns to scale at the firm level and increasing returns to scale at the aggregate level. Thus the assumption of perfect competition can be retained.

In his paper, Romer assumed that technological knowledge can be accumulated through R&D and other activities. Research technology which exhibits diminishing returns creates new knowledge and knowledge can grow without bound. Since the knowledge can not be perfectly patented, the creation of new knowledge has positive externalities on the other firms. By using externalities, increasing returns in the production of output and decreasing returns in the production of new knowledge, Romer specified the competitive equilibrium. In his model per capita income can grow without limit and the rate of return to capital may increase. It is important to note that in his model, investment in research technology which exhibits diminishing returns is the ultimate determinant of long run growth. In the neoclassical growth model, per capita output should converge to a steady state with no per capita growth in the absence of technological change. On the other hand, Romer's model suggests that convergence does not take place, because increasing GDP per capita does not reduce the marginal productivity of capital. Thus rich countries may stay rich and poor countries may stay poor.

Romer (1990a)[7] argued that technical advance comes from a sector which produces ideas. In this model knowledge enters production in two different ways. A

[7] This paper is the following of Uzawa's (1965) paper which claimed that the evolution of stock of knowledge is determined by the allocation of resources between a final good sector and a research sector.

new design allows the production of a new intermediate input. Also a new design increases the total stock of knowledge and productivity of human capital. If the firm owns a new idea, it has some property rights to produce of new durables but not over its use in research. In his paper Romer says that:

> ***"If an investor has a patented design for widgets, no one can make or sell widgets without the agreement of the inventor. On the other hand, other inventors are free to spend time studying the patent application for the widget and learn knowledge that helps in the design of a wodget."*** (Romer, 1990)

In his model there are four basic inputs: capital, labor, human capital and an index of the level of technology. In addition to this, Romer claimed that economy has three sectors: Research sector, intermediate good sector and final good sector. In research sector human capital and existing stock of knowledge produce new knowledge and designs for new producer durables. Intermediate good sector uses designs which are produced by research sector with forgone outputs to produce producer durables. Finally, labor, human capital and the set of producer durables are used to produce final output in the final good sector. Moreover he separated human capital into two classes: human capital devoted to produce final output (H_Y) and human capital devoted to research sector (H_A).

Moreover to keep analysis simple, he used some assumptions. Firstly, both population and labor supply are constant. The second assumption is the fixed total stock of human capital. Thus the supply of the aggregate factors L and H is fixed. Another assumption is that capital can be accumulated as forgone output. Finally, only knowledge and human capital are used to produce new designs and knowledge. Under these assumptions, the Cobb-Douglas production function is as follows:

$$Y\left(H_Y, L, x\right) = H_Y^{\alpha} L^{\beta} \sum_{i=1}^{\infty} x_i^{1-\alpha-\beta} \qquad (3.1)$$

where Y is final output. In equation (3.1) H_Y and L denote human capital and physical labor respectively. Output depends on an infinite list of possible types of durable goods and this list is denoted by $x = \{x_i\}_{i=1}^{\infty}$. In this equation all different types of capital have additively separable and they are perfect substitutes. It means that marginal products of the one type of the capital goods is independent from the number of the another type of the capital goods. It also implies that the growth in capital which results from a new type of durable goods does not exhibit diminishing returns.

Romer defined the total capital as a cumulative forgone output with the assumption of absence of depreciation. Thus the rate of increase in capital is as the following:

$$\dot{K}(t) = Y(t) - C(t) \tag{3.2}$$

where $C(t)$ represents aggregate consumption at time t.

If it takes η units of forgone output to produce one unit of durable, total capital can be written as the following:

$$K = \eta \sum_{i=1}^{\infty} x_i = \eta \sum_{i=1}^{A} x_i \tag{3.3}$$

Since H and L are fixed, growth in K depends on the forgone output which is specified with the new designs. The accumulation of new designs $(A(t))$ is provided by the human capital and existing stock of knowledge. Thus in continuous case, equation (3.1) can be rewritten as:

$$Y(H_Y, L, x) = H_Y^{\alpha} L^{\beta} \int_0^{\infty} x(i)^{1-\alpha-\beta} d_i \tag{3.4}$$

Since technological knowledge is free for all the firms, they are all available to use the same technology. Under this assumption, the growth rate of the designs is written as the following equation:

$$\dot{A} = \delta H_A A \tag{3.5}$$

where δ denotes the productivity. Equation (3.5) implies that increase in human capital devoted to research leads to increase in rate of production of new designs and greater the total stock of knowledge leads to higher productivity in research sector.

For a given H_Y and L, to derive aggregate demand for the durables the maximization problem of the firms which produce final output is:

$$\max_x \int_0^\infty \left[H_Y^\alpha L^\beta x(i)^{1-\alpha-\beta} - p(i)x(i) \right] d_i. \tag{3.6}$$

where $p(i)$ is the rental price for the *ith* durable good.

To find a profit maximizing quantity of durable goods, we differentiate equation (3.6) and then equate this function to the zero:

$$(1-\alpha-\beta) H_Y^\alpha L^\beta x(i)^{-\alpha-\beta} - p(i) = 0 \tag{3.7}$$

So the inverse demand function for durables is as the following:

$$(1-\alpha-\beta) H_Y^\alpha L^\beta x(i)^{-\alpha-\beta} = p(i) \tag{3.8}$$

By using this inverse demand function, firm determines the level output x which maximizes it's profit for a given H_Y, L and r:

$$\pi = \max_x p(x)x - r\eta x$$

$$= \max_x (1-\alpha-\beta) H_Y^\alpha L^\beta x^{1-\alpha-\beta} - r\eta x \tag{3.9}$$

where r is the interest rate on loans denominated in goods. In equation (3.9) the first term represents the revenue from rent of durables and the second term is cost of designs. There are ηx units of output which is used to produce x units of durables. Thus the interest cost is equal to $r\eta x$. In equation (3.9) monopoly pricing problem is specified. Solution of this maximization problem gives monopoly price and profit[8] as follows:

$$\bar{p} = r\eta/(1-\alpha-\beta) \quad (3.10)$$

$$\pi = (\alpha+\beta)\,\overline{px} \quad (3.11)$$

Since the market for designs is competitive, present value of the net revenue of a monopolist is equal to price for designs at time t:

$$\int_t^\infty e^{-\int_t^\tau r(s)ds}\pi(\tau)d\tau = P_A(t) \quad (3.12)$$

Since the price of designs is constant, by differentiating equation (3.12) with respect to time t, we can obtain:

$$\pi(t) - r(t)\int_t^\infty e^{-\int_t^\tau r(s)ds}\pi(\tau)d\tau = 0 \quad (3.13)$$

Now, we can substitute (3.12) into (3.13):

$$\pi(t) - r(t)P_A = 0$$

$$\pi(t) = r(t)P_A \quad (3.14)$$

It means that net revenue must cover the interest cost on investment needed for designs.

In Romer's model technological advance comes from a sector which produces new ideas. The optimal intertemporal allocation of consumption derives the optimal plan for the resources allocated to research sector. If we look at the consumer side, his or her utility function which has discounted constant elasticity preferences is as the following:

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8 See details from Appendix B

$$U[C(.)] = \int_0^{\infty} e^{-\rho t} \frac{C(t)^{1-\sigma} - 1}{1-\sigma} dt \qquad (3.15)$$

where $\sigma \rangle 0$ is the inverse of the intertemporal elasticity of substitution, C is consumption and ρ is the rate of time discount. The relation between r and ρ determines the rate of consumption growth. The intertemporal optimization condition is as the following[9]:

$$r = \sigma \frac{\dot{C}}{C} + \rho \qquad (3.16)$$

In this model, at the equilibrium;

(i) For a given interest, consumers choose saving and consumption level.

(ii) For a given price of designs P_A, a wage rate in manufacturing sector w_A, and total stock of knowledge A, human capital holders decide whether to work in the research sector or the manufacturing sector.

(iii) For a given price producers of final good firms choose the labor, human capital, and durables.

(iv) For a given interest rate firms which produce durables and own a design set a price level to maximize their profits.

(v) Firms contemplate entry into business to produce durables take the prices of designs as given.

(vi) Demand is equal to supply of each good.

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[9] See details from Appendix A

3.1.1 Balanced Growth Equilibrium

In this model, since there is symmetry between different types of firms producing durables, they have the same level $\overline{x}$. Thus we can rewrite equation (3.3) as follows:

$$K = \eta A\overline{x} \qquad \Rightarrow \overline{x} = K/\eta A \tag{3.3'}$$

Then production function (3.5) can be rewritten as follows:

$$Y(H_A, L, x) = H_Y^{\alpha} L^{\beta} A\overline{x}^{1-\alpha-\beta} \tag{3.5'}$$

If we substitute equation (3.3') into equation (3.5'), we can obtain:

$$Y(H_A, L, x) = H_Y^{\alpha} L^{\beta} A\left(\frac{K}{\eta A}\right)^{1-\alpha-\beta}$$

$$= H_Y^{\alpha} L^{\beta} A^{\alpha+\beta} K^{1-\alpha-\beta} \eta^{\alpha+\beta-1} \tag{3.17}$$

Also we can write the common growth rate as follows:

$$g = \frac{\dot{C}}{C} = \frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} = \delta H_A \tag{3.18}$$

So the social planning problem is:

$$max \int_0^{\infty} \frac{C^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt \ ,$$

subject to:

$$\dot{K} = H_Y^{\alpha} L^{\beta} \eta^{\alpha+\beta-1} A^{\alpha+\beta} K^{1-\alpha-\beta} - C$$

$$\dot{A} = \delta H_A A$$

$$H_Y + H_A \leq H$$

After solving this optimization problem[10] the balanced growth rate g^* was found as follows:

$$g^* = \frac{\delta H - \Phi\rho}{\Phi\sigma + (1-\Phi)} = \delta H_A \qquad (3.19)$$

where Φ is equal to $\frac{\alpha}{\alpha+\beta}$. This means that if the economy has a larger total stock of human capital it will experience faster growth.

3.2 Criticism of Endogenous Growth

3.2.1 Existence of a Common Growth Rate

Mankiw et al (1992) show that a simple neoclassical model can explain up to 80 per cent of the cross-country variation in the log of per capita GDP, especially if it incorporates differences in human capital investment across countries. They modeled a human-capital-augmented Solow model. Their approach builds on a Solow model with exogenous technological progress. There is no research, no non-rivalry, no imperfect competition, and no learning to use newly-invented technologies.

They used a production function with constant returns to scale as follows:

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta} \qquad (3.20)$$

where A is the technical efficiency index and L is the labor supply. Also production function requires two types of capital; human capital (H) and physical capital (K).

There are some basic assumptions in their analysis. Firstly, the investment rates for human capital and physical capital are constant at s_k and s_h respectively. Second one is that both types of capital depreciate at a rate δ. The third assumption is that the growth rate of technical efficiency (g) is the same exogenous rate for all countries but

[10] Details of solution are shown in Appendix C

the growth rate of labor force (n) is different across countries. Because of the country's local factors, initial efficiency is assumed to vary across countries.

Under these basic assumptions the evolution of the economy is as follows:

$$\dot{k} = s_k y(t) - (n+g+\delta)k(t) \tag{3.21}$$

$$\dot{h}(t) = s_h y(t) - (n+g+\delta)h(t) \tag{3.22}$$

where $y = Y/AL$, $k = K/AL$ and $h = H/AL$. They found that economy converges to a steady state[11] which is defined by:

$$k^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n+g+\delta}\right)^{1/(1-\alpha-\beta)} \tag{3.23}$$

$$h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n+g+\delta}\right)^{1/(1-\alpha-\beta)} \tag{3.24}$$

and the growth in this model is given by:

$$\ln\frac{Y(t)}{L(t)} - \ln\frac{Y(0)}{L(0)} = \theta \ln A(0) + gt + \theta\frac{\alpha}{1-\alpha-\beta}\ln s_k + \theta\frac{\beta}{1-\alpha-\beta}\ln s_h - \theta\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) - \theta\ln\frac{Y(0)}{L(0)} + \varepsilon$$
(3.25)

where $\theta = 1 - e^{-\lambda t}$.

If the convergence rate is λ, the equations for the equilibrium path and convergence rate are written as follows:

$$\frac{d\ln y(t)}{dt} = \lambda\left[\ln y^* - \ln y(t)\right] \tag{3.26}$$

and

$$\lambda = (n+g+\delta)(1-\alpha-\beta) \tag{3.27}$$

---

[11] See details from Appendix D

Because of the negative coefficient in the equation (3.25), if we consider two different countries which have the same interest and efficiency rate, the poorer country will grow faster than the other one (transitional dynamics). This is because for a given investment rate, the poorer economy has lower stocks of capital and thus higher marginal product of capital.

After implementing the equation empirically, Mankiw et al (1992) concluded that:

"In contrast to endogenous growth models, this model predicts that countries with similar technologies and rates of accumulation and population growth should converge in income per capita. Yet this convergence occurs more slowly than the textbook Solow model suggests.

......our results indicate that the Solow model is consistent with the international evidence if one acknowledges the importance of human as well as physical capital. The augmented Solow model says that differences in saving, education, and population growth should explain cross-country differences in income per capita." (Mankiw et al, 1992)

3.2.2 The Jones Critique

According to R&D based models focusing on endogenous technological change, permanent change in potential determinants of long-run growth should lead to permanent changes in growth rates (Romer, 1990; Grossman and Helpman, 1991b; Aghion and Howitt, 1992). These models imply that increase in the amount of resources devoted to R&D leads to higher growth rates.

Jones (1995a) tested endogenous growth models by using time series data. In contradiction to endogenous growth models he concluded that despite the increase in the number of scientists and engineers engaged in R&D, growth of productivity has not risen. Jones argued that this is the evidence of decreasing returns in the production of new knowledge. He pointed out that since World War II growth rates in OECD countries have not shown any persistent upwards trend in spite of policy changes such as trade liberalization, increases in investment, increases in R&D efforts and increase in average years of schooling.

Jones (1995b) developed a semi-endogenous R&D based growth model which is consistent with empirical observations. He modified Romer's equation of technical knowledge growth (3.5) to accommodate decreasing returns in the production of new knowledge:

$$\frac{\dot{A}}{A} = \delta H_A^{\lambda} A^{\phi-1} \quad \Rightarrow \dot{A} = \delta H_A^{\lambda} A^{\phi} \tag{3.28}$$

where $\phi < 1$ and $\lambda \leq 1$. He found that long run growth is as follows:

$$g = \frac{\lambda n}{1-\phi} \tag{3.29}$$

The last equation implies that the long run growth rate is proportional to the rate of population growth which is an exogenous variable. This shows that long run growth is independent of policy. In this sense, his model is similar to Solow growth model. He summarized the differences and similarities with the other models as follows:

"...,the model differs from the Solow model in a crucial respect. Although the growth rate of the economy turns out to be a function of parameters that are typically thought of as exogenous, growth in this model is endogenous in the sense that it derives from the pursuit of new technologies by rational, profit maximizing agents." (Jones 1995b)

3.2.3 The Growth Accounting Results

Some results from growth accounting exercises which I have discussed before imply that technical progress is relatively unimportant determinant of growth. For instance, as I said before results of Jorgenson and Griliches (1967) demoted technological progress. They concluded that if there is no measurement error, total input largely explains the growth in total output.

Also Young (1995) found that the TFP growth is negligible. His empirical results are for Hon Kong, Singapore, South Korea, and Taiwan for the period 1966-1990. The estimates of TFP growth for these countries are 2.3 percent, 0.2 percent, 1.7 percent and 2.1 percent respectively.

3.2.4 R&D and Spillovers

R&D and spillovers derived from activities are critical variables in endogenous growth models. In these models R&D has a positive externality and productivity is increased by R&D of technological neighbours. In contrast to this positive externality Jaffe (1986) found the existence of negative externality. Also Aghion and Howitt (1992) argued that innovation creates "creative destruction". Moreover it is important to say that for empirical works, it is difficult to measure activities for R&D.

3.3 R&D, Patenting and Technological Change

Technological change has a crucial role for economic growth. As in the endogenous growth model, it is possible to influence rate of technological change by research and development decisions. Many empirical studies have shown that there is a positive relationship between research and productivity[12]. Also it is the fact that patented invention is positively related to R&D activities.

Howitt (2000) argued that endogenous growth theory can explain the cross country income differences and convergence more than neoclassical growth theory. He constructed a Schumpeterian growth model. He found that the common long-run growth rate among growing economies will be raised by an increase in R&D subsidy rate and investment rate.

Davidson and Segerstrom (1998) presented an endogenous growth model by using two different R&D activities. The first one is innovative R&D activities which develop higher quality products and the second of them is imitative R&D activities which copy the higher quality products. He argued that innovative R&D subsidies lead to faster economic growth while imitative R&D subsidies lead to slower economic growth under the key assumption of constant returns to scale for R&D activities.

Keely (2002) presented a summary of empirical studies about R&D and other factors that are related to R&D. This summary is presented in table 2. These studies

[12] It is important to point out that identifying proxies for ideas and knowledge is so difficult. Temple (1999) focused on the cross country empirical work carried out by economist. Some problems of empirical framework were discussed.

examine the existence of relation between R&D and other factors such as investment, sales growth, patent, output, market share.

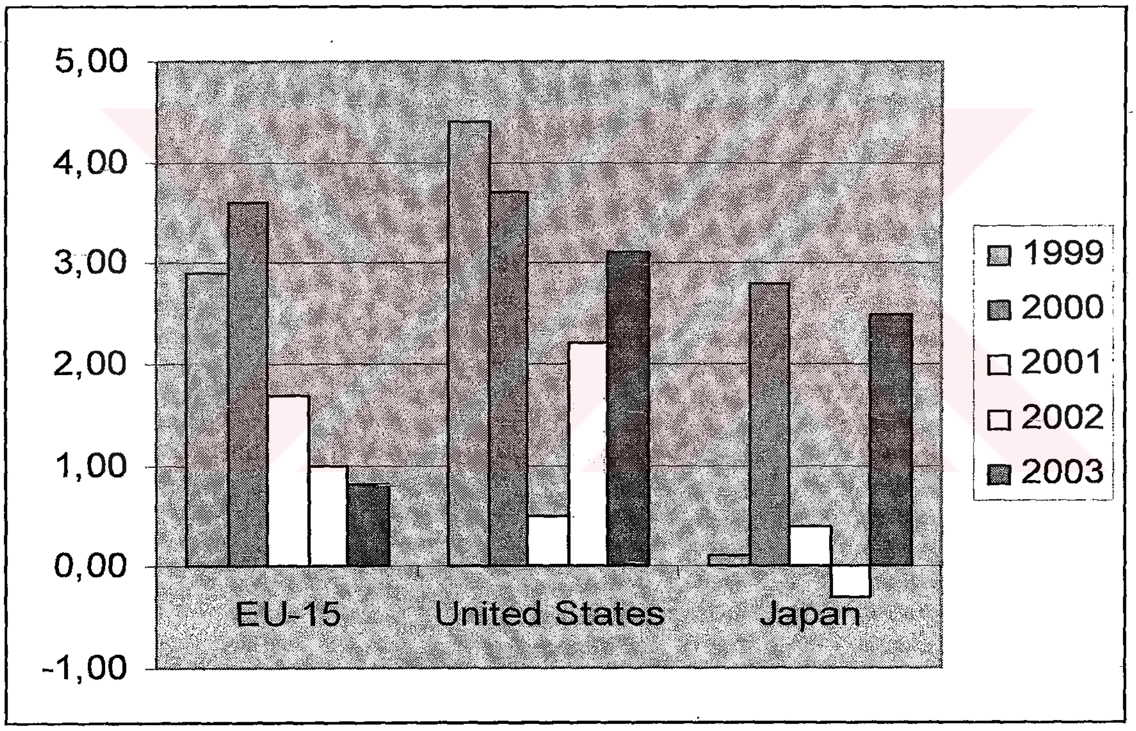
Table 2 Models to examine the relationship between R&D and related factors

Author	Data	Model	Results
Scherer (1982)	Industry-level data (245 industries) based on 443 large United States firms, divided into material goods and capital goods	Dependent variable: 1976-77 patents level or log Independent variable: 1974 investment level or log	Coefficient on log variables regressions between 0.443 and 0.686 and significantly different from zero.
Jaffe (1988)	537 United States firms with positive R&D in 1976	Dependent variable: 1976 log of R&D Independent variables: Log of sales, log of capital stock, market share, log of industry R&D	Coefficient on sales is between 0.877 and 0.98 and significantly different from zero; coefficient on capital stock is not statistically significantly different from zero.
Kleinknecht&Verspagen (1990)	Industry-level data (46 industries) based on Dutch firms with positive R&D	Dependent variable: 1983 R&D man years as a percentage of total manpower per industry Independent variable: Sales growth 1981-1983 or 1982-1983	Coefficient on sales growth is 0.11 and 0.14 and statistically significantly different from zero.
Geroski&Walters (1995)	1948-83 United Kingdom data on firms with quality weighted innovations and patents in the United States	Dependent variable: Time-differenced log of innovations Independent variables: Time-differenced lagged log of innovations, of output and of patents	Coefficient on the change in the log of output is 1.2 but statistically insignificant. The other coefficients are less than one.

Source: Keely (2002, pp. 288)

4. EUROPEAN ECONOMIC PERFORMANCES AND TECHNOLOGY

In the last two years, overall economic performance of Europe has fallen down gradually like the other economies in the different regions such as Japan and US. Figure 6 shows the comparisons of the real GDP growth rate between EU-15, US and Japan. The growth rate of the European Union was 3,5% in 2000 but this rate has been declined to 1,6% and 1% in 2001 and 2002 respectively. In 2003 economy grew by only 1,2%.



Data: OECD Statistical Compendium (2004)

Figure 6 - Real GDP Growth Rates

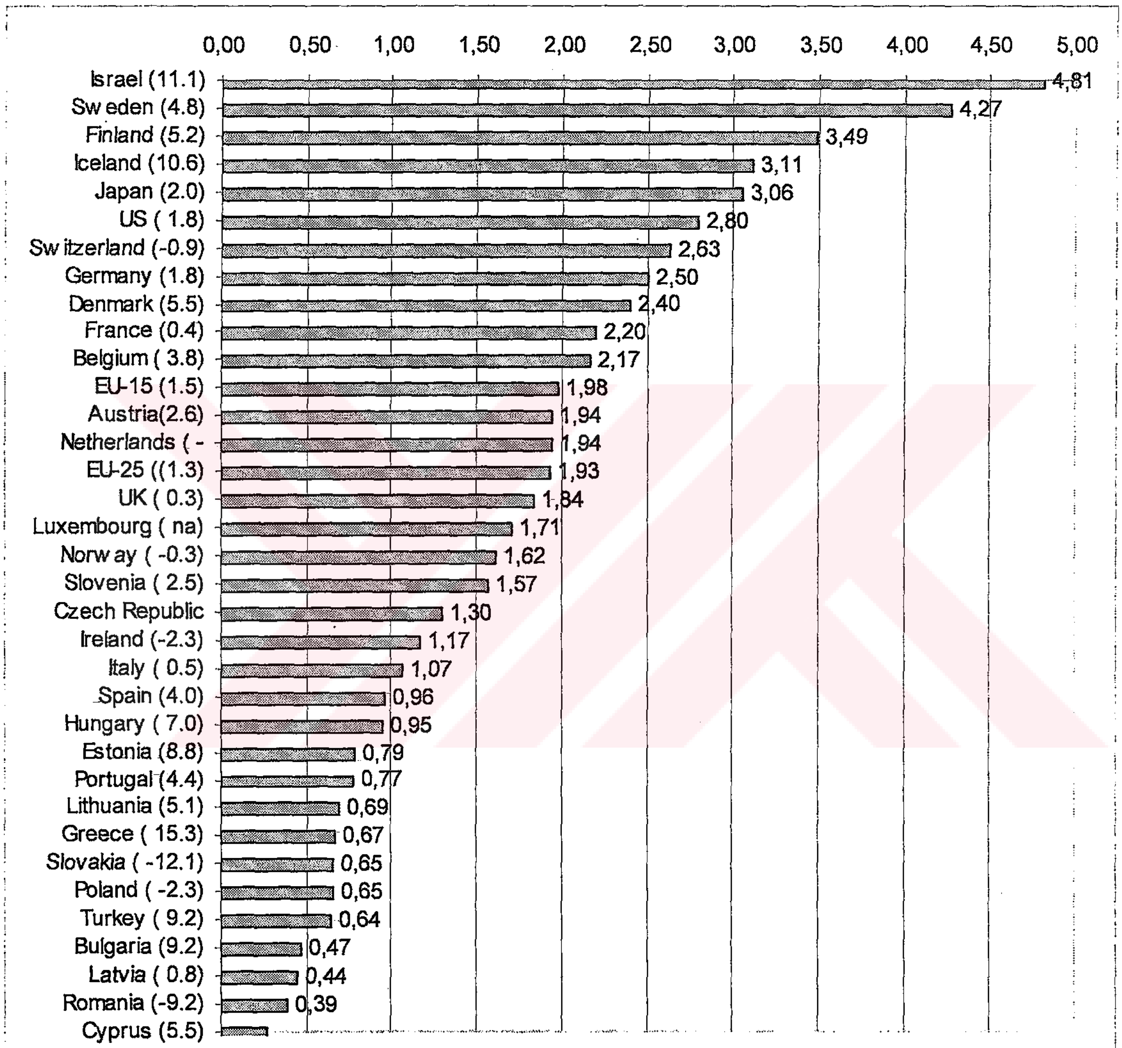
Transforming economy into the knowledge-based economy becomes more important for the European Union. Lisbon strategy has a crucial role for this transition. The Lisbon Strategy is a commitment to bring about economic, social and environmental renewal in the European Union. The European Council in Lisbon set out a ten-year strategy in March 2000. The aim of this strategy is to make the European Union the world's most dynamic and competitive economy. Lisbon strategy requires three main reforms: The first one is a further consolidation and unification of the European economic environment, the second of them is improvement of the creation, absorption, diffusion and exploitation of knowledge and the last one is modernization of the social model. So research and innovation are important to reach the Lisbon objectives.

It is the fact that R&D, technological progress and innovation are the most important means to increase productivity and economic growth. Many empirical and theoretical works show the importance of these factors. Europe needs to invest more in R&D and to expand the exploitation of technological innovation.

Spending more for R&D expenditure, purchasing of new capital, investment in highly skilled human capital such as researchers and PhDs, investment in education system and modernization of public services such as e-government allow the knowledge creation and diffusion. If these investments and activities are realized in an effective way, productivity, competitiveness and economic growth are increased. In this sense these are the main indicators of the knowledge-based economy.

By using the knowledge-based economy indicators, European Commission (2004) found that if we consider EU-15 as a whole, it has a lower investment level in 2000 than the US and Japan. In this comparison gross domestic expenditure on R&D, number of new science and technology PhDs per capita, number of researchers per capita, gross fixed capital formation and e-government are used as indicators. Also it is found that slowing down in investment leads to significant decline in its performance. So EU-15 should increase the effective investment to close the gap with the US. According to data collected by European Commission, the average annual real growth rates of R&D investment are 4.8 and 4.5 for US and EU-15 economies respectively. So there is no huge difference between US and EU-15 in terms of the real growth rates of the R&D investment. In spite of this investment trend in EU-15, the gap between EU-15 and US has increased. In order to reduce the R&D investment gap relative to the US, EU-15 should increase its annual rate of growth.

Figure 7 shows the R&D intensities for 2001 and average annual growth rates of R&D intensity for the period 1997-2001 for Japan, US and some countries in Europe. R&D intensity can be measured by Gross Domestic Expenditure as a percentage of GDP.



Source: European Commission, 2004, pp.22

Figure 7 - R&D intensity for 2001 and average annual growth rates of R&D intensity (%) for the period 1997-2001

4.1 Results from Growth Accounting

In this section I regressed the growth rate of output, $\dot{Y}/Y$, on the growth rates of inputs, $\dot{K}/K$ and $\dot{L}/L$ in the form of equation (1.31). Thus the intercept measures the total factor productivity growth, and the coefficients of growth rates of input measures market share of capital and labor. So the rate of growth of total factor productivity is defined as the difference between the rate of growth of real product and the rate of growth of real factor input.

To make growth accounting analysis, I used the panel data. One of the advantages of using panel data techniques is that they allow one to control for omitted variables which are persistent over time. Another advantage is using several lags of the regressors which reduce the measurement error and endogeneity biases. In my analysis the static panel model is used:

$$\left(\dot{Y}/Y\right)_{it} = g + \left(\frac{F_K K}{Y}\right).\left(\dot{K}/K\right)_{it} + \left(\frac{F_L L}{Y}\right).\left(\dot{L}/L\right)_{it} + \lambda_t + \eta_i + \varepsilon_{it} \qquad (4.1)$$

where λ_t and η_i are time and individual specific effects respectively and, $t = 1971,...,2000$ and $i = 1,...,10$. There are 10 cross-section observations and the total number of observations is 300.

I analyzed the 10 of the EU-15 countries which have the available data for this construction for the period 1971-2000. All data are taken from OECD Statistical Compendium (2004). To measure the output growth I used the gross domestic product volume of these countries with constant purchasing power parity. Also the stock of capital was proxized by total gross fixed capital formation at 1995 prices of these countries. Finally the stock of labor is taken to be number of employed people. This analysis covers Spain, United Kingdom, Denmark, Finland, France, Germany, Ireland, Italy, Luxemburg and Sweden.

The estimation method which I have used here is least squares dummy variables which uses individual dummies in the OLS (Ordinary Least Squares) regression. Table 3 reports the results of this analysis for growth accounting.

Table 3 Estimation of Panel Data

	Coefficient	Std. Error	t-value	t-probability
$g_{capital}$	0.165452	0.01243	13.3	0.000
g_{labour}	0.424826	0.05034	8.44	0.000
Constant	2.30641	0.03065	75.3	0.000
I_1	-0.576393	0.007672	-75.1	0.000
I_2	-0.693218	0.01611	-43.0	0.000
I_3	0.192404	0.01776	10.8	0.000
I_4	-0.399111	0.009465	-42.2	0.000
I_5	-0.402233	0.05735	-7.01	0.000
I_6	1.35156	0.04284	31.5	0.000
I_7	-0.202723	0.01439	-14.1	0.000
I_8	0.394050	0.07479	5.27	0.000
I_9	-0.679733	0.01495	-45.5	0.000

* I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8, I_9 are the individual dummies for United Kingdom, Denmark, Finland, France, Germany, Ireland, Italy, Luxemburg and Sweden respectively.

As we can see from table 3 constant term and other coefficients are statistically significant. In this table each dummy variable represents the differences for constant term across the countries. Since the constant term represent the TFP growth rate for Spain, we can calculate the TFP growth rate, $g(TFP)$, for the other countries as follows:

$$g(TFP_i) = \text{Constant} + I_i$$

I concluded all the results in table 4. We can say that the result is that on average 75 percent of the rise in gross domestic product to be attributable to technical progress.

Table 4 Growth Accounting Results for European Countries

Country	Growth Rate of GDP	Contribution from Capital	Contribution from Labour	TFP Growth Rate
Spain	3,07	0,56 (18%)	0,20 (6%)	2,31 (75%)
United Kingtom	2,34	0,44 (19%)	0,17 (7%)	1,73 (74%)
Denmark	2,18	0,36 (17%)	0,21 (10%)	1,61 (74%)
Finland	2,91	0,27 (9%)	0,14 (5%)	2,5 (86%)
France	2,51	0,43 (17%)	0,18 (7%)	1,91 (76%)
Germany	2,70	0,27 (10%)	0,53 (20%)	1,9 (70%)
Ireland	5,22	0,89 (17%)	0,67 (13%)	3,66 (70%)
Italy	2,51	0,30 (12%)	0,10 (4%)	2,1 (84%)
Luxemburg	4,35	0,75 (17%)	0,90 (21%)	2,7 (62%)
Sweeden	2,04	0,30 (15%)	0,12 (6%)	1,63 (80%)

5. CONCLUSION

This thesis attempted to review some leading macroeconomic growth models such as Classical, Keynesian, Neoclassical and Endogenous growth models which were discussed and compared in terms of the technological view. We can write the types of production which is used in these macroeconomic growth models as follows:

(1) $Y_t = A_t f(L_t)$ Ricardo (1817)

(2) $Y = A(t) K^{\alpha} L^{1-\alpha}$ Solow (1956)

(3) $Y_j = A(K) K_j^{\alpha} L_j^{1-\alpha}$ Arrow (1962) (Learning by doing)

(4) $Y_j = A(R) F(R_j, K_j, L_j)$ Romer (1986) (R=Knowledge)

(5) $Y_j = A(H) F(K_j, H_j)$ Lucas (1988) (H=Human Capital)

The first two equations represent an autonomous innovation and the others use the innovation as endogenous.

In the Ricardian model with highly productive land abundant, output is more than sufficient to provide subsistence to agricultural workers. This initially yields high profits and it leads to increasing innovation and expanding the demand for labor. Higher wages stimulate an expanded population. But he stressed on the diminishing returns which means that the increasing in profits, wages, population and output will become smaller than the previous one. Until the output level becomes sufficient for only subsistence wages this process continues. The process ends in the stationary state. But Ricardo and other classical economists claimed that innovation does occur and this leads to expanding by shifting the production functions. In the Ricardian model examination of innovation process is not sufficient to explain the sources of innovation and differences in growth rates across the countries.

The original Solow model is the first model of neoclassical theory. It's representation of innovation is not much different from Ricardo's. As in the Ricardo's model innovation is seen as an autonomous variable. The model also assumes that there are diminishing returns to capital. Since the wealthier economies have more capital stock than poorer economies, this assumption allows the convergence of productivities and per-capita incomes in different economies. The merit of Solow was providing a solution to the knife-edge dynamics posed by Harrod (1939) and Domar (1946). For Harrod-Domar convergence to the equilibrium growth path is possible by only chance, thus each economy can have different growth rates.

In recent years some economists have developed a class of models, called endogenous growth models. In these models long-term rate of economic growth is not determined exogenously, as in the neoclassical model.

As one of the first authors, Kenneth Arrow published an article 'The Economic Implications of Learning by Doing' in 1962. It became the most reputable reference for the literature on endogenous evolution of technical progress, education and growth. The other leading paper is written by Uzawa (1965) who stressed on the existence of research sector in which technology can be produced.

Following in the tradition of Uzawa (1965), Romer (1986) developed a model which explains long-run rate of growth endogenously. In his model the crucial endogenous variable is the amount of resources allocated to the technology producing sector.

Being another important attempt to make growth model endogenous, the Lucas model of 1988 can be described as taking the innovation function as A(H), where H is the investment in human capital of the economy. The main engine of growth is the accumulation of human capital and that human capital is the main source of differences in living standards among countries[13]. He also argued that human capital investment has important spillover effects.

[13] Mankiw et al (1992), also suggested that human capital is important for growth.

In conclusion, both neoclassical and endogenous growth theories focus on the technological change as a source of economic growth. In the neoclassical growth model the long-run growth rate of output is determined by the rate of technical progress which is exogenous. All endogenous variables grow at the same rate in the equilibrium, so there is a balanced growth. Full employment of capital and labor exist at all time. On the other hand the new growth theories provide an endogenous model to explain long-run growth. In contrast to neoclassical growth model, these models use the assumption of increasing returns to scale. Thus the higher rate of growth of capital is permanent.

I believe that endogenous growth models provide a richer framework for the growth theory than the neoclassical model. Even though empirical analyses lead to thinking about many questions, we know much more about the growth factor than before.

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APPENDICES

APPENDICES

A. Optimal Consumption for an Infinitely-Lived Household

The preferences of each identical individual are demonstrated as time discounted utility function form:

$$\int_0^{\infty} \frac{C_t^{1-\sigma}-1}{1-\sigma} e^{-\rho t} dt \tag{A.1}$$

where $\sigma \rangle 0$ is the inverse of the intertemporal elasticity of substitution, C is consumption and ρ is the rate of time discount. At each point in time, individual has a budget constraint:

$$\dot{a}_t = a_t r_t + y_t - C_t \tag{A.2}$$

where a_t and y_t denote existing assets and income at time t respectively. Also $a_t r_t$ represents interest earnings from existing assets. Thus equation (A.2) shows that the change in the stock of real assets held by the household $(\dot{a}_t)$ is equal to difference between current flow of earnings and current consumption. The agent chooses an optimal path for consumption to maximize equation (A.1) subject to equation (A.2). The current value Hamiltonian for this optimization problem is as the following:

$$H_t^c = \frac{C_t^{1-\sigma}}{1-\sigma} + \lambda_t \left(a_t r_t + y_t - C_t\right) \tag{A.3}$$

where λ_t is the shadow price of wealth. This equation represents the current flow of utility plus the increase in the value of the stock of assets. The Pontryagin conditions[14] can be written as the following:

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[14] The typical continuous time maximization principle problem with discounting is the control problem:

$(i) \quad \frac{\partial H^c}{\partial C} = C^{-\sigma} - \lambda = 0$ (A.5)

$(ii) \quad -\frac{\partial H^c}{\partial a} = -\lambda r = \dot{\lambda} - \rho\lambda$ (A.6)

$\Rightarrow \frac{\dot{\lambda}}{\lambda} = \rho - r_t$ (A.6')

Equation (A.5) can be written as:

$C^{-\sigma} = \lambda$ (A.7)

If we take logarithms of both sides we can obtain:

$ln C = (-1/\sigma) ln\lambda$ (A.8)

By differentiating with respect to time we can find the time path of the consumption:

$\frac{\dot{C}}{C} = -\frac{1}{\sigma}\frac{\dot{\lambda}}{\lambda}$ (A.9)

$\max_{\{u(t)\}} J = \int_0^T e^{-\delta t} V(x,u)\,dt$

s.t. $\dot{x} = f(x,u)$

$x(0) = x^0$, $x(T) = x^T$

The *current value of Hamiltonian function is:*

$H_c(x,u) = V(x,u) + \mu f(x,u)$ where $H_c = He^{\delta t}$ and $\mu = \lambda e^{\delta t}$

The optimization conditions are:

$(i) \frac{\partial H_c}{\partial u_t} = 0 \qquad 0 \le t \le T$

$(ii) \dot{\mu} = -\frac{\partial H_c}{\partial x_t} + \delta\mu \qquad 0 \le t \le T$

$(iii) \dot{x} = \frac{\partial H_c}{\partial \mu} = f(x_t, u_t)$

$(iv) \mu(T)e^{-\delta t} = 0$

$(v) x(0) = x^0$

If we substitute (A.6') into this equation we can yield:

$$\frac{\dot{C}}{C}=\frac{1}{\sigma}(r-\rho) \qquad \text{(A.10)}$$

B.Maximization of Monopoly Profit

The maximization problem of a monopolist is:

$$\pi = \max_x p(x)x - r\eta x \qquad (B.1)$$

The inverse demand function for durables is:

$$(1-\alpha-\beta)H_Y^{\alpha}L^{\beta}x(i)^{-\alpha-\beta} = p(i) \qquad (B.2)$$

Substituting (B.2) into (B.1) we can rewrite profit function as follows:

$$\pi = \max_x (1-\alpha-\beta)H_Y^{\alpha}L^{\beta}x^{1-\alpha-\beta} - r\eta x \qquad (B.1')$$

If we take the first derivative of this equation we can obtain:

$$(1-\alpha-\beta)^2 H_Y^{\alpha}L^{\beta}x^{-\alpha-\beta} - r\eta = 0 \qquad (B.3)$$

We can rewrite (B.3) in terms of p(i):

$$P(i)(1-\alpha-\beta) = r\eta \qquad (B.4)$$

If we leave p(i) alone,

$$p(i) = r\eta/(1-\alpha-\beta) \qquad (B.5)$$

Substituting (B.5) into (B.1) the profit function of profit maximizer monopolist can be found as follows:

$$\pi = \left[r\eta/(1-\alpha-\beta)\right]x - r\eta x$$

$$= \left(\frac{1}{1-\alpha-\beta} - 1\right)r\eta x$$

$$= \left(\frac{1-(1-\alpha-\beta)}{1-\alpha-\beta} \right) r\eta x$$

$$= \frac{r\eta}{1-\alpha-\beta}(\alpha+\beta)x$$

$$= (\alpha+\beta)\,\overline{px} \tag{B.6}$$

C. Calculation of Balanced Growth Rate

The optimization problem is:

$$max \int_0^\infty \frac{C^{1-\sigma}-1}{1-\sigma}e^{-\rho t}dt \ , \tag{C.1}$$

subject to:

$$\dot{K} = H_Y^\alpha L^\beta \eta^{\alpha+\beta-1} A^{\alpha+\beta} K^{1-\alpha-\beta} - C$$

$$\dot{A} = \delta H_A A$$

$$H_Y + H_A \leq H$$

Then the current value of Hamiltonian is as follows:

$$H_c = \frac{C^{1-\sigma}}{1-\sigma} + \lambda\left[\eta^{\alpha+\beta-1} A^{\alpha+\beta}\left(H - H_A\right)^\alpha L^\beta K^{1-\alpha-\beta} - C\right] + \mu\delta H_A A \tag{C.2}$$

The optimization conditions are:

i) $$\frac{\partial H_c}{\partial C} = C^{-\sigma} - \lambda = 0 \tag{C.3}$$

ii) $$\frac{\partial H_c}{\partial H_A} = -\lambda\left[\eta^{\alpha+\beta-1} A^{\alpha+\beta}\left(H - H_A\right)^{\alpha-1} L^\beta K^{1-\alpha-\beta}\right] + \mu\delta A = 0 \tag{C.4}$$

iii) $$\dot{\lambda} = \rho\lambda - \frac{\partial H_c}{\partial K} \tag{C.5}$$

iv) $$\dot{\mu} = \rho\mu - \frac{\partial H_c}{\partial A} \tag{C.6}$$

We can rewrite equation (C.3) as follows:

$$C^{-\sigma} = \lambda \tag{C.3'}$$

Taking the logarithms of both sides and then first derivatives with respect to time t, we can obtain this relationship:

$$\frac{\dot{C}}{C} = -\sigma\frac{\dot{\lambda}}{\lambda} \qquad \text{(C.7)}$$

This the fact that in the case of balanced growth some conditions such that $\dot{\mu}/\mu = \dot{\lambda}/\lambda$ and $\dot{C}/C = \dot{A}/A$ should be satisfied. Thus we can write:

$$-\sigma\left(\dot{A}/A\right) = \dot{\mu}/\mu \quad \Rightarrow -\sigma\delta H_A = \dot{\mu}/\mu \qquad \text{(C.8)}$$

where $\dot{A}/A = \delta H_A$.

Also we can rewrite equation (C.4) as follows:

$$\lambda\left[\Omega\left(H - H_A\right)^{-1}\right] = \mu\delta A \qquad \text{(C.4')}$$

where Ω reflects the term $\left[\eta^{\alpha+\beta-1}A^{\alpha+\beta}\left(H - H_A\right)^{\alpha} L^{\beta}K^{1-\alpha-\beta}\right]$. If we leave Ω alone, we can obtain:

$$\Omega = \frac{\mu\delta A}{\lambda}\left(H - H_A\right) \qquad \text{(C.9)}$$

By using equation (C.6) we can write:

$$\dot{\mu} = \rho\mu - \lambda\Omega A^{-1}\left(\alpha+\beta\right) - \mu\delta H_A \qquad \text{(C.10)}$$

Dividing by μ of both sides, we obtain:

$$\dot{\mu}/\mu = \rho - \frac{1}{\mu}\lambda\Omega A^{-1}\left(\alpha+\beta\right) - \delta H_A \qquad \text{(C.11)}$$

If we substitute (C.9) into (C.11), evolution equation can be rewritten as follows:

$$\dot{\mu}/\mu = \rho - \frac{\lambda}{\mu}(H - H_A)\frac{\delta\mu}{\alpha\lambda}AA^{-1}(\alpha+\beta) - \delta H_A$$

$$= \rho - \frac{\delta}{\alpha}(H - H_A)(\alpha+\beta) - \delta H_A \qquad \text{(C.12)}$$

Since the equation (C.8), (C.12) can be rewritten as:

$$-\sigma\delta H_A = \rho - \frac{\delta}{\alpha}(\alpha+\beta)H + \frac{\delta}{\alpha}H_A(\alpha+\beta) - \delta H_A$$

$$= \rho - \delta\left[\frac{\alpha+\beta}{\alpha}H - H_A\frac{\alpha+\beta}{\alpha} + H_A\right]$$

$$= \rho - \delta\left[\frac{(\alpha+\beta)}{\alpha}H - \frac{\beta}{\alpha}H_A\right] \qquad \text{(C.13)}$$

This is the fact that $g = \delta H_A$. To find the growth rate g, we should leave this term alone. We can rewrite equation (C.13) as follows:

$$-\sigma\delta H_A = \rho - \delta\left(\frac{\alpha+\beta}{\alpha}\right)H + \delta\frac{\beta}{\alpha}H_A$$

$$\delta H_A\left(-\sigma - \frac{\beta}{\alpha}\right) = \rho - \delta\left(\frac{\alpha+\beta}{\alpha}\right)H$$

If we leave δH_A alone,

$$\delta H_A = \frac{\delta H\left(\frac{\alpha+\beta}{\alpha}\right) - \rho}{\sigma + \frac{\beta}{\alpha}} \qquad \text{(C.14)}$$

Multiplying both denominator and numerator with $\frac{\alpha}{\alpha+\beta}$, we can rewrite this equation as follows:

$$\delta H_A = \frac{\delta H - \rho \frac{\alpha}{\alpha+\beta}}{\sigma\left(\frac{\alpha}{\alpha+\beta}\right) + \frac{\beta}{\alpha}\frac{\alpha}{\alpha+\beta}}$$

$$= \frac{\delta H - \rho \frac{\alpha}{\alpha+\beta}}{\sigma\left(\frac{\alpha}{\alpha+\beta}\right) + \frac{\beta}{\alpha+\beta}} \tag{C.15}$$

If we called the term $\frac{\alpha}{\alpha+\beta}$ as Φ, the balanced growth rate can be written as:

$$g^* = \frac{\delta H - \Phi\rho}{\Phi\sigma + (1-\Phi)} \tag{C.16}$$

D. Solow Model with Human Capital

Suppose that the aggregate production function is:

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta} \quad \text{(D.1)}$$

where K and H are the aggregate stocks of physical capital and human capital, L is the size of the labour force and A is a productivity index. So the quantities per effective unit of labour are $y = Y/AL$, $k = K/AL$ and $h = H/AL$. We can rewrite (D.1) as follows:

$$Y = ALk^{\alpha} h^{\beta} \quad \text{(D.2)}$$

There are constant rates of population growth and exogenous technical progress ($\dot{L}/L = n$ and $\dot{A}/A = g$). The fractions of gross domestic product are assumed to be devoted to the investment in physical capital (s_k) and human capital (s_h) which are constant over time. Under these assumptions the accumulation of productive factors is described by:

$$\dot{K} = s_k Y - \delta K \quad \text{(D.3)}$$

$$\dot{H} = s_h Y - \delta H \quad \text{(D.4)}$$

where the depreciation rate δ is assumed to be the same for both types of capital.

Since $k = K/AL$ and $h = H/AL$, taking logs of both sides of these expression we can obtain as follows:

$$\ln k = \ln K - \ln A - \ln L \quad \text{(D.5)}$$

$$\ln h = \ln H - \ln A - \ln L \quad \text{(D.6)}$$

If we differentiate these equations with respect to the time, we can obtain:

$$\frac{\dot{k}}{k}=\frac{\dot{K}}{K}-\frac{\dot{L}}{L}-\frac{\dot{A}}{A} \quad \text{(D.7)}$$

This means that the rate of growth of physical capital stock per effective unit of labor is the difference between the rates of growth of the aggregate physical capital stock and the labor force, measured in efficiency units. Thus we can rewrite equation (D.7) as follows:

$$\frac{\dot{k}}{k}=\frac{\dot{K}}{K}-n-g \quad \text{(D.8)}$$

Also differentiating the equation (D.6) we can obtain:

$$\frac{\dot{h}}{h}=\frac{\dot{H}}{H}-n-g \quad \text{(D.9)}$$

If we substitute equation (D.3) into the equation (D.8), we can get:

$$\frac{\dot{k}}{k}=\frac{s_k Y-\delta K}{K}-n-g$$

$$=\frac{s_k Y}{K}-\delta-n-g \quad \text{(D.10)}$$

Dividing and multiplying by AL the first term of the last expression we can find:

$$\frac{\dot{k}}{k}=\frac{s_k Y}{AL}\frac{AL}{K}-\delta-n-g$$

$$=s_k y k^{-1}-\delta-n-g \quad \text{(D11)}$$

If we substitute equation (D.2) into (D.11),

$$\frac{\dot{k}}{k}=s_k k^{\alpha-1}h^{\beta}-(\delta+g+n) \quad \text{(D.12)}$$

In similar way we can write:

$$\frac{\dot{h}}{h} = s_h k^{\alpha} h^{\beta-1} - (\delta + g + n) \qquad \text{(D.13)}$$

Setting $\dot{k}$ and $\dot{h}$ equal to zero in equations (D.12) and (D.13), we can solve for the steady state values of k and h. We have

$$\dot{k} = 0 \Rightarrow s_k k^{\alpha-1} h^{\beta} = (\delta + n + g) \qquad \text{(D.14)}$$

$$\dot{h} = 0 \Rightarrow s_h k^{\alpha} h^{\beta-1} = (\delta + n + g) \qquad \text{(D.15)}$$

If we equate (D.14) and (D.15) we obtain:

$$s_h k^{\alpha} h^{\beta-1} = s_k k^{\alpha-1} h^{\beta} \Rightarrow h = \frac{s_h}{s_k} k \qquad \text{(D.16)}$$

Substituting (D.16) into (D.14), we see that

$$s_k k^{\alpha-1} \left(\frac{s_h}{s_k} k \right)^{\beta} = (\delta + n + g) \Rightarrow s_k^{1-\beta} s_h^{\beta} k^{\alpha+\beta-1} = (\delta + g + n) \qquad \text{(D.17)}$$

If we leave k alone we can find the steady state value of k:

$$k^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{(\delta + g + n)} \right)^{1/(1-\alpha-\beta)} \qquad \text{(D.18)}$$

Substituting (D.18) into (D.16) steady state value of h can be written as follows:

$$h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{(\delta + g + n)} \right)^{1/(1-\alpha-\beta)} \qquad \text{(D.19)}$$

We can define output per efficiency unit of labor as follows:

$$y=\frac{Y}{AL}=k^{\alpha}h^{\beta} \tag{D.20}$$

Substituting (D.18) and (D.19) into the last expression we can find the steady state value of output per efficiency unit of labor;

$$y^{*}=\left(\frac{s_k^{1-\beta}s_h^{\beta}}{(\delta+g+n)}\right)^{\alpha/(1-\alpha-\beta)}\left(\frac{s_k^{\alpha}s_h^{1-\alpha}}{(\delta+g+n)}\right)^{\beta/(1-\alpha-\beta)}$$

$$=\left(\frac{s_k}{(\delta+g+n)}\right)^{\alpha/(1-\alpha-\beta)}\left(\frac{s_h}{(\delta+g+n)}\right)^{\beta/(1-\alpha-\beta)} \tag{D.21}$$

Taking logarithms the last expression can be rewritten in the form

$$\ln y^{*}=\frac{\alpha}{1-\alpha-\beta}\ln s_k-\frac{\alpha}{1-\alpha-\beta}\ln(\delta+n+g)+\frac{\beta}{1-\alpha-\beta}\ln s_h-\frac{\beta}{1-\alpha-\beta}\ln(\delta+n+g)$$

(D.22)

D.1 Linear Approximation and Stability of the System:

Let $\ln k=a$ and $\ln h=b$. Thus $k=e^{a}$ and $h=e^{b}$. If we differentiate a and b,

$$\dot{a}=\frac{\dot{k}}{k} \quad \text{and} \quad \dot{b}=\frac{\dot{h}}{h}$$

Using these last expressions we can rewrite (D.12) and (D.13) as follows:

$$\dot{a}=s_k e^{(\alpha-1)a}e^{\beta b}-(\delta+n+g)=F(a,b) \tag{D.23}$$

$$\dot{b}=s_h e^{\alpha a}e^{(\beta-1)b}-(\delta+n+g)=G(a,b) \tag{D.24}$$

Setting $\dot{a}$ and $\dot{b}$ equal to zero, we see that in the steady state,

$$s_h e^{\alpha a}e^{(\beta-1)b}=(\delta+n+g)=s_k e^{(\alpha-1)a}e^{\beta b} \tag{D.25}$$

Taking the partial derivatives of the functions $F(a,b)$ and $G(a,b)$ with respect to a and b, and using (D.25), we can obtain the following equations:

$$F_a = (\alpha-1)s_k e^{(\alpha-1)a}e^{\beta b} = -(1-\alpha)(\delta+n+g) \quad \text{(D.26)}$$

$$F_b = \beta s_k e^{(\alpha-1)a}e^{\beta b} = \beta(\delta+n+g) \quad \text{(D.27)}$$

$$G_a = \alpha s_h e^{\alpha a}e^{(\beta-1)b} = \alpha(\delta+n+g) \quad \text{(D.28)}$$

$$G_b = (\beta-1)s_h e^{\alpha a}e^{(\beta-1)b} = -(1-\beta)(\delta+n+g) \quad \text{(D.29)}$$

Let $\ln y = c$. Using (D.20) we can write,

$$c = \alpha \ln k + \beta \ln h \Rightarrow c = \alpha a + \beta b \quad \text{(D.30)}$$

Thus the current deviation of c from its steady state value is as follows:

$$\tilde{c} = \alpha\tilde{a} + \beta\tilde{b} \quad \text{(D.31)}$$

where $\tilde{c} = c - c^*$, $\tilde{a} = a - a^*$ and $\tilde{b} = b - b^*$

Using Taylor's formula we have

$$F(a,b) \cong F_a\tilde{a} + F_b\tilde{b} = -(1-\alpha)(\delta+n+g)\tilde{a} + \beta(\delta+n+g)\tilde{b}$$

$$= (\delta+n+g)(\tilde{c}-\tilde{a}) \quad \text{(D.32)}$$

$$G(a,b) \cong G_a\tilde{a} + G_b\tilde{b} = \alpha(\delta+n+g)\tilde{a} - (1-\beta)(\delta+n+g)\tilde{b}$$

$$= (\delta+n+g)(\tilde{c}-\tilde{b}) \quad \text{(D.33)}$$

Hence the linear approximation to the system is of the form,

$$\dot{a} = -(1-\alpha)(\delta+n+g)\tilde{a} + \beta(\delta+n+g)\tilde{b} = (\delta+n+g)(\tilde{c}-\tilde{a}) \quad \text{(D.34)}$$

$$\dot{b} = \alpha(\delta+n+g)\tilde{a} - (1-\beta)(\delta+n+g)\tilde{b} = (\delta+n+g)(\tilde{c}-\tilde{b}) \tag{D.35}$$

The coefficient matrix can be written as follows:

$$A = \begin{pmatrix} -(1-\alpha)(\delta+n+g) & \beta(\delta+n+g) \\ \alpha(\delta+n+g) & -(1-\beta)(\delta+n+g) \end{pmatrix}$$

Hence

$$trA = -(2-\alpha-\beta)(\delta+n+g) < 0$$

$$\det A = (1-\alpha)(1-\beta)(\delta+n+g)^2 - \alpha\beta(\delta+n+g)^2$$

$$= (1-\alpha-\beta+\alpha\beta-\alpha\beta)(\delta+n+g)^2$$

$$= (1-\alpha-\beta)(\delta+n+g)^2 > 0$$

$$\Delta = tr^2 - 4\det = (2-\alpha-\beta)^2(\delta+n+g)^2 - 4(1-\alpha-\beta)(\delta+n+g)^2$$

$$= (\delta+n+g)^2\left\{\left[1+(1-\alpha-\beta)\right]^2 - 4(1-\alpha-\beta)\right\}$$

$$= (\delta+n+g)^2\left[1+2(1-\alpha-\beta)+(1-\alpha-\beta)^2 - 4(1-\alpha-\beta)\right]$$

$$= (\delta+n+g)^2\left[1-2(1-\alpha-\beta)+(1-\alpha-\beta)^2\right]$$

$$= (\delta+n+g)^2\left[1-(1-\alpha-\beta)^2\right]$$

$$= (\delta+n+g)^2(\alpha+\beta)^2 > 0$$

from where

$$\lambda_1, \lambda_2 = \frac{tr \pm \sqrt{tr^2 - 4\det}}{2} = \frac{-(2-\alpha-\beta)(\delta+n+g) \pm (\delta+n+g)(\alpha+\beta)}{2}$$

$$= (\delta+n+g)\frac{(\alpha+\beta-2) \pm (\alpha+\beta)}{2}$$

and therefore

$$\lambda_1 = -(\delta+n+g) \text{ and } \lambda_2 = -(\delta+n+g)(1-\alpha-\beta)$$

The eigenvalues are negative real numbers and the steady state of the system is stable.

D.2 Derivation of Convergence Equation:

Using (D.34) and (D35) and the fact that $c = \alpha a + \beta b$ we have

$$\dot{c} = \alpha\dot{a} + \beta\dot{b} = (\delta+n+g)\left[\alpha(\tilde{c}-\tilde{a}) + \beta(\tilde{c}-\tilde{b})\right] = (\delta+n+g)\left[(\alpha+\beta)\tilde{c} - \tilde{c}\right]$$

(D.36)

If we leave $\dot{c}$ alone,

$$\dot{c} = -\lambda\tilde{c} \quad \Rightarrow \dot{c} = -\lambda(c - c^*) \qquad \text{(D.37)}$$

where $\lambda = (1-\alpha-\beta)(\delta+n+g)$ and $\tilde{c} = c - c^*$. If we consider the period from t to t+d, the final value of c is given by

$$c_{t+d} = c_t e^{-\lambda d} + c^*\left(1 - e^{-\lambda d}\right) \qquad \text{(D.38)}$$

Hence, output per efficiency unit of labor converges to its steady state value at an exponential rate λ that depends on the degree of returns to scale $(1-\alpha-\beta)$ the rate of depreciation, population growth and technical progress.

If we want to rewrite (D.38) in terms of the log of output per worker (q) we obtain,

$$q = c + z$$

where z is $\ln A$. We have

$$q_{t+d} = c_{t+d} + z_{t+d} = c_t e^{-\lambda d} + c^* \left(1 - e^{-\lambda d}\right) + z_{t+d}$$

$$= \left(q_t - z_t\right) e^{-\lambda d} + c^* \left(1 - e^{-\lambda d}\right) + z_t + gd$$

$$= q_t e^{-\lambda d} + c^* \left(1 - e^{-\lambda d}\right) + z_t \left(1 - e^{-\lambda d}\right) + gd \qquad \text{(D.39)}$$

Subtracting q_t from both sides of the last expression and dividing by the duration of the period, d, we obtain the following expression:

$$\frac{q_{t+d} - q_t}{d} = g + \frac{1 - e^{-\lambda d}}{d}\left[c^* - \left(q_t - z_t\right)\right] \qquad \text{(D.40)}$$

If we substitute equation (D.22) into (D.40) we have

$$\frac{q_{t+d} - q_t}{d} = g + \frac{1 - e^{-\lambda d}}{d}\left[\frac{\alpha}{1-\alpha-\beta}\ln s_k + \frac{\beta}{1-\alpha-\beta}\ln s_h - \frac{\alpha+\beta}{1-\alpha-\beta}\left(\delta + n + g\right) - \left(q_t - z_t\right)\right]$$

Letting $\frac{1 - e^{-\lambda d}}{d} = \Omega$ we can rewrite the last equation as follows:

$$\frac{q_{t+d} - q_t}{d} = g + \Omega\frac{\alpha}{1-\alpha-\beta}\ln s_k + \Omega\frac{\beta}{1-\alpha-\beta}\ln s_h - \Omega\frac{\alpha+\beta}{1-\alpha-\beta}\left(\delta + n + g\right) + \Omega z_t - \Omega q_t$$

(D.41)