Chapter 4
Technological Progress and Economic Growth

4.1 Introduction

- Technical progress is defined as new, and better ways of doing things, and new techniques for using scarce resources more productively.

- An improved technology yields greater output from the same quantity of resources.

- A formal neo-classical definition of technical progress states that it is an autonomous phenomen causing the aggregate production function of an economy to shift upwards. This brings about a higher level of output for each different level of capital-labor ratio.

- Technical progress involves two activities: process innovation and product innovation.

- No sharp distinction between process innovation and product innovation because a new process requires, same product innovation and product innovation involves some elements of a new process.

- Process innovation is placed much emphasis because many literatures concern much on the effects of technical change on factor productivity or new ways of satisfying existing wants, rather than on satisfying new wants.

- Producing a new technology involves two processes: invention and innovation.

- Invention entails the conception of a basic idea. This is the product of laboratory scientists. Innovation is the application of that idea to something directly useful to humankind. This is the work of engines.

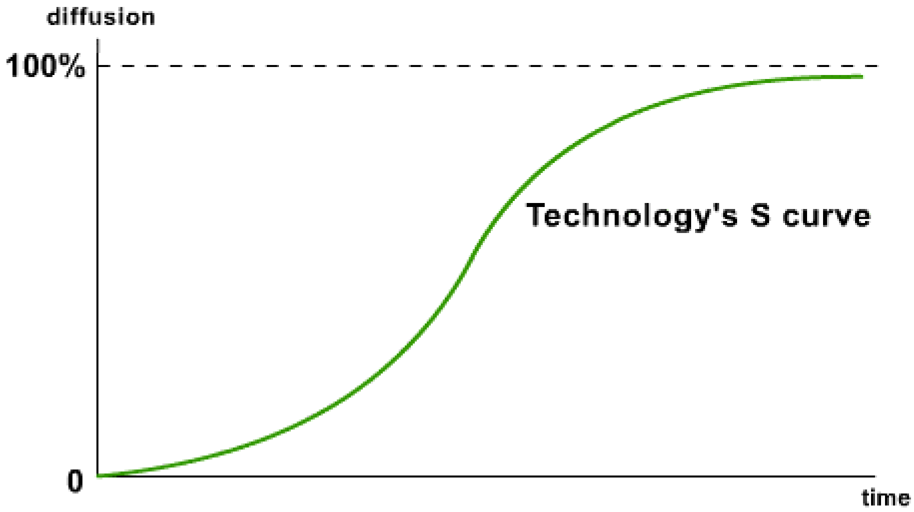
- Innovation provides more efficient and cheaper ways to make existing goods. It can also result in creating new products.

- Joseph Schumpeter states that technical progress is partly technological and partly economic in nature. Inventions are the emergence of new scientific or technological ideas that may be part of a random, exogenous process. An innovation is an economic process that occurs as a response to perceived profit opportunities, through an act of foresight of the capitalist entrepreneurs, who create or realize these opportunities though innovations.

4.2 The characteristics of technological progress

- Technology is a complex set of knowledge, ideas and methods and is likely to be the result of a variety of different activities, both intentional and accidental.

- Technological progress is a gradual process consisting of a sequence of small increments lying along a continuous path.



- For examples, a generator and electric lights were demonstrated in 1876. Until six years later, Thomas Edison opened the first commercial generator to power electric lights in the Wall Street district of New York. Only in the 1930s, 60 years later, the Rural Electrification Act provided the financing to bring electric power to most rural areas of the United States.

- It seems that the new idea spreads slowly initially, then it begins to be applied more often, gradually attaining widespread acceptance and adoption; and finally it reaches 100% diffusion as the last potential users are won over.

- While the growth path of technology is continuous, it does not generally exhibit a constant slope or growth rate; technology can grow rapidly, stagnate, or even decline. The path may take sudden sharp turns.

- Technology is partially nonrival in nature. If one person uses an idea or method, that does not prevent another from using it. Thus the marginal cost of using a particular form of technology is zero, meaning that competitive market forcer will tend to drive the price of existing technology toward zero.

- Creativity and innovation will tend to be very low if nonrival ideas are freely used by anyone. Therefore, the creators of the new ideas get no reward from their creative efforts.

- New ideas may be excludable. Patent laws seek to give the creator of an idea to use the product or process exclusively for a specified number of years.

- For example, the Coca-Cola Company has kept its formula secret for over 100 years; its idea is protected by the complexity of a formula that no one has been able to reproduce exactly.

- Some growth economists describe technology as path-dependent. The ability to create new technologies depends on the level of technology already accumulated. It means that previous technologies are often difficult to abandon.

- Often, technology is not excludable. If old knowledge is not available, then others cannot create new knowledge. Thus, patent laws set limits on the length of time that a patent remains in effect.

- The formal recognition of intellectual property rights is likely to facilitate the spread of technology. Patents and copyrights permit the owners of intellectual property to sell and sent their rights to others.

- As long as the price for the use of the idea exceeds the possible loss of monopoly profit, the owner of the idea should be willing to let others use the idea.

- If a certain idea can be productively used elsewhere in the economy, others should be willing to pay for the right to use the idea.

4.2 The causes of technological progress

(1) Research and development (R&D) spending decisions made by firms

- With the increase of R&D spending, it is more likely for a firm to discovery and develop a new product.

- If the new product is successful, the firm's future profits will increase. If the expected present value of profits exceeds the expected cost of research, the firm will start on a new R&D project.

(4) Patent laws

- Weaker protection of new products, smaller expected profits can be gained from new products. Thus, lesser incentives for firms to engage in R&D.

- Even in the presence of patent laws, protection is incomplete. Other firms may learn ways of making another product not covered by the patent. They may learn how to make a better product, thus eliminating the market for the original product.

(3) The fertility of research

- If research is very fertile, it means R&D spending leads to many new products. Firms will have more incentives to do R&D, and R&D and technological progress will be higher.

(4) The appropriability of research results

- If firms cannot fully capture the profits from the development of new products, they will not engage in R&D and technological progress will be slow.

- Determinants of the appropriability of research results:

  a. If it is widely believed that the discovery of a new product will lead to a subsequent quicker puce in the discovery of other better products, there may be little payoff to bring first. Thus, a highly fertile field of research may not generate high levels of R&D.

  b. Too little protection will lead to little R&D. Too much protection will make it difficult for new R&D. Hence, R&D will be lowered.

(5) Innovations may occur in response to pressures on the commodity markets.

- With the rise of population and the increase of the scarcity of land, greater pressure on the demand for agricultural commodities. This may induce innovations in agriculture to takes advantage of increasing profit opportunities.

(6) Innovations are most likely to occur in rapid growing sectors of the economy.

- Market expansion increases profitability and makes firms to reap the benefits of scale – economies, which are characteristic of modern industrial innovations.

- Greater demand makes available investible funds that are required for new net investment. Firms in the industry will put in a better position to absorb any potential risks associated with new technology.

(7) Continuous competition in oligopolistic markets may lead firms to invest resources in a systematic search for new technology.

4.4 Technological progress as an externality to investment

- Bradford De Long and Lawrence Summers found a strong statistical correlation between investment in productive equipment and the countries' rate of economic growth. Their statistical analysis found that equipment investment causes economic growth.

- Indeed, new ideas and technologies are in some ways linked to the specific equipment, buildings, and tools used in production.

- Some statistical studies suggest that the effect of equipment investment on economic growth is stronger in development investment on economic growth is stronger in developing economies in the early stages of industrialization than it is in the more developed economies.

- New technologies often seemed to be embodied in new machines, and the introduction of a new technology usually coincided with the introduction of new machines or equipment.

- Structures also enable new ideas and methods to be implemented. New ideas cannot be put into practice unless people are trained to apply and use them. Without an investment in education and training, much new technology would not be used.

Therefore, technological progress is not an independent process, completely separate from investment in equipment, structures, and human capital.

4.5 Learning by doing

- The fact that economic growth accelerated over the past 200 years implies that we have also learned to create new methods, tools, and ideas at a more rapid pace.

- Learning-by-doing process is also a potential source of economic growth because experience causes per-worker output to rise.

- For an economy as a whole, learning could remain a constant proportion of the doing. New firms replace old ones, new production runs replace the production runs of older products. Each new firm product, or industry leads to another complete phase of learning by doing, and thus in the whole economy and over time there may be overall reduction in learning.

- Individual firms and industries begin new production runs when the learning by doing form further production of old products diminishes, even though initially costs may be higher when new products are introduced.

- Eventually, learning by doing reduces cost below those of the previous production run, and across all firms and industries, economy wide learning by doing, combined with continued introduction of new products and process, reduces unit costs over time.

- Learning has long been suggested as a potential source of technological progress. But the learning-by-doing model does not address the motivations for learning.

- Learning just happens without a conscious effort. Technological progress is endogenous because it is related to other variables within the model, but the learning-by-doing model is short on explaining how production generates learning.

- The fact that a lot of doing does not seem to be accompanied by much learning suggests that learning is not an incidental and automatic consequence of doing.

4.6 Growth as the result of costly innovative activity

- Philippe Aghion and Peter Howitt, Gene Grossman and Elhanan Helpman, and Paul Romer are those who have developed models of endogenous growth based on the assumption that R&D activities are carried out by profit – seeking entrepreneurs. R&D is regarded as a costly activity that is carried out with the intent to produce new products and earn temporary profits.

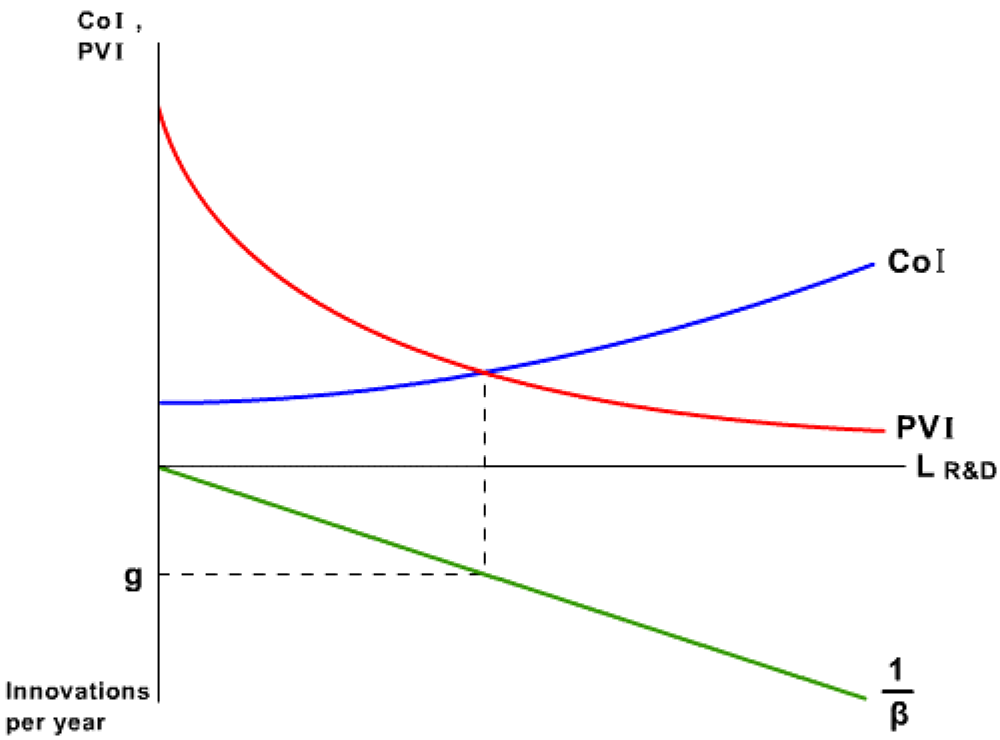
- Since the cost of R&D activities must be covered, the assumption of imperfect competition is introduced. The greater the potential profit earned by the monolistic producer, the greater will be the amount of innovative activity.

- Endogenous technological progress is a function of the supply of labor **L**, future profit **π**, the amount of resources needed to create an innovation **β** and the interest rate with which future profit is discounted **r**.

  i.e. $\mathbf{g = f(L, \pi, \beta, r)}$

  Where **g** = the number of innovations per year.

- The cost of innovation and the present value of innovation determine the equilibrium amount of resources that competitive entrepreneurs devote to innovative activity.



- The number of innovations per year remains constant if nothing else in the model changes. But that implies slower growth as the total number of accumulated innovations grows.

- The number of innovations per year must grow in line with the accumulated level of technology if the growth of technology is to remain constant.

4.7 R&D model formulated by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992)

- Assume that the effectiveness of labor (A) represents knowledge or technology.

- Production function in which labor, capital, and technology are combined to produce improvements in technology.

- Both the R&D and goods production functions are assumed to be generalized Cobb-Douglas production functions.

- The fraction of output saved and the fractions of the labor force and the capital stock used in the R&D sector are taken as exogenous and constant.

- There are two sectors, a goods-producing sector where output is produced and a R&D sector where additions to the stock of knowledge are made.

- Fraction a_L of the labor force is used in the R&D sector and fraction $1 - a_L$ in the goods-producing sector. Fraction a_K of the capital stock is used in the R&D sector and fraction $1 - a_K$ in the goods-producing sector.

- Two sectors can use the full stock of knowledge (A).

- The quantity of output produced at time t:

$$Y(t) = [\,(1 - a_K)\,K(t)\,]^{\alpha}\,[\,A(t)\,(1 - a_L)\,L(t)\,]^{1-\alpha} \quad , 0 < \alpha < 1 \quad \text{..........(1)}$$

(1) implies constant returns to capital and labor.

- The production of new ideas depends on the quantities of capital and labor engaged in research and on the level of technology:

$$\dot{A}(t) = G[\, a_k\, k(t)\,, a_L\, L(t)\,, A(t)\,] \quad \text{......(2)}$$

- Under the assumption of generalized Cobb-Douglas production function for knowledge, it is not assumed to have constant returns to scale to capital and labor:

$$\dot{A}(t) = B[\, a_K\, K(t)\,]^{\beta}\, [\, a_L\, L(t)\,]^{\gamma}\, A(t)^{\theta}\ ,\ \ \beta > 0,\quad \gamma \geq 0,\quad B > 0 \quad \text{......(3)}$$

  where B is a shift parameter in order to analyze the results of changes in other determinants of the success of R&D.

- No restriction is placed on since there exists no strong basis for restricting how increases in the stock of knowledge affect the production of new knowledge.

- If $\theta = 1$, $\dot{A}$ is proportional to A; the effect is stronger if $\theta > 1$, and is weaker if $\theta < 1$.

- Depreciation is set to zero: $\dot{K}(t) = sY(t)$ ......(4)

- Treat population growth as exogenous: $\dot{L}(t) = nL(t),\quad n \geq 0$ ......(5)

4.7.1 R&D model without capital

(A) The dynamics of knowledge accumulation

- Without capital, set $\alpha = \beta = 0$. Equations (1) and (3):

$$Y(t) = A(t)\,(1 - a_L)\,L(t) \quad \text{......(6)}$$

$$\dot{A}(t) = B[\, a_L\, L(t)\,]^{\gamma}\, A(t)^{\theta} \quad \text{......(7)}$$

- The growth rate of A, $g_A(t)$:

$$\frac{\dot{A}(t)}{A(t)} = \frac{B\left[\,a_L\,L(t)\,\right]^{\gamma}\,A(t)^{\theta}}{A(t)} = B\,a_L^{\gamma}\,L(t)^{\gamma}\,A(t)^{\theta-1} \quad \text{...............................} \quad (8)$$

- Since B and a_L are constant, whether g_A is rising, falling, or constant depends on the behavior of $L^{\gamma}A^{\theta-1}$.

- Equation **(7)** implies that g_A is always positive.

- Equation **(8)** implies the growth rate of g_A :

$$\frac{dg_A(t)}{dt} = \dot{g}_A(t) = B\,a_L^{\gamma}\left[\gamma\,L(t)^{\gamma-1}\cdot\frac{dL(t)}{dt}\cdot A(t)^{\theta-1} + L(t)^{\gamma}(\theta-1)\cdot A(t)^{\theta-2}\cdot\frac{d\dot{A}(t)}{dt}\right]$$

$$= Ba_L\left[L(t)^{\gamma}A(t)^{\theta-1}\right]\left[\gamma\frac{\dot{L}(t)}{L(t)} + (\theta-1)\frac{\dot{A}(t)}{A(t)}\right]$$

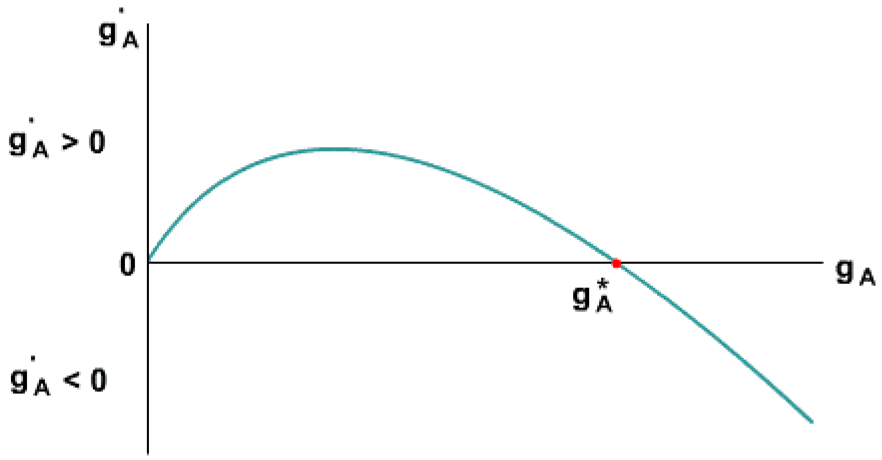
$$= g_A(t)\left[\,\gamma\,n + (\theta-1)\,g_A(t)\right] \quad \text{..} \quad (9)$$

- **(9)** shows that g_A is rising, $\dot{g}_A > 0$, if $\gamma\,n + (\theta-1)g_A$ is positive. g_A is falling, $\dot{g}_A < 0$, if $\gamma\,n + (\theta-1)g_A$ is negative.

- In steady state, $\gamma\,n + (\theta-1)g_A = 0$, $\dot{g}_A = 0$:

$$g_A = \frac{\gamma\,n}{1-\theta} \equiv g_A^{*} \quad \text{...} \quad (10)$$

- In case of $\theta < 1$, **(9)** implies that when $\theta < 1$, $\dot{g}_A < 0$, g_A is galling if g_A exceeds g_A^{*}. $\dot{g}_A > 0$, g_A is rising if g_A is less than g_A^{*}.



- Ultimately, g_A converges to g_A^*. Once g_A^* is reached, both A and Y/L grow steadily at this rate, thus the economy is on a balanced growth path.

- **(10)** implies that g_A^* is an increasing function of the rate of population growth n.

- The model does not imply that countries with greater population enjoy greater income growth. It only means that higher worldwide population growth raises worldwide income growth.

- Higher population is beneficial to the growth of worldwide knowledge in the sense that the larger the population is, the more people there are to make new discoveries.

- When $\theta < 1$ and $n = 0$, equation **(9)** implies:

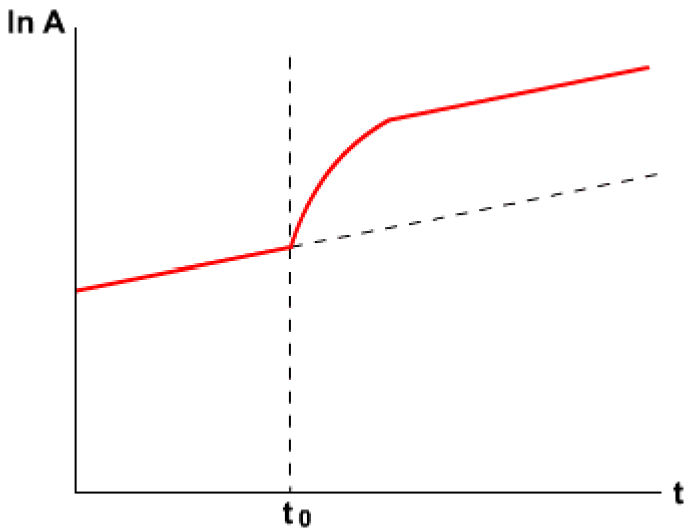
$$\dot{g}_A(t) = [(\theta - 1)\, g_A(t)]\, g_A(t) < 0$$

  it adding to the stock of knowledge becomes more difficult, $\dot{g}_A$ is negative and hence growth would slow sown in the absence of population growth.

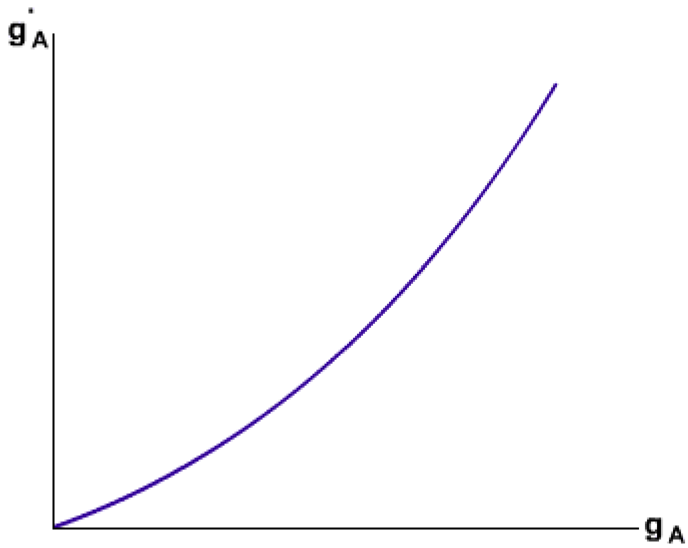
- **(10)** also implies that although the rate of population growth affects long-run growth, the fraction of the labor force engaged in R&D (a_L) does not.

- When $\theta < 1$, the increase in a_L has only a level effect (slope remains zero) but not a growth effect on the path of A.

- Although **(8)** implies that the increase in $\mathbf{a_L}$ causes an immediate increase in $\mathbf{g_A}$, the level of A moves gradually to a parallel path higher than its initial one. This is the level effect.

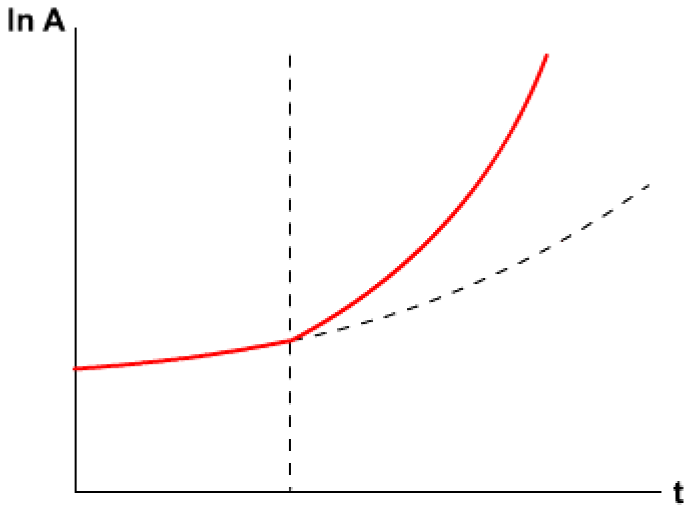


- When $\boldsymbol{\theta > 1}$, equation **(9)** implies that $\dot{g}_A$ is increasing in g_A. Such g_A is positive, it also implies that g_A must be positive.



- The economy now exhibits ever-increasing growth rather than converging to a balanced growth path. The more rapidly g_A rises, the more rapidly its growth rate rises.

- The increase in a_L leads to an ever-widening gap between the new path of **A** and its original path.

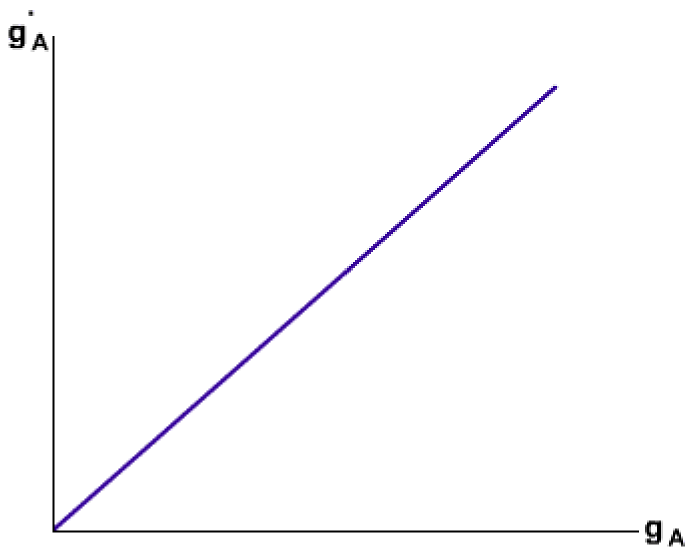


- When $\boldsymbol{\theta = 1}$, equation **(8)** and **(9)** become:

$$g_A(t) = Ba_L^{\gamma} L(t)^{\gamma} \quad \text{(11)}$$

$$\dot{g}_A(t) = \gamma n g_A(t) \quad \text{(12)}$$

- **(12)** implies that if population growth is positive, g_A is growing over time.



- **(12)** also implies that if $\mathbf{n = 0}$ or $\gamma = 0$, $\mathbf{g_A}$ is constant over time. There is no adjustment toward a balanced growth path. The economy immediately exhibits steady growth.

- As equation **(6) (7) (11)** shown, the growth rate of knowledge, output, and output per worker are all equal to $\mathbf{Ba_L^{\gamma} L^{\gamma}}$. Thus, in this case α_L affects the long-run growth rate of the economy.

(B) The importance of returns to scale to produced factors

- This model states that knowledge is the only produced factor.

- If $\theta = 1$, **1%** increase in **A** causes only **1%** increase in **A**. This implies the jump in **A** has no effect on its growth rate.

- If $\theta > 1$, **1%** increase in **A** causes more than **1%** increase in **A**. This implies the increase in **A** raises the growth rate.

- If $\theta < 1$, **1%** increase in **A** results in an increase of less than **1%** in **A**, and so the growth rate of knowledge falls.

4.7.2 R & D model with capital

- The model is now described by equations **(1) (3) (5)** including two endogenous stock variables **A** and **K**.

- Subs. **(1)** into **(4)**:

$$\dot{K}(t) = sy(t) = s\left[(1-a_K)K\right]^{\alpha}\left[A(1-a_L)L\right]^{1-\alpha}$$

$$= s(1-a_K)^{\alpha}K^{\alpha}(1-a_L)^{1-\alpha}A^{1-\alpha}L^{1-\alpha} \quad \text{.......................................(13)}$$

- Divide both sides of **(13)** by **K(t)** and define $C_K \equiv s(1 - a_K)^{\alpha}(1 - a_L)^{1-\alpha}$:

$$\frac{\dot{K}(t)}{K(t)} \equiv g_K(t) = s(1-a_K)^{\alpha}(1-a_L)^{1-\alpha}\left(\frac{K^{\alpha}}{K}\right)(AL)^{1-\alpha}$$

$$= C_K\left[\frac{A(t)L(t)}{K(t)}\right]^{1-\alpha} \quad \text{.......................................(14)}$$

since $\left(\frac{AL}{K}\right)^{1-\alpha} = (AL)^{1-\alpha}(K^{-1})^{1-\alpha} = (AL)^{1-\alpha}K^{-1+\alpha} = \left(\frac{K^{\alpha}}{K}\right)(AL)^{1-\alpha}$

- Whether g_K is rising, falling, or holding constant depends on the behavior of **AL/K**.

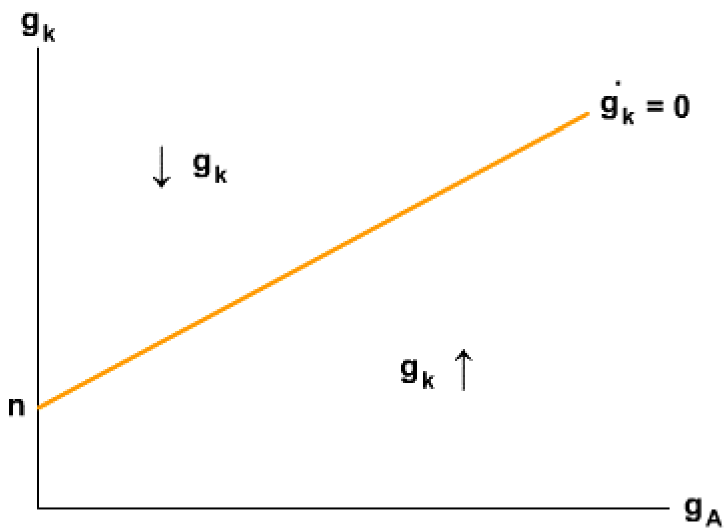
- The growth rate of **AL/K**, g_K:

$$\dot{g}_K = g_A + n - g_K \quad \text{.......................................(15)}$$

- Positive relationship between g_A and g_K:

$$\frac{dg_K}{dg_A} = 1 > 0$$

- If $g_A + n - g_K > 0$, g_K is rising, $\dot{g}_K > 0$. If $g_A + n - g_K < 0$, g_K is falling, $\dot{g}_K < 0$. If $g_A + n - g_K = 0$, g_K is constant, $\dot{g}_K = 0$.



- Divide both sides of **(3)** by **A(t)**:

$$\frac{\dot{A}(t)}{A(t)} \equiv g_A(t) = B(a_K K)^{\beta}(a_L L)^{\gamma} A^{\theta-1} = B a_K{}^{\beta} K^{\beta} a_L{}^{\gamma} L^{\gamma} A^{\theta-1}$$

$$\equiv C_A K(t)^{\beta} L(t)^{\gamma} A(t)^{\theta-1} \quad \text{where} \quad C_A \equiv B a_K{}^{\beta} a_L{}^{\gamma} \text{ .... 16)}$$

$$\frac{dg_A(t)}{dt} = C_A \left\{ \left[BK(t)^{\beta} \cdot \frac{dK(t)}{dt} \cdot L(t)^{\gamma} A(t)^{\theta-1} \right] + \left[K(t)^{\beta} \cdot A(t)^{\theta-1} \cdot \gamma L(t)^{\gamma-1} \cdot \frac{dL(t)}{dt} \right] + \left[K(t)^{\beta} L(t)^{\gamma} (\theta-1) A(t)^{\theta-2} \cdot \frac{dA(t)}{dt} \right] \right\}$$

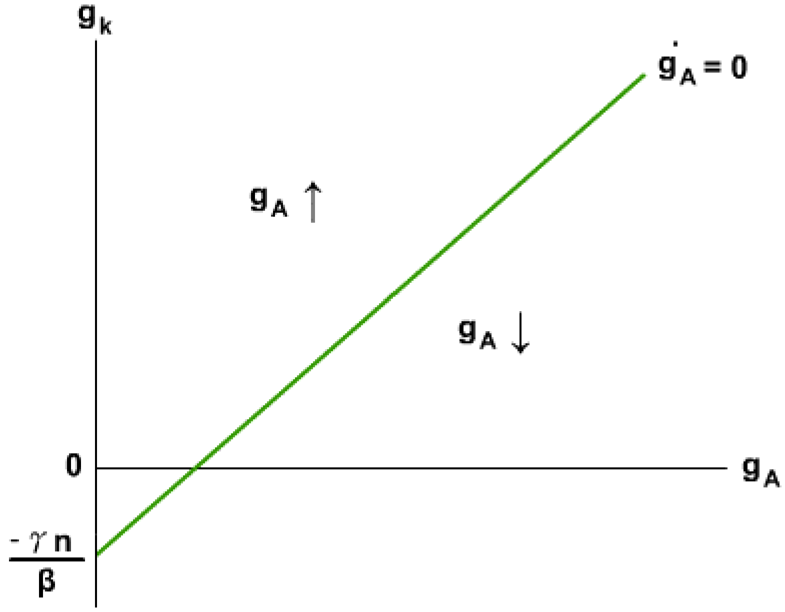
$$= C_A \left[BK(t)^{\beta} \cdot \frac{\dot{K}(t)}{K(t)} \cdot L(t)^{\gamma} A(t)^{\theta-1} + \gamma L(t)^{\gamma} \frac{\dot{L}(t)}{L(t)} K(t)^{\beta} \cdot A(t)^{\theta-1} + (\theta-1) K(t)^{\beta} L(t)^{\gamma} A(t)^{\theta-1} \frac{\dot{A}(t)}{A(t)} \right]$$

$$= C_A K(t)^{\beta} L(t)^{\gamma} A(t)^{\theta-1} \left[\beta \frac{\dot{K}(t)}{K(t)} + \gamma \frac{\dot{L}(t)}{L(t)} + (\theta-1) \frac{\dot{A}(t)}{A(t)} \right]$$

the behavior of $\dot{g}_A(t)$ depends on $\beta g_K + \gamma n + (\theta-1) g_A$

$$\frac{\frac{dg_A(t)}{dt}}{g_A(t)} = \beta\, g_K + \gamma\, n + (\theta - 1)\, g_A \text{ ....} (17)$$

- **(17)** implies that g_A is rising when $\beta\, g_K + \gamma\, n + (\theta - 1) > 0$ and vice versa. g_A is constant when $\beta\, g_K + \gamma\, n + (\theta - 1) = 0$.



- The set of points where g_A is constant has an intercept of $-\frac{\gamma\, n}{\beta}$:

g_A is constant => $\dot{g}_A = 0$ => $\beta\, g_K + \gamma\, n = (1 - \theta)\, g_A$

when $g_A = 0$, $\beta\, g_K = -\gamma\, n$ => $-\frac{\gamma\, n}{\beta}$

- The set of points where g_A is constant has a slope of $\frac{(1 - \theta)}{\beta}$:

$$\beta\, g_K = (1 - \theta)\, g_A - \gamma\, n \quad \Rightarrow \quad g_A = \frac{(1 - \theta)\, g_A - \gamma\, n}{\beta}$$

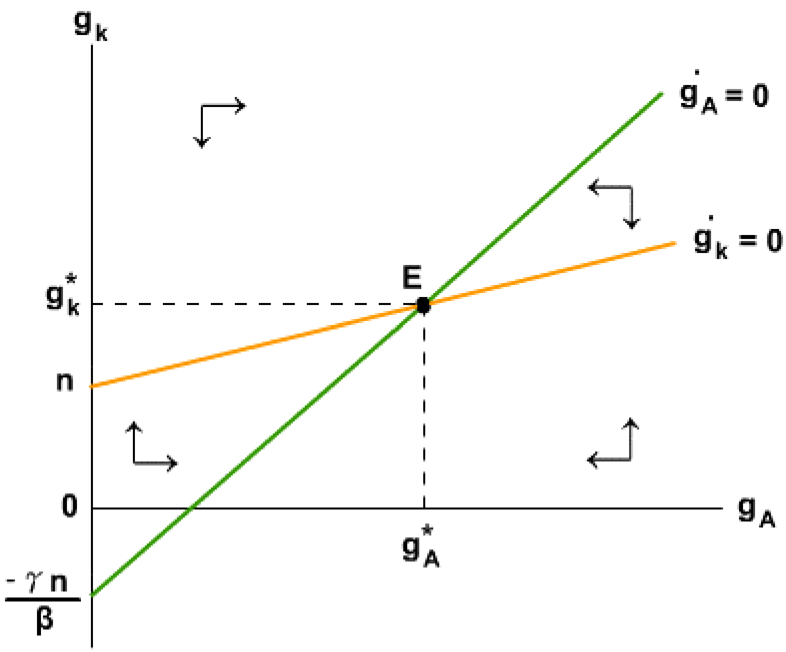
where $\theta < 1$ => the slope is positive

- Positive relationship between $\dot{g}_A$ and g_K:

$$\frac{d\dot{g}_A}{g_K} = \beta > 0$$

- Equation **(3)** shows that the degree of returns to scale to **K** and **A** in knowledge production is $\beta + \theta$.

- When $\beta + \theta < 1$, the slope of $(1 - \theta)/\beta$ is greater than **1**. thus, the locus of points where $\dot{g}_A = 0$ is stepper than the locus where $\dot{g}_K = 0$.



- Regardless of where g_A and g_K begin, they converge to point **E** where $\dot{g}_A$ and $\dot{g}_K$ are zero:

From **(15)**: set $\dot{g}_K = 0$ => $g_A{}^* + n - g_K{}^* = 0$ .... **(18)**

From **(17)**: set $\dot{g}_A = 0$ => $\beta\, g_K{}^* + \gamma\, n - (\theta - 1)\, g_A{}^* = 0$ .... **(19)**

- Rearrange **(18)**: $g_K{}^* = g_A{}^* + n$ .... **(20)**

- Subs. **(20)** into **(19)**:

$$\beta(g_A^* + n) + \gamma n + (\theta - 1) g_A^* = 0 \quad => \quad \beta g_A^* + \beta n + \gamma n + (\theta - 1) g_A^* = 0$$

$$=> \quad \beta g_A^* + (\beta + \gamma) n + (\theta - 1) g_A^* = 0$$

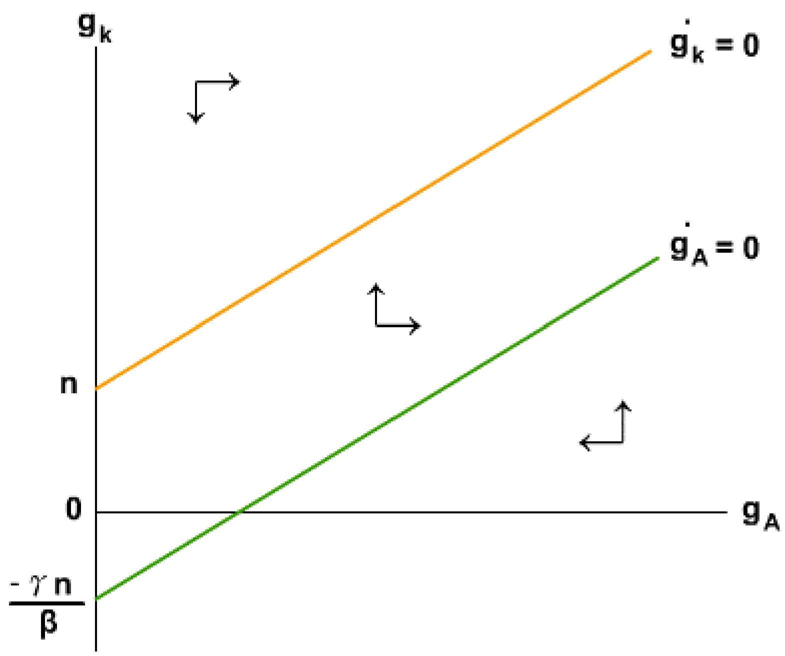
$$=> \quad \frac{(\beta + \gamma) n}{-\beta - \theta + 1} = g_A^* \quad => \quad g_A^* = \frac{(\beta + \gamma) n}{1 - (\theta + \beta)} \qquad \text{(21)}$$

- **(20)** shows that the long-run growth rate of the economy is endogenous, and long-run growth is an increasing function of population growth and is zero if population growth is zero.

- The fraction of the labor force and the capital stock engaged in R & D, a_L and a_K, do not affect long-run growth.

- When $\beta + \theta > 1$, the loci where g_A and g_K are constant diverge. Regardless of where the economy starts, it eventually enters the region between the two loci.

- The growth rates of **A** and **K**, and the growth rate of output increase continually.



- When $\beta + \theta = 1$**,** the slope $(1 - \theta) / \beta = 1$, and thus the loci of $\dot{g}_A$ and $\dot{g}_K$ have the same slope:

  From **(15)**: as $\dot{g}_K = 0$, $g_A = g_K - n$ => slope = 1

- If $n > 0$, the $\dot{g}_K = 0$ line lies above the $\dot{g}_A = 0$ line.

- Regardless of where the economy starts, it eventually enters the region between the two loci. The growth rates of both **A** and **K**, and the growth rate of output increase continually.

- If $n = 0$, the two loci lie on top of one another. Regardless of where the economy begins, it converges to a balanced growth path.