1 Technical Progress

1.Technical progress has been the only real way out from the decreasing returns deadlock.

2.Technical change before the Industrial Revolution did occur but the pace was slow, haphazard and not capable of warding off the decreasing returns curse. The time pattern of output per head was basically portrayed by long-term waves: according to many economic historians the time span from peak to peak (or from trough to trough) was approximately 150 years. The following are the major European and Western cycles identifying both the time span and the hegemonic powers:

- 1300-1450: The Italian one-hundred year war
- 1450-1560: Genoa and Spain

1560-1650: El Siglo de Oro: the age of Charles V and Philip II.

- 1650-1720: The United Provinces and their world trade.

1720-1780: Dutch financial success and decline.

Mid-18th century: the onset of the industrial revolution

3. To be fair, to some historians this pattern, with scarcely any upward trend, continues in terms not of magnitude levels but of growth rates:

- 1780-1880: The first Industrial Revolution and Great Britain as the first true World Power

1880-1915: British (relative) industrial decline.

- 1915-1970: The US hegemony

1970-2000....Financial supremacy and... final demise??

4. But what happened half way through the seventeen hundreds?

The answer is simple: nothing that could really catch the eye. Yet, economic historians began to observe that a systematically rising trend in output per capita appears at about that time and, more specifically, in Britain.

5. It is a well documented fact that Britain became a world power by a long-drawn process that prepared the ground for what has been termed a take-off. Britain took the upper hand as a sea-faring power after the victory over the Dutch Provinces in the mid-17th century at the time of Cromwell's rule. International long-distance trade, replacing the Dutch merchants and their Navy, gave a thrust to the domestic economy fostering momentous change. New markets, urbanisation through the impulsion of fast growing port cities, much technological change being introduced in consequence.

6. The role of an exogenous source of demand growth can be appreciated by means of the vertically integrated

case that has been discussed. The fact that the growth of economic activity brought about technological advancement merits to be stressed.

1.1 A model of sustained growth with technical progress: a so called 'post-keynesian' model

1. In 1949, a simple econometric paper appeared in a fairly obscure Italian journal, L'Industria, published by a Dutch economist Petrus Johannes Verdoorn. He found that there was a strong a robust relationship between the growth of output and the growth of productivity. In very crude terms

$$g_{\frac{Y}{L}} = \alpha + \beta g_Y$$

$\frac{Y}{L}$ being a macroeconomic index of labour productivity, Y aggregate output, α and β two positive coefficients and, as usual, g_i, $i = \frac{Y}{L}, Y$, the growth rates.

2. This simple relationship struck scholars and policy makers alike since, contrary to some received ideas, it stated that productivity growth, an index of technical change, depends on the growth of output: as the economy expands productivity rises.

This was a period of time in which many economists, especially on the European side of the Atlantic, were under the spell of Keynes' 'General Theory': the key to an expanding economy was seen in the autonomous sources of *effective* demand and the most important amongst them: investment demand. An economy that invests much is also likely to grow much. The above simple relation, moreover, apparently stated something more: a self-feeding process seems to be in operation.

3. This observation alerted some economists to the fact that if investment lies at the heart of expansion explaining why output grows, it is clear that it is also and above all the carrier of innovations in the production process: it is the means through which technical progress is applied. Investment means new equipment and means of production embodying new applied knowledge and technologies. This thread of thought led to the idea (N. Kaldor) that at the heart of the simple Verdoon's law, as it began to be called, rests a more complex relationship tying the degree to which the economy is capitalised in real terms. i.e. the extent to which real capital assists labour, to productivity.

4. It is the growth of this degree of real capitalisation, in other words the deepening of the capital structure in terms of labour that explains productivity growth. This amounts to postulate a relationship between these two variables that can be rendered by a function of the type

$$g_{\frac{Y}{L}} = F(g_{\frac{K}{L}})$$

with the plausible properties $F^{'}(\cdot) > 0$, $F^{''}(\cdot) < 0$. This relationship may be regarded as a technical progress function that states that the higher is the growth of $\frac{K}{L}$, where K is a measure of aggregate real capital, the higher is the growth of $\frac{Y}{L}$. Put differently, the higher is the effort to introduce innovations through new equipment into production by increasing the level to which the latter empowers labour, the higher is the growth of productivity. Returns are, it is a matter of realism, decreasing, as expressed by the second derivative.

5. The question to be asked at this point is: how far should the growth of the capital to labour ratio be taken? Note that by definition:

$$g_{\frac{K}{L}} \equiv g_K - g_L$$

Thus, the question amounts to asking by how much is the capital stock to grow over and above the growth of the labour force. Note, moreover, that

$$g_K \equiv \frac{I}{K}$$

the question boiling down to how far, for any existing level of the capital stock K, should investment I be undertaken.

6. In this matter, Kaldor's theory followed in Joseph Schumpeter's footsteps: entrepreneurs are the actors of creative destruction. They invest in new more advanced means of production and scrap obsolete capital stock in an attempt to increase profitability. This means that the higher is I, the more innovations are introduced in the system.

7. The answer to this question stems from a simple, possibly question begging, answer. Note also that, always as a matter of definition, the profit rate r in a simple world of firms and workers is simply:

$$r = \frac{\Pi}{K} \equiv \frac{\pi Y}{K} \equiv \pi \frac{\frac{Y}{L}}{\frac{K}{L}}$$

where Π is the total flow of profits and π the share of profits in total output (GDP). The latter therefore is the distributional share going to firms whilst the workers' cut is merely $\omega = 1 - \pi$.

8 Assume, just for the time being, a constant distribution. Then, the variation of the profit rate must be attributed to an increase in productivity over the capital intensity:

$$\frac{dr}{dt}\frac{1}{r} \equiv g_r = g_{\frac{Y}{L}} - g_{\frac{K}{L}} = F(g_{\frac{K}{L}}) - g_{\frac{K}{L}}$$

If the problem is looked at according to this perspective, it clearly pays to push $g_{\frac{K}{L}}$until:

$$\frac{dr}{dt}\frac{1}{r} \equiv g_r = 0$$

so that $r = r_{\text{max}}$, the solution to be obtained from:

$$F(g_{\frac{K}{L}}) = g_{\frac{K}{L}}$$

i.e. $g_{\frac{K}{L}} = g^*_{\frac{K}{L}}$.

9. In a full employment context, namely when the economy is able to absorb the entire labour force and the latter grows at a rate n

$$g^*_{\frac{K}{L}} \;=\; g_K - n \quad \rightarrow \quad g^*_{\frac{K}{L}} + n = g_K \equiv \frac{I}{K}$$

Note, then, that this amounts to establish that in a full employment context, for any given K:

$$K(g^*_{\frac{K}{L}} + n) = I^*$$

10. What remains to be seen is π. Here, the simple macroeconomic equilibrium between savings and investment, read the Keynes' way, comes to the rescue

$$I^* = S$$

In this context and in keeping with Keynes, investment generates its flow of savings ($I \longrightarrow S$). Consider that in this simple framework with workers having a propensity to save s_w and profit earners (firms) having a different one and equal to s_π , savings are equal to $S = s_w W + s_\pi \Pi$ and dividing through by Y:

$$\frac{I^*}{Y} = s_w \frac{W}{Y} + s_\pi \frac{\Pi}{Y}$$

remembering that $\frac{\Pi}{Y} = \pi$ and $\frac{W}{Y} = 1 - \pi$, it follows that

$$\frac{I^*}{Y} = s_w(1-\pi) + s_\pi\, \pi \quad \longrightarrow \quad \frac{I^*}{Y} = s_w + (s_\pi - s_w)\, \pi$$

from which the very Keynesian multiplier:

$$Y = \frac{1}{s_w + (s_\pi - s_w)\,\pi} K(g^*_{\frac{K}{L}} + n)$$

but if there is full employment and there is a given capital stock

$$\frac{Y}{K} = \frac{1}{s_w + (s_\pi - s_w)\,\pi}(g^*_{\frac{K}{L}} + n) = \overline{v}$$

that is, equal to a given output to capital ratio (a technical ratio) and finally:

$$\pi = \frac{\left(g^*_{\frac{K}{L}} + n\right) - s_w \overline{v}}{\overline{v}\left(s_\pi - s_w\right)}$$

11. This last equation returns the equilibrium share of profits. This leaves the question open of how can $\pi^* = 1 - \omega$ be achieved. The answer lies, in brief, with the following point: $\omega = \frac{w}{P}\frac{L}{Y} = \frac{w}{P}l$ where l is the reciprocal of productivity, given at each point in time, and P the price level. Hence, $\pi^* = 1 - \frac{w}{P}l$, then

$$\frac{w}{P}l = 1 - \pi^* \text{ from which } P = \frac{wl}{1 - \pi^*}$$

The problem boils down to getting an appropriate price level!

12. Can this be done? Kaldor was confident that yes: for any given nominal wage, aggregate demand pushes the price level to equilibrium.

13. This model nicely explains Verdoorn's law, especially if one reads it the other way around, i.e. as

$$g_y = \frac{1}{\beta} F(g^*_{\frac{K}{L}}) - \frac{\alpha}{\beta}$$

The growth of output depends on the technical progress determined $g^*_{\frac{K}{L}}$ which in turn implies

an equilibrium flow of investment that actually embodies innovations in the production process.

1.2 A neoclassical, new growth theory

1. Let us take a simple but paradigmatic model: Romer to the fore.

2. The previous model leaves out too many issues: namely how are knowledge and innovations generated.

3.Here is a simple way to approach this problem. Take a two sector model. One sector is the usual, aggregate production sector, conceptually rather similar to a one commodity economy. The basic feature of this sector is that the technology according to which supply is made available is a Cobb-Douglas production function, that is a continuum of techniques to choose from. The factors of production are the standard capital and labour. The latter, however, enters the process according to a productivity index that incorporates the applied knowledge of this economy.

The other sector is the very heart of this model. It is a sector in which the applied knowledge that enhances labour efficiency is itself produced: it is the consequence of specific efforts to increase it. As such it must utilise concrete means of production as the other, 'traditional' sector does, that is capital and labour, but more importantly it builds upon the existing stock of applied knowledge: in some sense, it is a case of production of knowledge by means of knowledge.

4. The stocks of capital and labour endow the economy as a whole with quantities that are defined at each point in time: $K(t)$, $L(t)$ and the two sectors share them out and in principle compete for their use. Define these shares as a_k , a_l and $(1-a_k)$, $(1-a_l)$, respectively for capital and labour as well as for the knowledge producing and the final output producing sectors. In this exercise, the assumption is made to hold them constant. Consider now the two production functions:

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

for the final output producing sector. While for the most part quite straightforward, note however the time function $A(t)$: it is the current stock of knowledge that multiplies the capabilities of the labour factor as it enters the

Cobb Douglas function. It is a time function since it is subject to change on account of the other sector's efforts to increase it.

$$\dot{A}(t) = B\left[a_k K(t)\right]^{\beta}\left[a_L L(t)\right]^{\gamma} A(t)^{\Theta}; \quad B > 0;\ \beta \geq 0;\ \gamma \geq 0;$$

It is partly a standard production function but it includes novel features.

The model closes for the simple saving function and the growth of the labour force:

$$\begin{aligned} \dot{K}(t) &= sY(t) \qquad\qquad (I = S) \\ \dot{L}(t) &= nL(t) \end{aligned}$$

5.Cosider first the role played by $A(t)$. It is the base upon which new knowledge is produced. Think in terms of 'books of blueprints', i.e. of specific engineering designs. The extant ones are the 'raw material' which is subject to investigation, study, efforts to improve and ameliorate, activities that will ultimately lead to new 'books of blueprints' that do not necessarily oust the previous ones but that enrich them increasing the stock that is made available to the rest of the economy. As you can see, there is a feedback principle: a state of $A(t)$ contributes to explain its variation $\dot{A}(t)$.This is an important point since, it is clear that new knowledge builds upon the stock of existing knowledge. Yet, Θ has an important role to play. If it were equal to 1, knowledge would smoothly increase on account of the mere impact of production factors. If it were 0, new 'books of blueprints' would entirely wipe out old ones and the latter would have no impact whatsoever on the former. $\Theta > 1$ signals an increasing impact whilst $\Theta < 1$ a decreasing one: in the former case the current stock of knowledge is practically never obsolete, in the latter it partly wanes. B is a scale factor.

6. To highlight the role of $A(t)$ consider the simpler case of a pure labour economy for $K = 0$.

The system reduces to:

$$
\begin{aligned}
Y(t) &= [A(t)(1-a_l)L(t)] \\
\dot{A}(t) &= B\,[a_L L(t)]^{\gamma}\,A(t)^{\Theta}
\end{aligned}
$$

Define $\frac{\dot{A}(t)}{A(t)} = g_A(t)$, and

$$
g_A(t) = B\,[a_L L(t)]^{\gamma}\,A(t)^{\Theta-1}
$$

Question: how does this growth rate behave in time? Consider $\frac{dg_A(t)}{dt}$ and $\Theta < 1$

$$
\frac{dg_A(t)}{dt} = \gamma n g_A(t) + (\Theta - 1)\,g_A^2(t)
$$

this is a simple differential equation that solves for

$$g_A(t) = \left[\frac{\gamma n - (1-\Theta)\overline{g}_A(0)}{\gamma n \overline{g}_A(0)} e^{\gamma n t} + \frac{(1-\Theta)}{\gamma n}\right]^{-1}$$

but check at once for the stationary state, i.e. either assume $\overline{g}_A(0) = \frac{n}{1-\Theta}\gamma$, i.e. the initial condition is such that

$$\overline{g}_A(0) = \frac{n}{1-\Theta}\gamma = g_A$$

or simply solve for $\frac{dg_A(t)}{dt} = 0$.

7. A simple phase diagram enables us to check for the stability of this steady-state point.

An elementary study of the function $y \equiv \frac{dg_A(t)}{dt} = \gamma n g_A(t) + (\Theta - 1)\, g_A^2(t)$ indicates that the steady state solution is in fact stable.

8. Suppose that $\Theta > 1$. It is at once seen that $y^{'} = \gamma n + 2\left(\Theta - 1\right) g_A(t) > 0$ and $y^{''} = 2\left(\Theta - 1\right) > 0$. Hence the growth rate increases all the time and it accelerates all the time.

9. Suppose now that $K > 0$. If this is the case, the capital stock rate of growth g_K is :

$$g_K(t) = c_k K(t)^{\alpha-1} L(t)^{1-\alpha} A(t)^{1-\alpha}$$

where $c_k = s(1-a_k)^{\alpha}(1-a_l)^{1-\alpha}$ is simply a constant. Furthermore, the time derivative of g_K is (omitting the time variable):

$$\dot{g}_K = (1-\alpha) g_K \left(g_A + n\right) - (1-\alpha) g_K^2$$

As it is to be expected the rate of growth of the capital stock (in fact, investment per unit of capital) depends on the stock of knowledge and, therefore, the accumulation of the capital stock accelerates when the stock of knowledge grows. For a given g_A (constant), the function has a stationary state $\dot{g}_K = 0$ for $g_K = g_A + n$ and it is stable. Moreover, if not on the stationary state, convergence occurs.

10. The question to ask now is: what happens to the growth rate of $A(t)$?

From above and omitting t:

$$g_A = z_k K^{\beta} L^{\gamma} A^{\Theta - 1}$$

where $z_k = B a_k^{\beta} a_l^{\gamma}$ is a constant. The time derivative of this growth rate is.

$$\dot{g}_A = (\beta g_K + \gamma n)\, g_A + (\Theta - 1)\, g_A^2$$

As expected it feeds on itself for any given size of the stock of capital growth rate. But here Θ reappears. Let it be assumed that $\Theta < 1$.For any given rate of growth of the capital stock, the stationary state is

$$g_A = \frac{\beta}{1-\Theta} g_K + \frac{n}{1-\Theta}\gamma$$

a solution which is also stable, given g_K

11. It is now possible to characterise the steady state, in this case:

$$\begin{aligned} g_K^* &= g_A^* + n \\ g_A^* &= \frac{\beta}{1-\Theta} g_K^* + \frac{n}{1-\Theta}\gamma \end{aligned}$$

This a system that yields the solutions for g_K^*,g_A^*:

$$
\begin{aligned}
g_K^* &= \frac{1 + (\gamma - \Theta)}{1 - (\beta + \Theta)} n \\
g_A^* &= \frac{\beta + \gamma}{1 - (\beta + \Theta)}
\end{aligned}
$$

these solutions are, of course, significant if $(\beta + \Theta) < 1$

1.3 Towards a more realistic view of technical progress

Consider the following propositions concerning technical progress:

1. it is a process of searching and learning
2. it is path-dependent
3. it is cumulative
4. it is irreversible (and non-ergodic)
5. it has become systematic (in the limit continuous)
6. it requires a structural incentive
7. it is a process of information collection

8. it is process that is rationality bounded

9. it is subject to cognitive and searching processes that are highly local.