" Endogenous Growth and General Purpose Technologies".

Ornella Tarola

August,2001

Abstract

The aims of this work is to investigate the relationship between endogenous growth and human capital. The starting point is represented by the following question: how does human capital or the educational attainment of the workers affect the output and the growth of the economy? In order to answer this question, the meaning of endogenous growth theory is briefly specified and different notions of human capital introduced (human capital as either stock or accumulation). Finally a new endogenous growth model, in which the engine of growth is represented by GPT with endogenous obsolescence rate is elaborated. Some policy implications linked to this framework are considered.

1 Introduction

The more recent endogenous growth theory provides the tools to handle the technological change and its interaction with the real life: people's lives can be considered as an endless succession of economic development affected by technological progress and innovations.

Of late, several country experienced industrial re-organization, turnover among jobs, dismissals. Since seventies there has been documented a slump of GDP growth rate, in spite of the increasing progress[1].

[1] Just of late an opposite trend is experienced in the same countries where since 1974 the slump of GDP growth rate has been documented.

However this is consistent with the macroeconomic performance due to the introduction of general purpose technologies,defined later, as it will be shown .

Many debates on the reasons why in several dynamic economies -like that of the United States- these phenomena occurred.

Some economists argue that the slump of GDP growth rate and the productivity slowdown are due to that technological innovations before mentioned. Because of the embodied nature of the recent progress, an increasing amount of capital has become obsolete affecting negatively the production, while economic resources has been devoted to R&D in order to improve the quality of capital employed in the final output sector.

In other words self-enforcing mechanism of innovation-embodied progress-obsolescence has been considered by many researchers as a crucial element in explaining the economic performance of several countries.

In this work I would analyze this phenomenon by using models based on general purpose technologies (GPTs) with a relevant obsolescence rate.

The idea of using GPT depends on its charateristics:

"GPTs are characterized by the following features: (1) They are extremely pervasive; that is, they are used as inputs by a wide range of sectors in the economy. (2) Their potential for continual technical advances manifests itself ex post as sustained improvements in performance. (3) Complementarities with their user sector arise in manufacturing or in R&D technology."[2]

As these features point out, from empirical point of view, GPTs are a very good representation of the actual innovations of these years. Moreover, from a theoretical one, to introduce them in an economic model provides a interesting tool to evaluate the obsolescence phenomenon due to the development of compatible components needed to implement the GPT. These compatible components can be considered as skilled human capital, that has to be educated once a new GPT is introduced in the system in order to be GPT-specific.

Indeed one of the aims of this work is to investigate the relationship between endogenous growth and human capital. Indeed the starting point is represented by the following question: how does human capital or the educational attainment of the workers affect the output and the growth of the economy? In order to answer this question, a endogenous growth model, in which the engine of growth is represented by GPT with endogenous obsolescence rate is elaborated. Some policy implications linked to this framework

[2]Helpman, E. and Trajtenberg, M. (1998) "A Time to Growth and a Time to Reap: Growth Based on General Purpose Technologies" in Helpman, E. (ed), *General Purpose Technologies and Economic Growth*, Cambridge (MA), MIT Press, pp.55.

will be considered.

In the history of the growth theory, two main approaches can be distinguished: the first one is based on the traditional neoclassical models, the second one relies on the more recent endogenous growth theory.

Traditional neoclassical models adopt as production function:

$$Y = Ae^{\mu t} K^{\alpha} L^{1-\alpha}$$

where A is the technological state of the society, μ is the exogenous growth rate of the technology, K and L capital and labor inputs respectively.

As α is less than one, the economy faces diminishing returns to K and L.

In exogenous growth theory, the growth rate of technology is not explained. It is just assumed.

Endogenous growth models, on the other hand, try to explain the source of economic growth and to assure, through constant returns to scale, long run growth.

As far as endogenous growth model is concerned, the basic equation is

$$Y = AK$$

A can be defined as the parameter representing the factors that affects technology, and K as a broad notion of capital including human and physical capital. In this framework the returns to capital are constant due to the presence of both the forms of capital: human and physical ones.

- One way to classify the endogenous growth models can refer to different views of human capital:
  - human capital defined as *accumulation*: in these models, human capital can be considered as an input of production. Hence the growth rate of output depends on the growth rate of human capital. In other words, the higher the accumulation of human capital, the higher the growth rate of the economy.
  - human capital as *stock*: that is as a crucial source of innovation. It means that the growth rate of output is closely linked to the rate of innovation and indirectly to the level (or stock) of human capital. The idea of stock of human capital as engine of growth has been developed by Nelson and Phelps (1966). Their model can

be considered as a pioneristic attempt to consider three aspects of innovation: the abilities to create new technologies (to innovate), to adopt the innovation by using it profitably, and to diffuse the innovation.

In the analysis of this complex process of innovation, several recent models separate explicitly the innovating aspect from the adopting one. Consistently with this approach, the innovation process can be modeled according to a particular timing:

- the innovation time
- the adoption time.

Moreover, a deeper distinction can be made with respect to the models based on the stock of capital.

Depending on the assumption on the intermediate inputs, the introduction of new kinds of goods (or techniques of production) can (not) make the old ones obsolete: in this case the *creative destruction* issue has (not) to be tackled.

The growth of A can be associated to learning by doing or it can the result of research and development (R&D).

- In models based on learning by doing, the growth is explained as a consequence of the experience of producing new capital goods.
- In models where an increasing variety of quality of intermediate inputs that can offset the propensity to diminishing returns to capital is assumed, the mere accumulation of capital, even thought conceived in broader terms, cannot sustain the long-run growth; hence a process of technological improvement due to R&D is postulated.

This feature will be deepened in the following section.

2 Endogenous Obsolescence and Learning: a Model

A *new* growth is introduced, in which the obsolescence rate is endogeneized. The innovation is linked in this setup to an obsolescence rate of human capital and to the development of compatible components needed to implement the new GPT.

In this framework, there are two sectors, the manufacturing sector and the R&D one. The resources employed in R&D are devoted to introduce an innovation and to develop the components that are GPT-specific. The final output sector is supposed to be perfectly competitive, the R&D sector has monopolistic structure, in consistence with the familiar assumptions previously seen. The resources employed in R&D are devoted to introduce an innovation and to "educate" the workers intended as compatible components to operate the new technology.

The production function in the manufacturing sector is

$$Q_i = \mu\left(H_i\right) K_p^{1-\alpha} \sum_{i=1}^{I} \chi^i (H_{it})^\alpha$$

where μ is productivity of GPT that is an increasing function of H, χ is the index of the quality of these components, K_p is the physical capital that is supposed not GPT-specific[3], H_i are the GPT i-specific components. These compatible components are intended in this model as human capital, that is GPT-specific: in other words, due to the technological innovations, workers are subject to obsolescence because of the de-skilling process. This process induces firms to replace the old workers with new skilled ones, well-suited to use the latest GPT.

The profit for the producer of the final output is

$$Q_i - rK_p - \sum p_i H_{it} \tag{1}$$

where r is the cost of physical capital and p the price of the compatible components used as intermediate inputs.

The rate of arrival of innovation i at time t ϕ_{it}, including its implementation due to the development of the specific components, depends on the

[3]In this model, physical capital is supposed to be independent of the vintage of GPT, while the compatible components, that is human capital, are supposed to be GPT-specific. This assumption implies that the obsolescence rate affects only human capital. It could be more realistic to suppose also phisical capital to be GPT-specific. However this assumption makes the model easier to analyze.Moreover this assumption remains consistent with Helpman and Trajenteberg model.

human capital employed in R&D, on the quality of the innovation and on the learning[4]. Hence

$$\phi_{it} = \frac{\lambda H_t}{\chi_t^i} \tag{2}$$

where λ is the learning productivity and H the human capital. In R&D sector the new skilled human capital is educated in order to implement the latest GPT. Hence it follows

$$H_{it} = \frac{H_t}{\chi_t^i} \tag{3}$$

The compatible components are produced by using human capital H_t, furthermore the higher the quality of these components that are required for implementing the new GPT, the more difficult their production.

The net expected benefit from the research is

$$V_{it}\phi - \omega_t H_t$$

where V_{it} is the present value of research and ω_t is the cost of human capital employed in R&D sector

$$\omega = w + \beta$$

with w wage rate, β obsolescence rate where consistently with Howitt[5] (1998),

$$\beta = (1 - \eta)\,\phi \tag{4}$$

and

$$V_{it} = \int_t^\infty e^{-\int_t^\tau (w_s + \phi_s) ds} \pi_t$$

[4]This last element represents a crucial point of the analysis. Indeed, the slump of GDP appeared in Helpman and Trajenteberg model, magnified in this context by the obsolescence of the human capital, is reduced by the learning-productivity: the faster is the learning by the worker, the less is the duration of the first phase described in Helpman and Trajenteberg model, the lower is the obsolescence rate affecting the human capital. This point is developed in the next pages.

[5]In (4) I follow Howitt: the same expression has been explained before. See (**??**)in Howitt model.

The same obsolescence effect of human capital occurs in the final output sector where any GPT can operated by compatible components, that is specific human capital.

The profits are discounted by including in the discount rate both the cost of capital employed in R&D and the creative-destruction rate, given by the arrival rate of an innovation.

$$\pi_t = \left(p_t - \omega_t \chi_t^i\right) x_{it}$$

where is $\omega_t \chi_{mit}$ the cost function from (3) . From the profit maximization process, it follows that the price of each component p is

$$p = \frac{\omega \chi}{\alpha} \tag{5}$$

and

$$H = \left(\frac{\mu}{\omega}\right)^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} K$$

The free entry condition is

$$V_{it} \phi = \omega_t H_t$$

By combining (1)and (3) ,the production function can be written

$$Q = \mu\left(H\right) K^{1-\alpha} H^{\alpha} \tag{6}$$

The growth rate of GDP, by considering (6) is

$$\frac{\dot{Q}}{Q} = \gamma_Q = \frac{\dot{\mu}}{\mu} + (1-\alpha) \frac{\dot{K}}{K} + \alpha \frac{\dot{H}}{H}$$

In this last formula, the GDP growth rate is linked to the growth rate of H. The higher the growth rate of H, the faster and the bigger is the production of compatible components and because of this, the higher is the productivity of the new GPT. However, the human capital growth rate increases the obsolescence rate, as (2)and (4) show.

The negative effect on GDP due to the obsolescence rate can be reduced by modifying the learning productivity.

As far as the obsolescence rate is concerned, from (4) : the faster the innovation process, the higher should be the obsolescence rate. This depends on the fact that a new GPT makes the old components, specific to the previous innovation, obsolete. For a new GPT i the components $i-1$ cannot be employed, and they must be replaced by new ones. However, if the learning-productivity is very high, the substitution process can become unprofitable: depending on the parameters of the model, it can be less costly to modify the components $i-1$, than replace them[6]. From this consideration it follows

$$\beta = F_{-}(\lambda)$$

where F_{-} refers to the negative relationship between the obsolescence rate and the learning productivity. Moreover with reference to the Helpman and Trajtenberg model, the raise of the learning productivity can reduce the duration of first phase, that is the time of the slump.

However, the obsolescence rate includes trade-off between a static and a dynamic inefficiency. The static inefficiency is linked to the price of the compatible components, that is higher than in a perfectly competitive framework. From (5) it can be seen that the lower the obsolescence rate is, the lower is the monopolistic price. However, the monopolistic structure assumption is needed to provide an incentive for research, hence the lower the obsolescence rate, the lower the incentive in R&D sector.

It can be interesting to investigate on the policy implication due to the previous considerations.

2.1 Some Policy Observations

Two distortions can affect the economic growth rate in this model, as previously said.

The first distortion is due to the assumption of monopolistic structure of the intermediate sector, needed to provide an incentive in R&D sector.

The second one is linked to the creative destruction rate, employed to discount the present value of returns to research.

In order to eliminate the first distortion, a familiar policy instrument can be introduced: a lump-sum tax can be used to finance a subsidy on the purchase of all the intermediate products (in this model higher skilled workers). This policy reduces the distortion linked to the monopoly price without modifying the incentive in R&D.

[6]This phenomenon can be intended as if just a reduced fraction of human capital was made obsolete by the new GPT.

As far as the second distortion, a policy affecting human capital can be employed. The arrival rate is intended as a creative destruction rate since it cause a replacing process between resources. However, to the extent the arrival rate of innovations does not increase the obsolescence rate (that is the replacing process previously mentioned), and it is supposed to be an increasing function of resources already employed in R&D sector, the nature of the arrival rate changes.

The (2)by posing can be modified as follows

$$\phi_{it} = \frac{\lambda S_t(\lambda) - \kappa_t}{\chi_t^i} \tag{7}$$

with $\kappa = H - S(\lambda)$

$$\beta = (1 - \eta)\,\kappa_t$$

$$V_{it} = \int_t^{\infty} e^{-\int_t^{\tau}(w_s + \kappa_s)ds}\pi_t$$

where S_t is the total amount of human capital available at time $t$and κ_t is the amount of human capital that cannot be used after the switch between GPTs. The creative destruction process is directly linked to the loss of human capital (represented by κ) due to the switch.

The policy instrument that is considered in this framework is intended to increase the learning parameter λ and to reduce the loss of human capital κ. The channel through which these parameters can be affected is represented by R&D investment. In order to develop this last part of the analysis, the Cohen and Levinthal approach is mentioned.

According to Cohen and Levinthal, R&D "not only generates new information, but also enhances the firms' ability to assimilate and exploit existing information."[7]

This analysis focuses on the learning capacity that can be developed by R&D.[8]

According to this approach

[7]Cohen, W.M., and Levinthal, D. A. (1989) "Innovation and Learning: The Two Faces of R&D." in The Economic Journal, 99 (397) pp.569.

[8]This learning capacity is also called by absorptive capacity. These two terms will be used in this setup indifferently.

$$z_i = M_i + \gamma_i \left(\theta \sum_{j \neq i} M_j + T \right) \tag{8}$$

where z_i is the technological knowledge, M is the firm's investment in R&D, T is the level of extra-industry knowledge, θ is the degree of intra-industry spillovers and γ the firm's absorptive capacity.

By treating as endogenous the absorptive capacity, it can be shown that an increase of these parameters can increase the level of the firm's investment in R&D and indirectly the absorptive capacity, that is supposed to be an increasing function of M[9].

In order to combine the Cohen and Levinthal approach with the growth model that has been developed, (8) is modified in the following way

$$S_t = R_t + \lambda_i \left(\sum_{\tau=0}^{t-1} R_\tau + P \right) \tag{9}$$

In this last formula, S_t is the human capital intended as expertise or ability in using the present GPT, R is the firm's investment in R&D and P is the public investment in R&D and λ the learning productivity.

The higher is the investment in R&D (public and private ones), the higher is the amount of human capital that is used after the switch and, given H, the lower is κ.

Hence, the amount of human capital that becomes obsolete due to the new GPT decreases as the learning productivity, the past R&D investment and the public resources devoted to research raises.

As far as the policy implications derived from this analysis are concerned, public investment in R&D should increase in order to develop the absorptive capacity. However, the type of public investment to finance should affects only the amount S of human capital. Since this fraction is an increasing function of the learning productivity, public policy should focus on λ. According to the researches on the learning curve, the λ parameter is higher, the more educated are the workers[10]. This implies that the basic education

[9]To make the analysis more complete, the absorptive capacity is supposed to be an increasing function of M and β, where β represents the dependency of γ on the firm's own R&D.

[10]See for example Bartel, A.P. and Lichtenberg F.R. (1987) "The Comparative Advantage of Educated Workers in Implementing New Technology" in *The Review of Economics and Statistics*, 69 (1).

should increase[11]: more resources should be devoted to the education sector in order to improve the basic knowledge where the basic knowledge can be intended as a tool to improve the absorptive capacity.

This work does not intend to be exhaustive. Its aim is to give an overview of the relevant contributions in the field and to provide some interesting suggestions by combining a new theoretical version of an endogenous growth model and policy considerations linked to the framework.

3 Conclusion

The aim of this paper is to analyze several significant features of the weightless economy. There are many debates on the weightless economy's meaning, on the social and economic changes that it can cause. Therefore it is difficult to consider the policy implications of a process that is still in progress. This is just a preliminary remark: it is intended to provide an analytical tool to evaluate several features of this complex phenomenon.

[11]This is suggested also by Schivardi, F. and Trento, S. (2000) in "La New Economy: Aspetti Analitici e Implicazioni di Policy", (relazione di), due to XLI Annual Scientific Meeting of Italian Economist' Society, even if their starting point is quite different from the approach that has been adopted in this work.

References

[1] Aghion,P.,P.Howitt (1992), “A Model of Growth through Creative Destruction” in *Econometrica*, 60,pp.323-51.

[2] Aghion, P. and Howitt, P., *Endogenous Growth Theory*, Cambridge (MA), MIT Press.

[3] Arrow, K.J.(1962) “The Economic Implication of Learning-by-Doing.” in *Review of Economic Studies* 29(1) pp.151-173.

[4] Bartel, A.P. and Lichtenberg F.R. (1987) ”The Comparative Advantage of Educated Workers in Implementing New Technology” in *The Review of Economics and Statistics*, 69 (1) pp.1-10.

[5] Benhabib, J. and Spiegel, M.M. (1994) “The Role of Human Capital In Economic Development: Evidence from Aggregate Cross-Country Data.” in *Journal of Monetary Economics* 34(2) pp.143-173.

[6] Cohen, W.M., and Levinthal, D. A. (1989) “Innovation and Learning: The Two Faces of R&D.” in The Economic Journal, 99 (397) pp.569-596.

[7] David,P.A. (1991), “Computer and Dynamo. The Modern Productivity Paradox in a Not-too-distant Mirror”, in OECD, *Tecnology and Productivity. The Challenge for Economic Policy*, Paris.

[8] Grossman, G.M. and E. Helpman (1991), *Innovation and Growth in the Global Economy*, Cambridge (MA), MIT Press.

[9] Helpman, E. and Trajtenberg, M. (1998) “A Time to Growth and a Time to Reap: Growth Based on General Purpose Technologies” in Helpman, E. (ed), *General Purpose Technologies and Economic Growth*, Cambridge (MA), MIT Press

[10] Helpman, E. and Trajtenberg, M. (1998) “Diffusion of General Purpose Technologies”, in Helpman, E. (ed), *General Purpose Technologies and Economic Growth*, Cambridge (MA), MIT Press.

[11] Howitt, P. (1998) “Measurement, Obsolescence and General Purpose Technologies” in Helpman, E. (ed), *General Purpose Technologies and Economic Growth*, Cambridge (MA), MIT Press.

[12] Jovanovic, B. (1995), "Learning and Growth", *NBER Paper* 956/7, n.188.

[13] Jovanovic, B., Stolyarov, D. (2000), "Optimal Adoption of Complementary Technology" in *American Economic Review*, 90, n.1, March pp.15-29.

[14] Lucas, R.E. (1988) "On the Mechanism Of Economic Development." in *Journal of Monetary Economics* 22(1) pp.3-42.

[15] Nelson,R. and Phelps, E. (1966) "Investment in Humans, Technological Diffusion, and Economic Growth." in *American Economic Review* 61, pp.69-75.

[16] Parente, S. (1994) "Technology Adoption, Learning by Doing, and Economic Growth", in *Journal of Economic Theory*, 63, pp.346-369.

[17] See for example Quah, D. (1999), *The Weightles Economy in Economic Development*, LSE Centre for Economic Performance, Discussion Paper 417.

[18] Redding, S. (1996) "Low-Skill, Low-Quality Trap:Strategic Complementarities between Human Capital and R&D" in Economic Journal 106, pp.458-470.

[19] Romer, P.M., (1986) "Increasing Return and Long Run Growth."in *Journal of Political Economy* 94 (5) part pp.1002-1037.

[20] Romer, P.M., (1990) "Endogenous Technological Change." in *Journal of Political Economy* 98 (5) part 2 pp.71-102.