Complementarity between Heterogenous Human Capital and R&D: can Job-Training Avoid Low Development Traps?

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Abstract

This paper uses a non-overlapping generations model of endogenous growth to describe the effect of human capital's heterogeneity on economic growth. In the model, workers can accumulate human capital not only through education, but also through on-the-job training (j-t); enterprenuers can invest in R&D and can offer training. We model two different typologies of training. The first, *technology-general* (T-GT), is offered even without R&D and to all workers; the second one, *technology-specific* (T-S T), is joined to the success of innovative activity and provided just to those workers engaged in research. The paper, by extending Redding (1996), demonstrates that human capital composition, which is often neglected in endogenous growth models, is important in determining the probability of innovation occurring and the economy's rate of growth. In particular, it shows that complementarities between different types of human capital investment are important. Moreover, training causes a multiplicity of equilibria in education investment and rate of growth, and *technology-general* training avoids low development traps when R&D is absent.

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1 Introduction[1]

In 1979 a research study was carried out about workers in Germany; they were asked about where they obtained the most important skills for the labor market. The most common answers were continuous formal job-training (j-t) provided by firms, informal j-t obtained by colleagues and *learning by doing.* The workers who worked for apprenticeships were asked which was the most important place to receive the most useful skills for the labor market: 32% of them chose the apprenticeship or school and higher education institutions, but 58% preferred continuous training offered by the German firms (Pischke 2001).

From the 1980s a period full of relevant changes started, particularly for the industrial countries, both in the labour market and in R&D activities. We refer to part-time labor contracts, and labor contracts for a certain period of time, to stages and continuous training for the labour market, on one hand, and to revolutions in computer sciences and telecomunications, on the other hand. Twenty years after the research mentioned above, two more research studies were conducted in Canada and they investigated the behaviour of firms: the *Survey of Manufacturing Technology* (1989) and the *Survey of Innovation and Advanced Technology* (1993)[2]. The main conclusions have been:

- Among the firms which do not use innovative technology, 77% of firms adopt training.
- Among those which carry out just one innovative technology, the percentage of the firms which train their workers increase to 90%.
- Almost all the firms (99%) which use 5 or more technologies are forced to adopt training.
- Among the firms which innovate by adopting existent technologies, the percentage of those which adopt *specific* training is 55%; on the contrary among those which innovate by inventing new technologies (radical R&D activity), 79% are forced to adopt *specific* training.

From some years, the economic literature has been studying the links between on-the-job training and R&D activity, because of their increasing importance for the industrial countries, especially in the last decade:

> "Training is most essential when new technologies are adopted, or in the process of a radical change of environment, for example, the

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[2] Main results of the surveys are contained in Baldwin, Gray, and Johnson, (1996), Baldwin (1999), and Baldwin, and Peters (2001), .

shift from low- to high-skill jobs taking place in most OECD countries today. In support of this view, survey evidence suggests that the availability of appropriate skills is a key determinant of innovation and technology adoption decisions, and the efficient adoption of new technologies by Japanese firms is often attributed to their effective training strategies." (Acemoglu, 1997, p. 446).

Labour economics, since the 1960s has discuss about human capital's heterogeneity by considering the different components, such as education, on-the-job training, off-the-job training, learning by doing. The theory of endogenous growth, especially the one based on the complementarity between human capital and R&D, on the contrary seems not to take it into account, by considering human capital as a homogeneous variable. This paper attempts to integrate these two literature; it will demonstrate the effect of human capital's heterogeneity and in particular the effect of training on economic growth.

This paper is related to some recent trends in the current economic literature. First of all, a trend of endogenous growth, started by a short paper of Nelson and Phelps (1966) studies complementarity between R&D and investments in human capital. Within this approach, human capital is not "simply another factor in growth accounting"[3], because it facilitates technology adoption and diffusion[4]. In particular, a model devised by Acemoglu (1994, 1997) and developed by Redding (1996), analyzes, within an imperfect labour market, *low-skill, low-quality traps,* caused by complementarity between education investments and R&D. Redding (1996) finds two possible equilibrium values for the economy's rate of growth: a *first best* equilibrium with high economy's rate of growth and R&D and a *low development trap* with low growth and no research. Our paper, by introducing the heterogeneity of the human capital, through both education and on-the-job training, concludes, differently from the previous study, that there are four different equilibria of the economy's rate of growth. Moreover, even without innovations, technology-general training avoids the *low development trap;* this occurs because if firms are able to train workers even without reasearch activity, job-training can increase human capital accumulation and support economic growth even when there is no R&D.

A second trend analyses investment in heterogeneous human capital within competitive and/or imperfect labor markets. The original paper by Becker (1964) has showed that human capital is not only education, because it displays *on-the-job training* even within firms; addittionally, he has introduced the distinction, used quite often later, between *general training,* which a worker can use both insiede and outside the firm which trains him and specific training adopted only within the same firm. Becker's analysis is developed within competitive labour markets; recently Acemoglu (1999) and Acemoglu and Pischke

[3] Benhabib and Spiegel (1994)

[4] Many recent empirical models have studied whether human capital is an ordirary input in the production function, or whether it increases technology diffusion. See for example, Bartel and Lichtenberg (1987), Benhabib and Spiegel (1994, 2003), Krueger and Lindhal (2001), Hall and Jones (1999), Bils and Klenow (2000), Duffy and Papageorgiou (2000), Hanushek and Kimko (2000).

(1998, 1999a, 1999b, 1999c) have introduced many labour market's imperfections, such as switching, turnover and search costs. Moreover, they have argued that, it is difficult for workers to find an alternative firm, as well as for the firms to find a substitute trained worker very quickly. Particularly, Acemoglu (1997) has demostrated that the interaction of innovation and training causes inefficiency in training and a multiplicity of equilibria. Furthermore, these papers conclude that, the actual labour markets, by their imperfections, "make technologically general skills de facto specific" (Acemoglu and Pischke 1999b, p.540).

Our study comes back to the distinction between general and specific training, but refers it to the R&D activity. The key point of the paper is that we consider as *technology-general* the training adopted even without R&D and offered to all workers, and *technology-specific* the training offered just to those workers engaged in R&D and, if and only if, firms engage in research. On the one hand, our definition of *t–g t* is quite close to beckerian general training, because a worker can use his skills with any firm. The difference is that Becker did not consider neither R&D activity engaged by firms nor distinction between high and low-skilled workers. On the other hand *t-s t* is different from beckerian specific training because now training is offered only when firms engage in research activity and just to workers engaged in high-skilled occupations. The general and specific definitions of training usually refer to the link between j-t and firms: in this model we connect training and innovation activity undertaken by firms. Both our typologies of training have received an empirical support, but economic literature still has not given an explicit definition. Moreover, the two typologies of training have never been accounted for a theorethical framework. In particular this paper analyses the two typologies of training within an imperfect labor market, in which firms can increase level of producivity, by investing in R&D. The main conclusions of the training literature are the presence of multiple equilibria and the inefficiencies of the human capital's accumulation function. Our model, although it considers different definitions of general and specific training, will reach similar conclusions: there will be four different equilibrium values of the education's average level and rate of growth, and the presence of training linked to R&D activity will cause a *second best* equilibrium. On the other hand *technology-general training* allows the highest level of rate of growth:

The paper is organized as follows: section 2 will evaluate the results of the empirical literature on the link between training and R&D; in the third section we will display the model. The fourth will show the possible extensions and the policy indications. The last section will discuss the main conclusions.

2 The link between R&D and job-training and previous studies

Recently, some empirical studies investigating the link between training and R&D have been published. All the papers agree about the complementarity, but the two economic concepts need an explanation. The innovation activity is usually divided into *incremental activity*, which uses the existing technologies in the best way and *radical activity*, which introduces new technologies. As regards training, we split it into *technology-general training*, which occurs even without R&D activity and is offered to all workers, and *technology-specific training*, connected to existing technology and provided just for high-skilled workers engaged for that technology.

The economic literature has argued that incremental R&D is usually supported by technology-general training, whereas the introduction and/or the use of new technologies need technology-specific j-t. In fact, if a firm has to modify an existing technology, there is no need to adopt a specific training programme for its workers; it can find workers on the labor market who already have the necessary skills or it can train them independently of its own innovation activity. Moreover, technology-general training is offered by firms which do not engage in R&D or by firms which consider research as a secondary activity. The case is different if R&D activity has to introduce and/or use new technologies: now workers need an *ad hoc* training, which schools and higher education istitutions are not able to provide and which has to be provided on the job.

Many empirical models have studied the effects of technology-general training on the performance of a firm and in particular on productivity. Dearden et al. (2000) analyse the linkages between j-t and productivity levels for English firms from 1983 to 1996. They find a significative direct link and conclude that a 5% increase in training determines a 4% increase in productivity. Barrett and O'Connell (2001) do a similar analysis for Irish firms in the second half of the 1990s. They distinguish between general and specific training (following Becker's definitions), but note that the specific j-t is sometimes not observable, and so not estimatable; however, the positive effect of training on productivity remains. Delame and Kramarz (1997) evaluate the same effect for French firms in the second half of the 1980s; they argue that because of the law existing in France by 1971, firms have to spend a part of the wage in training or to pay the same amount in form of a tax. The authors distinguish three groups of firms: firms which spend more in training programmes than the minimum level, those which spend exactly the necessary amount and firms which spend a lower share, paying the difference as a tax. The conclusion is that is there only for the first group of firms a significant effect of the training programmes. Also, other countries seem to prefer a technology-general training: Pischke (2001) and Loewenstein and Spletzer (1999b) argue that German and American firms especially adopt a training programme that is independent of R&D activity. Moreover, it is quite debatable in terms of the introduction, in

Germany, of a "certification" of job-training, connected to the effective effort of the worker: Acemoglu and Pischke (2000) demonstrate that the certification of training, financed by firms, is necessary in order to transmit sufficient incentives to workers.

Other studies are able to quantify the effect of technology-specific training. Ballot et al. (2001) analyse some French and Swedish firms and evaluate the effect of *firm-sponsored* training and R&D purchase on productivity. They find an interesting complementarity between training and R&D and notice that, particularly for French firms, there is a stronger direct link between R&D and specific training provided for managers and engineers; this provides evidence that specific training is more important for skilled labors. Also Baldwin et al. (1996) confirm that one of the most important factors which presses firms to adopt specific training is the introduction of new technologies, which need adequate skills, not available in the labor market. They notice that specific training is more common among large enterprises; in fact, they are more able to adopt sophisticated technologies, which need specific training in the firm. Hashimoto (1991) confirms that, for Japanese firms, specific training seems to be the main condition which allows to adopt new technologies.

Furthermore, Ok and Tergeist (2002) show that, for OECD countries, younger, better-educated workers and workers engaged in highly skilled occupations are more likely to enter training programmes. They find also that training reduces the erosion of skills with age: decline of adult literacy with age is faster where training participation is low. Moreover, training improves the efficiency of investments in new technology, because it avoids the skill obsolescence which is concomitant of technological change (Arnal et al. 2001).

By summarize the above considerations, this recent empirical literature argues that: (I) training has a positive effect on productivity levels, (II) workers with high levels of education and engaged in high-skilled occupations are more likely to receive further training, (III) training is able to support the workers' accumulation of human capital by avoiding the skill obsolescence which comes with age and technological change, (IV) firms which offer technology-specific training programmes are more likely to introduce new technologies. Furthermore, technology-specific training is usually adopted when firms (I) operate in economic activities in which the introduction, diffusion and use of new technologies are more likely, (II) adopt sophisticated and creative technologies, which need specific professional skills, (III) use own technologies, (IV) have medium-large dimensions.

3 The model

3.1 Description of the environment

This model is based on Redding (1996), but extends it by introducing the heterogeneity of human capital, through *technology-general* training (T-G T) and *technology-specific* training (T-S T). Redding himself notices a restriction of the model, as it results from the homogeneity of human capital and suggests an extension, by writing:

> "For the purpose of the present paper, we make the standard assumption that th education, training and skillls of an economy's workforce may be represented by an aggregate stock of human capital H. Hence, the terms education, training , skills and human capital will be used interchangeably. The many interesting issues concerning the heterogeneity of skills are left to one side" (Redding 1996, p. 458).

We selected that model in order to compare, in a framework of endogenous growth theory, the results without j-t (Redding, 1996) to those with technology-specific and technology-general j-t. Some empirical studies have considered these typologies of j-t, but they still have not been modelled in a theorethical model.

3.1.1 Workers

We adopt a non-overlapping generations model in which the agents, workers and entrepreneurs, live two periods (j=1,2); they have mass L and N respectively, normalised to 1.

Every worker l is assumed to be risk neutral, lives two periods and has the following utility function:

$$U_t(c_1, c_2) = c_{1,t} + \left(\frac{1}{1+\rho}\right) c_{2,t} \tag{1}$$

where $c_{j,t}$ is consumption of generation t in period j and ρ is the discount rate. All the workers are born with a stock of human capital inherited from the preceding generation. Every worker l of generation t, following Lucas (1998), has this human capital:

$$h_{1,t}(l) = (1-\delta) H_{2,t-1} \tag{2}$$

where δ shows the rate of depreciation of human capital and $H_{2,t-1}$ is the aggregate stock of human capital of generation t-1 in the period 2,

$$H_{2,t-1} = \int_o^1 h_{2,t-1}(l)\, dl \tag{3}$$

Workers have to choose, in the first period, the allocation of years between education (ν) and work $(1-\nu)$, with $(0 \leqslant \nu \leqslant 1)$.

The human capital's accumulation function is decomposed in two parts: the first is *education* $(1+\gamma\nu^{\theta})$ and the second is *on-the-job training* $(1+\tau)$; both connect to the stock inherited from the preceding generation (h). At the end of period 2, if firms are able to train on the job, a worker has the following stock of human capital

$$h_{2,t} = h_{1,t}\left(1+\gamma\nu^{\theta}\right)(1+\tau), \quad 0<\vartheta<1, \;\; \tau>0, \; \gamma>0 \tag{4}$$

where
τ= job-training
γ= productivity of education
υ= fraction of period 1 devoted to education
ϑ =elasticity of human capital with respect to time spent in education
The education's component refers to general version of Azariadis and Drazen (1990): it's compatible with every level of education's return (depending on ϑ) and, in particular, by $0<\vartheta<1$, it shows decreasing returns. The j-t's part is used to show the heterogenity of the human capital. The endogenous growth theory often forgets it: a worker can accumulate human capital not only through school and university, but also on the job[5].

During the first period, workers accumulate skills through education; in the second there is also the j-t's component and its presence is formerly known by workers in the first period.

This form of the human capital's accumulation function is useful not only to evaluate the complementarity of the two parts, but also to calculate their effect on the growth rate: the previous study -Redding (1996)- by considering only the education's component of human capital, observes its effect on the growth rate, but it does not consider either its heterogeneity or the possible complementarity between two components.

3.1.2 Entrepreneurs

There is a sequence of non-overlapping generations of entrepreneurs indexed by i. They produce homogeneous final goods with the following production function:

$$y_{j,t}(i) = A_{j,t}(i)\, h_{j,t} \tag{5}$$

where $A_{j,t}(i)$ is the productivity[6] and $h_{j,t}$ is the human capital. Final goods is assumed to be numeraire and so $p_t = 1$, for all t.

Employers can invest in R&D, in the first period, by devoting a fraction α of output. In R&D there are large sunk costs and indivisibilities; hence, as in Aghion and Howitt (1994), we consider fixed costs of research. R&D takes effect

[5] The complementarity between education and training is a well accepted hypothesis in training economics: see, for example, Rosen 1976 and recently Brunello 2001 and Ariga and Brunello 2002. In particular, a similar equation for human capital's accumulation function is also contained in Zotteri (2002).

[6] Following Redding (1996) $A_{j,t}(i)$ denotes also the quality of the technology used by entreprenuer

at the end of first period. If the entreprenuer engages in successfully research, he enjoys a one-period patent on the new technology, which can be used in production in period 2. By assuming that R&D's cost is α^*, where $0 < \alpha^* < 1$, if firms devote a fraction $\alpha > \alpha^*$ to research, technological innovation has a $\mu = \psi$ probability of research success, where $0 < \psi < 1$. If $\alpha < \alpha^*$ firms are not able to innovate and so $\mu = 0$. Since the mass of firms is 1 and each of them innovates with Poisson probability μ, this is also the fraction of firms that have success in research:

$$\mu = \begin{cases} 0 & \text{if } \alpha < \alpha^* \\ \psi & \text{if } \alpha > \alpha^* \end{cases} \tag{6}$$

Because of spillovers in research activity, every firm in the first period adopts the same technology; the effect of R&D on productivity will happen in the second period and, following Aghion and Howitt (1992) will be equal to λ $(\lambda > 1)$. The quality of technology used by firms in the first period is equal to $A_{1,t} = \lambda^m$, where $m = 0, ..., \widetilde{m}$ is the number of innovations introduced, and the initial productivity is normalised to 1. In the period 1

innovations will be available for all firms, as a result of the spillover and according to the distribution of innovating probability; hence, $m(i)$ denotes the quality of technology employed by entreprenuers i.

At the beginning of the second period a worker has a probability $0 6 \sigma 6 1$ to be engaged in research activity as high-skilled and $(1 - \sigma)$ to be hired in production activity. Since the mass of workers is 1, σ is also the fraction of workers engaged by employers for R&D.

Furthermore, in the second period the firms can train their own human capital on the job and training can assume two alternative forms:

1. J-T independent of technological innovation and provided to all workers or *technology-general j-t.*

2. J-T connected to technological innovation and offered to workers engaged in research or *technology-specific j-t.*

We also assume that training offered to workers engaged in no research has a cost function equal to $C(\tau)$; $C(\tau)$ is increasing and strictly convex in τ and, in addition, $C(0) = 0$, $\lim_{\tau \to 0} C'(\tau) = 0$ and $\lim_{\tau \to \infty} C'(\tau) = \infty$. Training cost for workers engaged in R&D is already included in the fixed cost of research α^*: firms must train workers in order to introduce new technologies.

Hence, the output surplus will be different, in the second period, depending on the types of j-t, which firms will offer:

1. *technology-general j-t* (T-GT): training is provided to all workers, engaged or not in research and independently of innovative activity of the firms. The expected second-period output will be:

$$\begin{aligned} E\left[y_{2,t}^g(i)\right] &= A_{1,m}h_{2,t} - C(\tau) \\ &= A_{1,m}h_{1,t}(1+\tau)\left(1+\gamma\nu^\theta\right)\left[\sigma(\lambda\mu + 1 - \mu) + (1-\sigma)\right] \\ &\quad - C(\tau) \end{aligned} \tag{7}$$

Firm supports training cost also for workers engaged in no research.

2 *Technology-Specific j-t* (T-ST): in this case j-t occurs only if firms engage in research and is offered just to workers engaged in research: The expected second-period output will be:

$$\begin{aligned} E\left[y_2^S(i)\right] &= A_{1,m}h_{2,t} \\ &= A_{1,m}\left(1+\gamma\nu^\theta\right)h_{1,t}\left\{\sigma\left[\lambda\mu(1+\tau)+(1-\mu)\right]+(1-\sigma)\right\} \end{aligned} \tag{8}$$

Econometrics studies have demostrated that this type of j-t is usually adopted by most advanced sectors, by those that use creative innovations and by big enterprises.

For a technology-general training to allow a higher expected second-period output we require that $E\left[y_{2,t}^g(i)\right] > E\left[y_{2,t}^S(i)\right]$; that is,

$$\tau > \frac{C(\tau)}{A_{1,m}(1+\gamma\nu^\theta)(1-\delta)H_{2,t-1}(1-\mu\sigma)} \tag{9}$$

Proposition 1 . *For a technology-general training to allow a higher expected second-period output we require either:*

(a) That the effect of training on human capital τ is sufficiently large

(b) That the training cost $C(\tau)$ is sufficiently small

(c) That the initial productivity $A_{1,m}$ is sufficiently large

(d) That the education productivity parameter γ is sufficiently large

(e) That the elasticity of human capital with respect to the time spent in education ϑ is sufficiently large

(f) That the time spent in education υ is large

(g) That the aggregate stock of human capital of preceding generation $H_{2,t-1}$ is large

(h) That the depreciation rate δ is small

(i) That the expected fraction of firms that successfully innovate μ is small

(l) That the fraction of workers engaged in research σ is small

Proof. *(a)-(g)* all follow from (2) and (9)¥

3.1.3 Wage and profit determination

Following Acemoglu (1994 and 1997), in an imperfect labour market workers and entreprenuers, by supporting searching costs, are randomly matched one-to-one and so all workers are employed[7]. Workers and entreprenuers share the expected value of the period 2 surplus in the constant proportions β and $(1-\beta)$ respectively [8].Workers engaged in research have an expected wage as a fraction β of expected second period productivity; wage of workers engaged in no research activity is equal to a fraction β of initial productivity. Hence the expected wages per unit of human capital are[9]

$$E\left[w_2(i)\right] = \begin{cases} \beta\left[\lambda\mu + (1-\mu)\right]A_{1,m} & \text{for workers engaged in research act.} \\ \beta A_{1,m} & \text{for workers engaged in no research act.} \end{cases} \quad (10)$$

3.2 General equilibria with tech-specific and tech-general training

3.2.1 I case: technology-specific training (T-S T)

Workers

The representative worker maximises intertemporal utility (1) given (2),(4) and this intertemporal budget constraint:

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[7] In a matching/searching model the assumption of full employment is not a necessary condition for an imperfect labour market. See, for instance, Acemoglu (1994 and 1997), Diamond and Maskin (1979), Diamond (1982), Mortensen (1982) and Pissarides (1990).

[8] Formally, we adopt an asymmetric Nash bargaining solution, in which workers and entreprenuers, depending on the bargaining power, share the surplus: $\underset{L,w}{Max}\ \pi(L,w)^{1-\beta}(w-w_0)^{\beta}$. An accurate analysis of the bargaining theory is contained in Muthoo (1999)

[9] In order to compensate for the cost of training supported by firms when they do not innovate and offer technology-general training, and to press firms to offer this typology of training, workers could accept a lower wage in exchange for training. They would have a trade-off between wage and training. Hence, we could have the following situation:

$$E\left[w_2^S(i)\right] = \begin{cases} \beta\left[\lambda\mu + (1-\mu)\right]A_{1,m} & \text{for workers engaged in research activity} \\ \beta A_{1,m} & \text{for workers engaged in no research activity} \end{cases}$$

when firms offer t-s training, and

$$E\left[w_2^G(i)\right] = \begin{cases} \beta'\left[\lambda\mu + (1-\mu)\right]A_{1,m} & \text{for workers engaged in research activity} \\ \beta' A_{1,m} & \text{for workers engaged in no research activity} \end{cases}$$

when firms offer T-G training, where $\beta' < \beta$.

$$c_{1,t} + \left(\frac{1}{1+\rho}\right) c_{2,t} \leq w_{1,t}(i)\, h_{1,t}(1-\nu) + \left(\frac{1}{1+\rho}\right) E\left[w_{1,t}(i)\right] h_{2,t} \qquad (11)$$

If worker is risk neutral, she has to choose ν in order to maximise the expected discounted lifetime income:

$$\begin{aligned} \underset{\nu}{Max}\, U(\nu) &= \qquad (12) \\ &= \beta A_{1,m} h_{1,t} \left\{ \begin{array}{c} (1-\alpha^*)(1-\nu) + \\ \left(\frac{1}{1+\rho}\right) \left\{ \begin{array}{c} \sigma\left(1+\gamma\nu^{\theta}\right)\left[\lambda\mu(1+\tau)+1-\mu\right] + \\ (1-\sigma) \end{array} \right\} \end{array} \right\} \end{aligned}$$

The first order conditions are:

$$\nu = \begin{cases} \left\{\frac{\gamma\vartheta\{\sigma\mu[\lambda(1+\tau)-1]+1\}}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} & \text{if } 0 \leq \left\{\frac{\gamma\vartheta\{\sigma\mu[\lambda(1+\tau)-1]+1\}}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} \leq 1 \\ 1 & \text{if } \left\{\frac{\gamma\vartheta\{\sigma\mu[\lambda(1+\tau)-1]+1\}}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} > 1 \end{cases} \qquad (13)$$

We will refer only to the parameter values for which an interior solution exists. From (6) and (13) we have the optimum values of workers' investments in education when firms offer t-s training:

$$\nu = \begin{cases} \nu^s_{\psi} \equiv \left\{\frac{\gamma\vartheta\{\sigma\mu[\lambda(1+\tau)-1]+1\}}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} & \text{if } \alpha > \alpha^* \\ \nu^s_{o} \equiv \left\{\frac{\gamma\vartheta}{1+\rho}\right\}^{\frac{1}{1-\theta}} & \text{if } \alpha < \alpha^* \end{cases} \qquad (14)$$

where $\nu^s_{\psi} > \nu^s_0$.

In addition to Redding (1996) in the model here the optimal level of education, when entreprenuers engage in research and offer a t-s t, directly depends upon the fraction of workers engaged in research σ. Furthermore, there is complementarity between the two forms of human capital: ν^s_{ψ} also directly depends on τ. This implies that if firms offer a technology-specific training and are able to innovate, then job-training, even if there is a low level of education, can support the accumulation of human capital.

Entrepreneurs

If firms are able to innovate -by investing a fraction α^* of period 1 output- and offer a t-s training, the expected return from R&D is:

$$\pi^s(\psi) = \tag{15}$$

$$= \quad (1-\beta) A_{1,m} h_{1,t} \left\{ \begin{array}{c} (1-\alpha^*)(1-\nu) + \\ \left(\frac{1}{1+\rho}\right)(1+\gamma\nu^\theta) \left\{ \begin{array}{c} \sigma[\lambda\mu(1+\tau)+1-\mu] + \\ (1-\sigma) \end{array} \right\} \end{array} \right\}$$

When entrepreneurs do not invest in R&D, they use the existing technology and the expected return is:

$$\pi^s(0) = (1-\beta) A_{1,m} h_{1,t} \left\{ (1-\nu) + \left(\frac{1}{1+\rho}\right)(1+\gamma\nu^\theta) \right\} \tag{16}$$

The incentive to invest in research is given by $\pi^s(\psi) - \pi^s(0)$, which now also depends upon the training offered and the fraction of workers engaged in research.

In addition to Redding (1996), in this model R&D activity directly depends upon training. Firms are interested in offering training: it can mantain their innovative activity, even if the education level of the workers is low.

3.2.2 II case: technology-general training (T-GT)

Workers

When firms offer technology-general training, they train workers even without research activity. Hence, the maximization problem for workers becomes:

$$\underset{\nu}{Max}\ U(\nu) = \tag{17}$$

$$= \beta \left\{ \begin{array}{c} A_{1,m} h_{1,t} \\ \left\{ (1-\alpha^*)(1-\nu) + \left(\frac{1}{1+\rho}\right) \left\{ (1+\tau)(1+\gamma\nu^\theta)[\sigma(\lambda\mu+1-\mu)+(1-\sigma)] \right\} \right\} \\ -\left(\frac{1}{1+\rho}\right) C(\tau) \end{array} \right\}$$

In this case, the first order conditions are

$$\nu = \begin{cases} \left\{\frac{\gamma\vartheta(1+\tau)[\sigma\mu(\lambda-1)+1]}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} & \text{if } 0 \leqslant \left\{\frac{\gamma\vartheta(1+\tau)[\sigma\mu(\lambda-1)+1]}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} \leqslant 1 \\ 1 & \text{if } \left\{\frac{\gamma\vartheta(1+\tau)[\sigma\mu(\lambda-1)+1]}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} > 1 \end{cases} \tag{18}$$

By refering only to the parameter values for which an interior solution exists, from (6) and (18) we have the optimum values of workers' investments in education when firms offer genral training:

$$\nu = \begin{cases} \nu_\psi^g \equiv \left\{\frac{\gamma\vartheta(1+\tau)[\sigma\mu(\lambda-1)+1]}{(1-\alpha^*)(1+\rho)}\right\}^{\frac{1}{1-\theta}} & \text{if } \alpha > \alpha^* \\ \nu_o^g \equiv \left\{\frac{\gamma\vartheta(1+\tau)}{1+\rho}\right\}^{\frac{1}{1-\theta}} & \text{if } \alpha < \alpha^* \end{cases} \tag{19}$$

where $\nu_\psi^g > \nu_0^g$.

Proposition 2:
a) There are 4 equilibrium values for the investments in education of workers:

i) A High Equilibrium value, ν_ψ^g, with research activity and technology-general training
ii) Two intermediate value: ν_0^g and ν_ψ^S, where $\nu_0^g > \nu_\psi^S \iff \tau > \dfrac{\alpha + \sigma(\lambda-1)\mu}{1-\alpha-\sigma\lambda\mu}$
iii) A Low Equilibrium value ν_0^S– equal to the low equilibrium value of Redding's model- with no research and technology-specific training

b) Whether firms invest in research or not, technology-general training allows a higher level of education: $\left(\nu_\psi^g > \nu_\psi^S \text{ and } \nu_0^g > \nu_0^S\right)$.

Proof: (a) and (b) follow from (14) and (19)¥

Unlike Redding (1996) the model here shows a higher "High Equilibrium" value and other two intermediate values.

The introduction of training in the model has allowed to increase the optimal level of education. Comparing the two types of training, technology-general training permits a higher level of education: a worker is more willing to invest in education if he knows that he will improve his skills on the job and that he will be able to do even if the firm will not innovate because of unsuccessful R&D.

From proposition 1 and 2b we note that, if some conditions hold, firms are more willing to provide technology-general training and pay for that. Technology-general training allows a higher level of education; moreover it improves skills even if R&D is unseccessful and also for workers engaged in production activity. This result is in accord to recent empirical and theoretical training literature (Acemoglu and Pischke 1998, 1999a,b, Autor 2001, Bhaskar and Holden 2002, Cappelli 2002). Furthermore, according to Acemoglu (1997) interaction between training and R&D determines inefficiency and multiple equilibria.

Entrepreneurs If firms are able to innovate -by investing a fraction α^* of period 1 output- and offer a t-g training, the expected return from R&D is:

$$\pi^g(\psi) = \tag{20}$$

$$= (1-\beta)\left\{ \begin{array}{c} A_{1,m}h_{1,t} \\ \left\{ \begin{array}{c} (1-\alpha^*)(1-\nu) + \\ \left(\frac{1}{1+\rho}\right)\left\{(1+\tau)\left(1+\gamma\nu^\theta\right)\left[\sigma(\lambda\mu+1-\mu)+(1-\sigma)\right]\right\} \end{array} \right\} \\ -\left(\frac{1}{1+\rho}\right)C(\tau) \end{array} \right\}$$

When entrepreneurs do not invest in R&D, they use the existing technology and the expected return is:

$$\pi^g(0) = (1-\beta)\left\{ \begin{array}{c} A_{1,m}h_{1,t}\left\{(1-\nu)+\left(\frac{1}{1+\rho}\right)(1+\tau)\left(1+\gamma\nu^\theta\right)\right\} \\ -\left(\frac{1}{1+\rho}\right)C(\tau) \end{array} \right\} \tag{21}$$

The incentive to invest in research is given by $\pi^g(\psi) - \pi^g(0)$. In this case there is training's effect also when firms do not invest in R&D: technology-general training is offered even without research and to all workers.

3.3 Rational Expectations equilibrium

Following Redding (1996), we use the Nash equilibrium solution to solve for a rational expectations equilibrium, using (2), $(14), (15), (16)$ for technology-specific training, and $(19), (20), (21)$ for technology-general training. Both players must decide their strategies before they enter the labour market. Workers' investment in human capital depends upon they expect the entreprenuer to engage in R&D. Entrepreneurs' decision of whether or not to invest in R&D depends upon her expectation of workers' investment in human capital. Moreover, in our model both strategies also depend upon job-training's typology offered in the labour market.

In Redding's model there were two kinds of equilibria; in our model 4 differerent equilibria exist.

3.3.1 Equilibria with R&D

In an equilibrium with research activity, workers expect the firm to invest in R&D ($\mu = \psi$). Firms can pay higher wages because of the increase in productivity and hence workers spend more time in education. A higher accumulation of human capital through education increases the expected return of R&D and so the firm does indeed invest in research.

When employers offer a technology-general training, then, from (19), $\nu = \nu_{\psi g}$. For research to be optimal, we require $\pi^g(\psi) > \pi^g(0)$; substituting, we require,

$$\alpha^* < \frac{\psi(\lambda - 1)(1 + \tau)\left[1 + \gamma\left(\nu_\psi^g\right)^\theta\right]\sigma}{(1 + \rho)\left(1 - \nu_\psi^g\right)} \tag{22}$$

When employers offer a technology-specific training, then, from (14), $\nu = \nu_{\psi s}$. For research to be optimal, we require $\pi^s(\psi) > \pi^s(0)$; substituting, we require,

$$\alpha^* < \frac{\psi(\lambda - 1)(1 + \tau)\left[1 + \gamma\left(\nu_\psi^s\right)^\theta\right]\sigma}{(1 + \rho)\left(1 - \nu_\psi^s\right)} \tag{23}$$

Training increases the firms' incentive to engage research , because it reduces cost threshold for R&D.

3.3.2 Equilibria without R&D

In an equilibrium without research activity, R&D is not convenient for the firm. Hence, workers make a lower investment in education; but, when firms offer a technology-general training workers can be trained even without R&D and so on-the-job training can maintain human capital accumulation.

By the same reasoning used above, now $\mu = 0$. For no research to be optimal, when employers offer a technology-general training we require $\pi^g(\psi) < \pi^g(0)$

$$\alpha^* > \frac{\psi(\lambda - 1)(1 + \tau)\left[1 + \gamma(\nu_0^g)^\theta\right]\sigma}{(1 + \rho)(1 - \nu_0^g)} \tag{24}$$

When employers offer a technology-specific training, then, from (14), $\nu = \nu_{0S}$. For no research to be optimal, we require $\pi^s(\psi) < \pi^s(0)$; substituting, we require,

$$\alpha^* > \frac{\psi(\lambda - 1)(1 + \tau)\left[1 + \gamma(\nu_0^s)^\theta\right]\sigma}{(1 + \rho)(1 - \nu_0^s)} \tag{25}$$

3.3.3 Existence of equilibria

The high growth equilibrium is characterised by both research and highest human capital accumulation, through education and training. The low growth equilibrium is characterised by both no innovative improvements and lowest human capital accumulation. The first one Pareto dominates the second one and, using Redding's terminology, they are interpreted as "high-skills, high-quality" and "low-skills, low-quality" equilibria.

We find other two intermediate equilibria: both dominate low growth equilibrium, but are dominated by high growth equilibrium.

When firms offer technology-general training we have

Proposition 3:
(a) If

$$\alpha^* < \frac{\psi (\lambda - 1)(1+\tau)\left[1+\gamma (\nu_0^g)^\theta\right]\sigma}{(1+\rho)(1-\nu_0^g)}$$

there exists a single pure strategy "High Growth" Nash Equilibrium, in which $\mu = \psi$ *and* $h_{2,t} = \left[1+\gamma\left(\nu_\psi^g\right)^\theta\right](1+\tau)h_{1,t}$.

(b)If

$$\alpha^* > \frac{\psi (\lambda - 1)(1+\tau)\left[1+\gamma (\nu_0^g)^\theta\right]\sigma}{(1+\rho)(1-\nu_0^g)}$$

$$\text{but} \quad \alpha^* < \frac{\psi (\lambda - 1)(1+\tau)\left[1+\gamma \left(\nu_\psi^g\right)^\theta\right]\sigma}{(1+\rho)\left(1-\nu_\psi^g\right)}$$

there exist multiple equilibria. Two pure strategy Nash Equilibria exist: the "High Growth", in which $\mu = \psi$ *and* $h_{2,t} = \left[1+\gamma\left(\nu_\psi^g\right)^\theta\right](1+\tau)h_{1,t}$, *and the "Intermediate Growth", in which* $\mu = 0$ *and* $h_{2,t} = \left[1+\gamma (\nu_0^g)^\theta\right](1+\tau)h_{1,t}$.

(c) If

$$\alpha^* > \frac{\psi (\lambda - 1)(1+\tau)\left[1+\gamma \left(\nu_\psi^g\right)^\theta\right]\sigma}{(1+\rho)\left(1-\nu_\psi^g\right)}$$

there exists a single pure strategy "Intermediate Growth" Nash Equilibrium, in which $\mu = 0$ *and* $h_{2,t} = \left[1+(\gamma\nu_0^g)^\theta\right](1+\tau)h_{1,t}$.

Proof. (a) Suppose it is false. If $\mu = 0$, then $\nu = \nu_0^g$. Hence, from (4) we have $h_{2,t} = \left[1+\gamma (\nu_0^g)^\theta\right](1+\tau)h_{1,t}$; but, from (20), (21) and proposition above (a)

, then we have $\pi^g(\psi) > \pi^g(0)$. Research is convenient and so μ has to be equal to ψ

(b) If $\mu = \psi$, then $\nu = \nu_\psi^g$ and, from (20), (21) and proposition above (b) $\pi^g(\psi) > \pi^g(0)$. If $\mu = 0$, then $\nu = \nu_0^g$ and, from (20), (21) and proposition above (b) $\pi^g(\psi) < \pi^g(0)$.

(c) Suppose it is false. If $\mu = \psi$, then $\nu = \nu_\psi^g$. Hence, from (4) we have $h_{2,t} = \left[1+\gamma\left(\nu_\psi^g\right)^\theta\right](1+\tau)h_{1,t}$; but, from (20), (21) and proposition above (c) , then we have $\pi^g(\psi) < \pi^g(0)$. Research is not convenient and so μ has to be equal to zero¥

With successfull R&D employers can increase productivity. Economic growth is supported by the highest education level and training provided to all workers; hence, we have the *"High Growth" Nash Equilibrium.* When firms are not able to innovate, they still have starting productivity; the education level is lower, but training can increase human capital accumulation and support economic growth. Hence there exists an *"Intermediate Growth".*

When firms offer technology-specific training we have:

Proposition 4 :
(a) If

$$\alpha^* < \frac{\psi(\lambda-1)(1+\tau)\left[1+\gamma(\nu_0^s)^\theta\right]\sigma}{(1+\rho)(1-\nu_0^s)}$$

there exists a single pure strategy "Intermediate Growth" Nash Equilibrium, in which $\mu = \psi$ *and* $h_{2,t} = \left[1+\gamma\left(\nu_\psi^s\right)^\theta\right](1+\tau)h_{1,t}$ *for workers engaged in research and* $h_{2,t} = \left[1+\gamma\left(\nu_\psi^s\right)^\theta\right]h_{1,t}$ *for the other workers.*

(b) If

$$\alpha^* > \frac{\psi(\lambda-1)(1+\tau)\left[1+\gamma(\nu_0^s)^\theta\right]\sigma}{(1+\rho)(1-\nu_0^s)}$$

$$but \quad \alpha^* < \frac{\psi(\lambda-1)(1+\tau)\left[1+\gamma\left(\nu_\psi^s\right)^\theta\right]\sigma}{(1+\rho)\left(1-\nu_\psi^s\right)}$$

there exist multiple equilibria with two pure strategy Nash Equilibria. An "Intermediate Growth", in which $\mu = \psi$ *and* $h_{2,t} = \left(1+\gamma\left(\nu_\psi^s\right)^\theta\right)(1+\tau)h_{1,t}$, *for workers engaged in research and* $h_{2,t} = \left[1+\gamma\left(\nu_\psi^s\right)^\theta\right]h_{1,t}$ *for the other* *workers; in addition, there exists the "Low Growth", in which* $\mu = 0$ *and* $h_{2,t} = \left(1 + \gamma\left(\nu_0^s\right)^\theta\right) h_{1,t}$.

(c) if

$$\alpha^* > \frac{\psi(\lambda - 1)(1 + \tau)\left[1 + \gamma\left(\nu_\psi^s\right)^\theta\right]\sigma}{(1 + \rho)\left(1 - \nu_\psi^s\right)}$$

there exists a single pure strategy "Low Growth" Nash Equilibrium, in which $\mu = 0$ *and* $h_{2,t} = \left[1 + \gamma\left(\nu_0^s\right)^\theta\right] h_{1,t}$.

Proof. (a) Suppose it is false. If $\mu = 0$, then $\nu = \nu_0^s$. Hence, from (4) we have $h_{2,t} = \left[1 + \gamma\left(\nu_0^s\right)^\theta\right](1 + \tau)h_{1,t}$; but, from (15), (16) and proposition above (a) , then we have $\pi^s(\psi) > \pi^s(0)$. Research is convenient and so μ has to be equal to ψ

(b) If $\mu = \psi$, then $\nu = \nu_\psi^s$ and, from (15), (16) and proposition above (b) $\pi^s(\psi) > \pi^s(0)$. If $\mu = 0$, then $\nu = \nu_0^s$ and, from (15), (16) and proposition above (b) $\pi^s(\psi) < \pi^s(0)$.

(c) Suppose it is false. If $\mu = \psi$, then $\nu = \nu_\psi^s$. Hence, from (4) we have $h_{2,t} = \left[1 + \gamma\left(\nu_\psi^s\right)^\theta\right](1 + \tau)h_{1,t}$; but, from (15), (16) and proposition above (c) , then we have $\pi^s(\psi) < \pi^s(0)$. Research is not convenient and so μ has to be equal to zero¥

When firms innovate, they are able to increase technology and to offer training to workers engaged in research, but the other workers are not trained; furthermore, the education level is lower than that one obtained by offering technology-general training. Hence we have an *"Intermediate Growth" Nash Equilibrium.* If there is no research, entrepreneurs continue to employ the starting technology and cause the lowest education level. Furthermore there is no training and so there exists the *"Low Growth" Nash Equilibrium.*

Proposition 5 . *As in Redding (1996), For a "High Growth" Equilibrium to be possible we require either:*

(a) That the "quality" of innovations $\lambda > 1$ *is sufficiently large*

(b) That the fixed cost parameter α^* *is sufficiently small*

(c) That the education productivity parameter γ *is sufficiently large*

(d) That the elasticity of human capital with respect to the time spent in education ϑ *is sufficiently large*

(e) That the expected fraction of firms that successfully innovate ψ *is sufficiently large*

(f) That the subjective rate of time discount ρ *is sufficiently small*

Furthermore, we also require that firms offer technology-general training and either

(g) That the effect of training on accumulation of human capital τ is sufficiently large

(h) That the fraction of workers engaged in research σ is sufficiently large

Proof (a)-(h) all follow from Proposition 3 and (19)¥

3.4 Steady-State growth

Aggregate final goods output, from (5), is given by $Y_{1,t} = \int_o^1 A_{1,t}(i) h_{1,t}(i)\, di$, in which $H_{1,t} = \int_o^1 h_{1,t}(i)\, di$. Hence, the expected rate of final goods output is:

$$\log\left(\frac{E\left[Y_{t+1}\right]}{Y_t}\right) = \left\{ \begin{array}{c} \log\left(\mathrm{E}\left[\int_o^1 A_{1,t+1}(i)\, di\right]\right) - \log\left(\int_o^1 A_{1,t}(i)\right) \\ +\log\left(\mathrm{E}\left[H_{1,t+1}\right]\right) - \log\left(H_{1,t}\right) \end{array} \right\}$$

in which $\mathrm{E}[H_{1,t+1}] = (1-\delta) H_{1,t} E\left[\int_0^1 \left(1+\gamma\nu(i)^{\theta}\right)(1+\tau)\, di\right]$.

Since the mass of firms is 1 and each of them innovates with Poisson probability μ, which is indipendently distibuted, from (6) we have

$$log\left(\mathrm{E}\left[\int_o^1 A_{1,t+1}(i)\, di\right]\right) = log\left\{\left[\lambda\mu + (1-\mu)\right] A_{1,t}\right\}$$

.

Proposition 6

(a) In the "High Growth Equilibrium" the economy's expected rate of growth is:

$$\begin{aligned} log\left(\frac{E\left[Y_{t+1}\right]}{Y_t}\right) &= g_H^* \equiv log\ \left[\lambda\psi + (1-\psi)\right] \\ &\quad + log\ (1-\delta)\int_0^1 \left\{1+\gamma\left[\nu_\psi^g(i)\right]^{\theta}\right\}(1+\tau)\, di \end{aligned}$$

with research and technology-general training

(b) *In the "Intermediate Growth Equilibria" the economy's expected rates of growth are:*

$$log\left(\frac{E\left[Y_{t+1}\right]}{Y_t}\right) = g_{IG}^* \equiv log\ (1-\delta)\int_0^1 \left\{1+\gamma\left[\nu_0^g(i)\right]^{\theta}\right\}(1+\tau)\, di$$

with no research and technology-general training, and

$$\begin{aligned} log\left(\frac{E\left[Y_{t+1}\right]}{Y_t}\right) &= g^*_{IS} \equiv log\ \left[\lambda\psi + (1-\psi)\right] \\ &+ log\ (1-\delta)\int_0^{\sigma}\left\{1+\gamma\left[\nu^s_{\psi}(i)\right]^{\theta}\right\}(1+\tau)\,di \\ &+ log\ (1-\delta)\int_{\sigma}^{1}\left\{1+\gamma\left[\nu^s_{\psi}(i)\right]^{\theta}\right\}di \end{aligned}$$

with research and technology-specific training.

(c) In the "Low Growth Equilibrium" the economy's expected rate of growth is:

$$log\left(\frac{E\left[Y_{t+1}\right]}{Y_t}\right) = g^*_L \equiv\ log\ (1-\delta)\int_0^1\left\{1+\gamma\left[\nu^s_0(i)\right]^{\theta}\right\}di$$

with no research and technology-specific training.

The economy's steady state rate of growth depends upon the rate of education accumulation, typology of training offered by firms and whether or not R&D is engaged by entreprenuers. According to the training literature's conclusions and applying them to a model of endogenous growth, *specific training* (following our definition of specifc training) determines a *second best* equilibrium of the economic growth's rate.

Proposition 7

(a) In all our four equilibria -as in the Redding's model, for its two equilibria- the economy's steady state rate of growth is increasing, (i) the smaller the depreciation rate δ, (ii) the smaller the rate of time discount ρ (iii) the larger the productivity of education parameter γ, (iv) the greater the elasticity of human capital with respect to time spent in education θ.

(b) In the "High Growth Equilibrium" and in the "Intermediate Growth Equilibrium" with technology-general training - as in the Redding's model, for its "High Growth Equilibrium"- the economy's steady state rate of growth is also increasing, (i) the greater the probability of innovation ψ and (ii) the better the quality of innovations λ.

In addition we find that:

(c) In the "High Growth Equilibrium" and in the "Intermediate Growth Equilibria" the economy's steady state rate of growth is also increasing the greater is training offered τ.

(d) In the "Intermediate Growth Equilibrium" with technology-specific-training the economy's steady state rate of growth is also increasing the greater is the fraction of workers engaged in research σ.

(e) Because of training's effect: (i) there exist other two "Intermediate Growth Equilibria", (ii) the "High Growth Equilibrium" is higher than the "High Growth Equilibrium" of Redding's model, (ii) when firms do not innovate, technology-general training allows an "Intermediate Growth Equilibrium"; hence, unsuccessful research, which in Redding's model was necessary and sufficient condition for "Low Growth Equilibrium", now is just necessary.

Proof. (a)-(e) all follow from proposition (6), equations (14), (19) and Redding (1996)¥.

If firms do not innovate ($\mu^* = 0$), it is not necessary -unlike Redding (1996)- to fall into the *"Low Growth Equilibrium",* identified by Aghion and Howitt (1998) with "L*ow Development Trap"* because, by assuming T-GT, human capital's rate and so growth's rate are supported by training. In this situation we have an *"Intermediate Growth Equilibria"*. The *Low Development Trap* occurs if and only if firms do not innovate *and* adopt a T-S T: in this case training's component of the human capital has no effect. In other words, in the Redding's model the absence of the R&D was a necessary and sufficient condition for the *Low Development Trap:* $g^*=g_L^* \Longleftrightarrow \mu^* = 0$. In our model the lack of innovations becomes necessary but not a sufficient condition, because also the use of a T-ST is necessary: $g^*=g_L^* \Longleftrightarrow \mu^* = 0$ and T-ST.

4 Further research and policy indications

In this paper we have adopted some hypotheses, which can be modified in order to generate other extensions of the model. First of all, we considered a two periods model. It could be interesting to extend the analysis to the long period, in order to evaluate the effects of technology-general training programmes on the accumulation of human capital and particularly on education level. Moreover, our paper gives equal relevance to both components of human capital: more emphasis could be placed on education, because education is, probably, more general and suitable to the labor market.

We obtain three policy indications from the model. First of all, the governments who want to increase the average level of accumulation of human capital can support both the on-the-job training and the education rate. On the other hand, an higher accumulation of human capital can be directly obtained by education policy and by indirectly subsidying R&D activities (Aghion-Howitt 1998).

Finally, it could be useful for the accumulation of workers' human capital and for an economy's rate of growth, if firms were to adopt a *technology-general* training, independently of their innovative activity. If training is offered just to highly-skilled workers, it tends to increase existing disparities in accumulation of human capital, as they result from education levels; hence governments should improve the access to training for low-skilled workers, by supporting firms which are able to increase all workers' skills through training programmes.

Thus, this paper shows that some level of publicly-sponsored technology-general training may be required to achieve an higher economic growth rate and a greater accumulation of human capital:

Proposition 8. *A subsidy towards the cost of training may induce entrepreneurs to prefer technology-general training, allows the highest accumulation of human capital and takes the economy to the "High-Growth Equilibrium"*

Proof: See Appendix ¥

5 Conclusions

In this paper we have introduced the heterogeneity of the human capital in a non-overlapping generations model of endogenous growth.

We have supposed that workers can accumulate human capital not only through education, but also through on-the-job training. Enterprises can invest in R&D and can offer two alternative forms of training: the first one, *technology-general* j-t , is offered even without R&D, to all workers and the second one, *technology-specific* j-t, is joined to the success of innovative activity and offered just to workers engaged in research. Both typologies of training have received an empirical support, but economic literature has not given an explicit definition yet.

The model has demonstrated that human capital composition, which is often neglected in endogenous growth models, is important in determining the probability of innovation occurring and the growth rate of the economy:

> "An interesting issue which is however completely ignored by the macro literature concerns the role of training in economic growth, and the connected relationship between the level of education and subsequent investments in human capital accumulation on the job. [...] The macro literature focuses on measures of human capital which ignore formal (and informal) on-the-job training, nor has it explored to date the possibility for education to have an indirect positive effect on economic growth by fostering training" (Sianesi and Van Reenen, 2002, pp.35-36 and 39).

The model has shown that complementarities between different types of human capital investment are important. In particular, workers are more likely to invest in education when they know that firms will offer *t-g t* and firms prefer *t-g t* when the time spent in education by workers is sufficiently large. Moreover, human capital's heterogeneity causes the multiplicity of equilibria in education investment and rate of growth, and avoids *low development traps* when R&D is absent.

Some recent empirical studies show that firms often train just those workers engaged in research activity, so that workers with high levels of education and engaged in highly skilled occupations are more likely to receive further training. Furthermore, firms who offer technology-specific training programmes are more likely to introduce new technologies. On the other hand theoretical and empirical literature demostrates that, if some conditions hold, firms provide technology-general training and pay for that. The model here confirms results of recent theoretical studies on *technology-general* training and may be useful in explaining the empirical evidence on *technology-specific* training. We have demonstrated that entrepreneurs prefer technology-general training when the training effect on human capital, the productivity and the average education level are large and/or the cost of training, the probability of successfully innovating and the fraction of workers engaged in research are small.

Unlike Redding's model, which found two equilibriun values for the education level, in our model there are other two equilibria. We find that technology-general training, in contrast to the technology-specific allows higher levels of education; this occurs whether entrepreneurs invest or not.

Additionally, Redding (1996) found two equilibria also for the economic rate of growth. In our model other two intermediate values exist and because of training the *"High-Growth Equilibrium"* is higher than the corrisponding value in that model. In Redding (1996) the *low development trap* occurred when firms did not innovate: g*= *low-skill, low-quality trap* $\Longleftrightarrow \mu^* = 0$. In other words, the lack of firms' innovation was a necessary and sufficient condition for the *low development trap.* In our model the lack of innovating activity is only a necessary but not a sufficient condition: it is necessary to adopt a tecnology-specific j-t. Without R&D, if firm offers a *technology-general* training, there will be an *"Intermediate-Growth Equilibrium",* because training can support economic growth. According to Acemoglu (1997) specific training (following our definition of *specific training*) causes inefficiency in accumulation of human capital and multiplicity of equilibria.

This model concludes, as main policy implication, that governments should prefer a technology-general training in order to obtain a higher economy's rate of growth and avoid existing disparities in accumulation of human capital, as they result from education levels. Training programmes should solve gaps in human capital, generated by schools and colleges. Governments could improve the access to training for low-skilled workers, by subsidying firms which are able to increase all workers' skills through technology-general training programmes.

Appendix

Proof of Proposition 8 :
Suppose that

$$\tau = \frac{C(\tau)}{A_{1,m}(1 + \gamma\nu^{\theta})\, h_{1,t}(1 - \mu\sigma)}$$

From (9) entrepreneurs are indifferent between technology-general and technology-specific training.

Consider a subsidy to the cost of training $\gamma > 0$, such that

$$\tau = \frac{C(\tau) - \gamma}{A_{1,m}(1 + \gamma\nu^{\theta})\, h_{1,t}(1 - \mu\sigma)}$$

Now, employers prefer technology-general training; if they are able to innovate $(\mu = \psi)$ and $\frac{\psi(\lambda-1)(1+\tau)\sigma}{1+\rho} > \frac{\alpha^{*}\left(1-\nu_{0g}^{\vartheta}\right)}{\left(1+\gamma\nu_{0g}^{\theta}\right)}$, then the *"High-Growth Equilibrium" exists.*

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