Complementarity between Heterogeneous 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 addition to education, we model two different typologies of training. The first, technology-general, is independent of R&D; the second one, technology-specific, is joined to the success of innovative activity and it is only provided for workers engaged in research. The paper, by extending Redding (1996), demonstrates that human capital composition is important in determining the probability of innovation occurring and the economy's rate of growth. Moreover, technology-general training avoids low development traps when R&D is absent

Keywords: general versus specific training, innovation, heterogeneous human capital, endogenous growth.
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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 provided 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 telecommunications, on the other hand. Twenty years after the research mentioned above, two more research studies were conducted in Canada and they investigated the behavior 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.

In 2000 *The Lisbon Strategy* was born within European Union; it was revised in 2005, by considering heterogeneous human capital and R&D as crucial elements, in order to facilitate growth rates and to create the most competitive economic area in the world.

From some years, the economic literature has been studying the links between on-the-job training and R&D activity[3], 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 shift from low- to high-skill jobs taking place in most OECD countries today." (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 lines of economic research; 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 subsets of 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 a factor in growth accounting[4], because it facilitates technology adoption and diffusion[5]. 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.

A second line of research analyses investment in heterogeneous human capital within competitive (e.g., Becker, 1964) and/or imperfect labor markets (e.g., Acemoglu, 1997, and Acemoglu and Pischke 1998, 1999a, 1999b). Particularly, Acemoglu (1997) has demonstrated that the interaction of innovation and training causes inefficiency in training and 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).

Furthermore, an other recent subset of empirical studies also investigate link between training and R&D. Many empirical models have studied the effects of a training independent of R&D, which we can define technology-general, on the performance of a firm and in particular on productivity (Dearden et al., 2005, Barrett and O'Connell, 2001, Pischke 2001 and Loewenstein and Spletzer, 1999). Other studies (Hashimoto 1991. Ballot et al.2001, Baldwin et al.1996, Baldwin 1999, Baldwin and Peters 2004) are able to quantify the effects of a specific training for R&D and provided for high- skilled workers, which we can consider as technology-specific; in particular, they find an interesting complementarity between R&D and training provided for workers engaged in research activity. 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). Substantially, this trend points out that some firms are able to provide training for all workers (low-skilled and high-skilled) and independently of their research activity, but other firms provide training only for high-skilled workers engaged in research activity and only when they engage in successful R&D.

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* (T-G T) the training adopted even without R&D and provided for all workers, and *technology-specific* (T-S T) the training provided just for 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 only provided 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.

Our model consider several complementarities, between human capital and R&D and inside human capital. (I) First of all there is a *proportional* complementarity between education and training: the larger the average level of education, the larger is the effect of training on productivity. Training is able to support accumulation of human capital on the job: without training workers have the same amount of human capital as it result from education level. (II) As in Redding (1996) there is a *strategic* complementarity between human capital and R&D; unlike Redding's model we consider strategic interdependences between *heterogeneous* human capital and R&D, by evaluating the effect of training on both strategies adopted by firms and workers. (III) There is a *strict* complementarity between T-S T and R&D: without t-s t firms are not able to invest in R&D and without research activity firms do not provide on-the-job training. This complementarity is different from complementarity between training and R&D used by Acemoglu (1997): in that model when firms do not use new technologies, they can provide training. T-G T and R&D are on the contrary *independent:* firms are also able to invest in successful R&D without T-G T (they only need to train workers engaged in R&D), and T-G T is also provided by firms when they do not engage in research activity. Also this typology of training is different from that used by Acemoglu (1997): he consideres that without training firms are not able to use new technologies.

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 model

2.1 Description of the environment

This model is based on Redding (1996), but extends it by introducing the heterogeneity of human capital, through T-G T and 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 the education, training and skills 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 T-S T and T-S T.

2.1.1 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 $(0 \leq \nu \leq 1)$.

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

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

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 component is used to show the heterogeneity 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[6].

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.

2.1.2 Entrepreneurs

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

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

where $A_{j,t}(i)$ is the productivity[7] and $h_{j,t}$ is the human capital. Final goods is assumed to be numeraire and so $\mathrm{p}_t = 1$, 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 at the end of first period. If the entrepreneur 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:

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

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 entrepreneurs i.

At the beginning of the second period a worker has a probability $0 \leq \sigma \leq 1$ 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 for all workers or *technology-general j-t.*

2. j-t connected to technological innovation and provided just for workers successfully 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. with T-GT, the expected second-period output will be:

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

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

2 With T-ST, the expected second-period output will be:

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

For a T-G T 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,

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

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).

2.1.3 Wage and profit determination

Following Acemoglu (1994 and 1997), in an imperfect labour market workers and entrepreneurs, by supporting searching costs, are randomly matched one-to-one and so all workers are employed[8]. Workers and entrepreneurs share the expected value of the period 2 surplus in the constant proportions β and

$(1-\beta)$ respectively [9].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[10]

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

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

2.2.1 I case: T-S T

Workers

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

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

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

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

The first order conditions are:

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

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 provide T-S T:

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

where $\nu_{\psi}^{s} > \nu_{0}^{s}$.

In addition to Redding (1996) in the model here the optimal level of education, when entrepreneurs 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 components of human capital: ν_{ψ}^{s} also directly depends on τ. This implies that if firms provide a T-S T 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 provide a T-S T, the expected return from R&D is:

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

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

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

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

The incentive to invest in research is given by $\pi^{s}\,(\psi) - \pi^{s}\,(0)$, which now also depends upon the training provided and upon 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 providing training: it can maintain their innovative activity, even if the education level of the workers is low.

2.2.2 II case: T-GT

Workers

When firms provide T-G T, they train workers even without research activity. Hence, the maximization problem for workers becomes:

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

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

In this case, the first order conditions are

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

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 provide T-G T:

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

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 $\nu_0^g > \nu_\psi^S \iff \tau > \dfrac{\alpha+\sigma\left(\lambda-1\right)\mu}{1-\alpha-\sigma\lambda\mu}$

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, T-G T 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 T-G T and pay for that. T-G T allows a higher level of education; moreover it improves skills even if R&D is unsuccessful and also for workers engaged in production activity. 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 provide a T-G T, the expected return from R&D is:

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

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

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: T-G T is provided even without research and for all workers.

2.3 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 T-S T, and (19) , (20) , (21) for T-G T. Both players must decide their strategies before they enter the labour market. Workers' investment in human capital depends upon they expect the entrepreneur 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 provided in the labour market.

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

2.3.1 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 provide a T-G T, 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 provide a T-S T, 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.

2.3.2 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 provide a T-G T 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 provide a T-G T we require $\pi^g(\psi) < \pi^g(0)$

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

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

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

2.3.3 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 provide a T-G T we have

Proposition 3:

(a) If

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

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

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

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

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* $h_{2,t} = \left[1+\gamma\left(\nu_0^g\right)^\theta\right](1+\tau)h_{1,t}$.

(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* $h_{2,t} = \left[1+\left(\gamma\nu_0^g\right)^\theta\right](1+\tau)h_{1,t}$.

Proof. (a) Suppose it is false. If $\mu = 0$, then $\nu = \nu_0^g$. Hence, from (4) we have $h_{2,t} = \left[1+\gamma\left(\nu_0^g\right)^\theta\right](1+\tau)h_{1,t}$; 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 successful R&D employers can increase productivity. Economic growth is supported by the highest education level and training provided for 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 provide a T-S T we have:

Proposition 4 :

(a) If

$$\alpha^{*}<\frac{\psi\left(\lambda-1\right)\left(1+\tau\right)\left[1+\gamma\left(\nu_{0}^{s}\right)^{\theta}\right]\sigma}{\left(1+\rho\right)\left(1-\nu_{0}^{s}\right)}$$

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

$$\alpha^{*}>\frac{\psi\left(\lambda-1\right)\left(1+\tau\right)\left[1+\gamma\left(\nu_{0}^{s}\right)^{\theta}\right]\sigma}{\left(1+\rho\right)\left(1-\nu_{0}^{s}\right)}$$

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

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 by providing T-S T, they are able to trainonly workers engaged in research; furthermore, the education level is lower than that one obtained by providing T-G

T. 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 provide 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)

2.4 Steady-State growth

Aggregate final goods output, from (5), is given by $\mathrm{Y}_{1,t} = \int_o^1 A_{1,t}(i)h_{1,t}(i)\,di$, 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 independently distributed, 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:

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

with research and T-G T

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

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

with no research and T-G T, and

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

with research and T-S T

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

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

with no research and T-S T.

The economy's steady state rate of growth depends upon the rate of education accumulation, upon the typology of training provided by firms and upon whether or not R&D is engaged by entrepreneurs. According to the training literature's conclusions and applying them to a model of endogenous growth, *specific training* (following our definition of specific 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 T-G T - 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 provided τ.

(d) In the "Intermediate Growth Equilibrium" with T-S T 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) other two "Intermediate Growth Equilibria" there exist, (ii) the "High Growth Equilibrium" is higher than the "High Growth Equilibrium" of Redding's model, (ii) when firms do not innovate, T-G T 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-G T, 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*=$g_L^* \iff \mu^* = 0$. 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*=$g_L^* \iff \mu^* = 0$ and T-ST.

3 Policy indications

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 subsiding 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 provided 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 T-G T, allows the highest accumulation of human capital and takes the economy to the "High-Growth Equilibrium"*

Proof: See Appendix.

4 Conclusions

In this paper we have introduced the heterogeneity of the human capital in a non-overlapping generations model of endogenous growth. In particular we have modelled two different typologies of training and we have demonstrated that they have different effect on the economy's rate of growth.

Some recent empirical studies report complementarities between training and R&D and show that firms often train only 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. We have given a theoretical representation of that and we have demonstrated that entrepreneurs, if some conditions hold, could prefer a training provided for all workers and independent of R&D activity.

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 (Sianesi and Van Reenen, 2003). In particular, 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.

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 to avoid existing disparities in accumulation of human capital, as they result from education levels.

Appendix

Proof of Proposition 8 :

Suppose that

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

From (9) entrepreneurs are indifferent between T-G T and T-S T training.

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

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

Now, employers prefer T-G T; if they are able to innovate $(\mu = \psi)$ and $\frac{\psi(\lambda-1)(1+\tau)\sigma}{1+\rho} > \frac{\alpha^{*}\left[1-\left(\nu_0^{g}\right)^{\vartheta}\right]}{\left[1+\gamma\left(\nu_0^{g}\right)^{\vartheta}\right]}$, then the *"High-Growth Equilibrium" exists.*

Notes

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[2]Main results of the surveys are contained in Baldwin, Gray, and Johnson, (1996), Baldwin (1999), and Baldwin and Peters (2004).

[3]For a brief overview see Scicchitano (2007).

[4]See Benhabib and Spiegel (1994).

[5]See for example, Bartel and Lichtenberg (1987), Benhabib and Spiegel (1994, 2005), Krueger and Lindhal (2001), Hall and Jones (1999), Lloyd-Ellis and Roberts (2002).

[6]The complementarity between education and training is a well accepted hypothesis in training economics: see Ok e Tergeist (2002), Zotteri (2002), Brunello (2004) and Ariga and Brunello (2006).

[7]Following Redding (1996) $\mathrm{A}_{j,t}(i)$ denotes also the quality of the technology used by entreprenuer

[8]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).

[9]Formally, we adopt an asymmetric Nash bargaining solution, in which workers and entreprenuers, depending on the bargaining power, share the surplus: $\underset{L,w}{Max}\ \pi\left(L,w\right)^{1-\beta}\left(w-w_0\right)^{\beta}$.

[10]In order to compensate for the cost of training supported by firms when

they do not innovate and provide T-G T, and in order to press firms to provide 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 provide T-S T, 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 provide T-G T, where $\beta' < \beta$.

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