

Human Capital Accumulation and the Transition from Specialization to Multi-tasking *

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Abstract

This paper provides theoretical foundations to the contemporaneous increase in computer usage, human capital and multi-tasking observed in many OECD countries during the 1990s. The links between work organization, technology and human capital is modelled by establishing the conditions under which firms allocate the workers' time among several productive tasks. Organizational change is then analysed in a dynamic perspective as the transition from specialization towards multi-tasking emphasizing its technological and educational determinants.

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1 Introduction

One of the most striking economic facts of the last decade is certainly the long lived expansion experienced by the US economy (around 4% of annual growth in productivity on average during the 1990s). Most industrial countries have benefited from the same conditions though at a lower extent compared to the US case. An important aspect of this expansion episode concerns the role of information and communication technologies (ICT). There is an unanimous view according to which ICT have been indeed the driving force behind the 1990s boom (Gordon, 2000, Jorgenson and Stiroh, 2000, and Oliner and Sichel, 2000). Indeed, productivity growth has been so impressive in the ICT sectors and the weight of such sectors in the economy has increased so markedly in the 1990s that there cannot be any doubt about the leading role of ICT in the boom.

Nonetheless, an intense debate on the precise role of ICT as a long term growth engine is still taking place. Is the ICT-induced growth in productivity just the result of a pure capital deepening mechanism, of massive purchases of ICT equipment, following the dramatic fall in the price of ICT tools? Or are there any **ICT usage effects** on total factor productivity in the non-ICT sectors? For Gordon, once the cyclical effects removed, there is no evidence on the existence of spillovers from the ICT sector (mainly hardware) to the rest of the economy. This view is challenged by Oliner and Sichel, for example.

For Askenazy and Gianella (2000), the absence of a compelling evidence on the existence of such spillovers on aggregate data reflect the role of organizational change. In the industries where new organizational practices (towards more flexibility) have accompanied the (rising) investment in ICT tools, the resulting productivity gains are significant. In others, such an adaptation effort in work organization has not been undertaken, and the increasing investment in ICT equipment has not proven productivity enhancing. In a few words, it seems that ICT investment and organizational change are complementary, spillovers only take place when some adequate changes in work organization are performed. Early empirical corroborations of such a complementarity property are due to Black and Lynch (2000), and Bresnahan *et al.* (2002).

As reported by Osterman (1994), there is an increasing use of flexible organization forms in the US. In the early 1990s, almost the two thirds of American firms use flexible forms of workplace organization, at least partially. Typical flexible organizations include work teams, job rotation, total quality control and quality circles. In particular, the ability of a worker to perform different tasks is becoming a key

requirement. Obviously, multi-tasking also raises the skills requirements, so that a natural trend would be an increasing average level of workers' qualifications as long as multi-tasking practices continue to be adopted. Indeed, the increasing employment share of skilled workers in the US economy is a clearly observed fact, as documented by Autor, Katz and Krueger (1998), see Table I below.

Table I

Employment shares in the United States, 1980-1996

	1980	1990	1996
High school dropouts	19.3 %	13.1 %	9.8 %
College graduates	19.9 %	24.6 %	26.7 %
College equivalents	31.3 %	37.6 %	41.6 %

Source: Autor, Katz and Krueger (1998)

Henceforth, one can identify three main trends in US manufacturing during the past two decades:

- An increase in the employment shares of skilled workers
- An important adoption of new technologies, especially micro computers
- The adoption of organizational forms favoring job rotation, team work, quality, with emphasis on multi-tasking

These trends are not confined to the United States. They are largely relevant in the case of Great Britain and France as shown in Caroli and Van Reenen (2001), and are also observed in many other OECD countries¹. We document in Tables II and III below, organizational change, technical change and the proportion of high and low educated workers employed in British firms between 1984 and 1990 using the data provided by Caroli and Van Reenen (2001).

¹Organizational change has been documented by Lindbeck and Snower (2001) for Nordic countries, Gollac, Greenan and Hamon-Chollet (2000) for a further study on France, and Bauer and Bender (2001) for Germany.

Table II

Organizational and technical change in Great Britain, 1984-1990

	1984	1990
Organizational Change - non manual workers	22.3 %	44.7 %
Organizational Change - manual workers	32.3 %	43 %
Use of microcomputer in plants	24.2 %	62.3 %
Proportion of workers using new technologies in industry	44.8 %	55 %
Proportion of college graduates	35.9 %	39.8 %
Proportion of workers with no qualification	42.7 %	32 %

Table III

Definition of organizational change in British Firms

	non manual workers	manual workers
Have more responsibility	46.2 %	32.8 %
Have to work at a more skilled level	50.4 %	29.8 %
Wider range of tasks performed	62.5 %	39.5 %
Have more interesting jobs to do	63.9 %	36.9 %

This paper is aimed at providing theoretical foundations to the three trends outlined above: more computers in the workplace, more skilled people, and increasing multi-tasking. Following Lindbeck and Snower (2000), we formalize work organization by the time allocation of workers among several tasks and distinguish between two types of work organization: specialization when workers perform only one task, or multi-tasking when workers allocate their working time between the multiple activities. In deciding whether workers should specialize or perform multiple tasks, firms hence face a trade-off between two sets of returns: “returns from specialization” or “intratask learning” whereby the more time a worker spends a task, the higher his productivity from this task, and “returns from multi-tasking” or “intertask learning” whereby a worker can use the information and skills acquired at one task to increase his productivity at another task. There is some empirical evidence in line with this story. Carstensen (2002) observes the existence of two polar forms of organizations in Germany: “tayloristic” organizations, based on labor specialization, and “holistic” organizations, based on multi-tasking. She reports that between 1993 and 1997, 57 % of German firms have adopted new organizational forms based on job enrichment, job enlargement and over time variability in task assignments. Holistic firms are also more productive, experience positive marginal returns from reorganization towards multi-tasking and rely on human capital accumulation strategies.

Returns to specialization and multi-tasking are influenced by technological change and human capital. On the one hand, ICT make information more abundant, thereby increasing informational tasks complementarities. Computers also seem to complement the performance of more educated workers in complex tasks. Autor, Levy and Murnane (2001) indeed observe that the task content of employment has changed during the 1960-1998 period in American firms. They show that computerization is associated with declining demand for routine manual and cognitive tasks and increased relative demand for non-routine cognitive tasks. Changes in task content would thus explain more than half of the overall demand shift induced by computerization.

On the other hand, the new modes of work organization that diffused in the 1990s have contributed to increase the scope for and the returns from learning. Using American data, Chaudhury (2002) indeed finds that the reorganization of work associated with the diffusion of information technology can be associated with steeper learning curves. But if the development of multi-tasking relies on the returns to task complementarities, it also creates complex interactions among the different activities performed. When production requires the realization of a series of tasks, mistakes in any of them can widely reduce the product's value. In the extreme case of O-ring technologies² (Kremer, 1993), interactions among tasks are multiplicative so that the entire value of output can be destroyed if only one task is incorrectly performed. The workers' productivity, which can be assimilated to the probability of correctly performing a task in Kremer's model, then interact in such a way that the quantity of labor is not perfectly substitutable to labor quality. An increase in the productivity of skilled workers can in turn makes it more profitable for skilled workers to work by themselves in separate reorganized firms to avoid that unskilled workers put downward pressure on the productivity of skilled workers (Kremer and Maskin, 1996 and Acemoglu, 1999).

This paper analyses the links between work organization, technology and human capital by establishing the conditions under which firms allocate the workers' time among several productive tasks. The trade-off between specialization to multi-tasking depends both on technological factors and on the human capital acquired by workers. The determinants of organizational change is analyzed in a dynamic perspective as the transition from specialization towards multi-tasking. This paper is organized as follows. Section 2 develops the model, section 3 analyses the stationary equilibria and section 4 studies the dynamics and transition from specialization to multi-tasking. Section 5 concludes the paper.

²O-rings were one of the components of the space shuttle Challenger. This shuttle exploded because the launching temperature caused these components to malfunction.

2 The model

2.1 Workers' production function

Firms produce a homogenous good using labor as only input. Production relies on the realization of $k = 1, \dots, n$ tasks. For the sake of simplicity, we restrict our attention to the case of two productive tasks: $n = 2$. Firms have to decide the range and proportion of tasks that will be performed. Both aspects are embedded into the allocation of the workers' time between both tasks. When workers are assigned to one task only, work organization is based on specialization, when workers perform both tasks work organization is based on multi-tasking.

As in Lindbeck and Snower (2000), the efficiency units of labor supplied by workers have two determinants: returns to specialization and returns to multi-tasking. Returns to specialization imply that a worker's productivity at one task increases with his exposure to that task. Returns to multi-tasking rely on the idea that a worker can also use the information and skills acquired at one task to improve his performance at another task. This kind of returns can be considered as "informational task complementarities".

We normalize workers' available time to one and denote by τ_t the time devoted to task 1 and $(1 - \tau_t)$ the time devoted to task 2. We consider that returns to specialization simply capture the fact that the greater the fraction of the worker's working time devoted to a particular task, the more productive he becomes at that task. However, we consider that human capital complements the time devoted to task 1. Returns to specialization are therefore given by:

$$s(\tau_t, h_t) = A_t \cdot \tau_t \cdot h_t^\alpha \tag{1}$$

where $0 < \alpha < 1$, h_t is the worker's human capital, and $A_t > 0$ is a productivity parameter.

Returns to multi-tasking exhibit more complex interactions. In the spirit of "O-ring technologies" (Kremer, 1993), we consider that when a worker's attention is allocated to several tasks, there exist multiplicative interactions among them. Returns to multi-tasking are therefore the product of two components: informational task complementarities and the quality of work performed (*i.e.* the worker's human capital). For informational task complementarities to exist, the worker must spend time both on task 1 and on task 2. Informational task complementarities are hence given by $\tau_t \cdot (1 - \tau_t)$. In addition, human capital complement informational task complementarities in the determination of returns to multi-tasking. Returns to

multi-tasking are hence defined by:

$$m(\tau_t, h_t) = B_t \cdot \tau_t \cdot (1 - \tau_t) \cdot h_t^\beta \quad (2)$$

where B_t is a productivity parameter, $0 < \beta < 1$ and $0 < \alpha < 1$.

Notice that in the basic O-ring technology, each worker performs only one task, it therefore formalizes team production rather than multi-tasking. Besides, the probability of success of each task is strictly equal the level of human capital of each worker. While our analysis clearly distinguishes between both elements, we still share the feature that multiplicative interactions among tasks arise as production becomes more complex. We assume that such complex interactions do not arise when workers are specialized simply to capture the idea that within organizations based on specialization, production is less complex and requires less human capital.

The output of a worker with human capital h_t is then given by:

$$y_t = A_t \cdot \tau_t \cdot h_t^\alpha + B_t \cdot \tau_t \cdot (1 - \tau_t) \cdot h_t^\beta \quad (3)$$

As Lindbeck and Snower (2000, 2001) we assume that production requires the realization of two tasks and relies on two sets of returns, returns to specialization and multi-tasking. However, we do not assume a fixed allocation of the workforce between two categories of workers, the human capital level of the workforce hence is endogenous. In turn, the returns to multi-tasking and the returns to specialization depend on the level of human capital. In particular, on the one hand, the marginal return of time spent on task 1 depends on a technological parameter and human capital, but not on the time spent on this task. On the other hand, the marginal return of time spent on task 2 not only depends on technology and human capital, but it also depends on informational task complementarity, that is on the time spent on task 1.

2.2 Optimal work organization

What we call work organization in this model is the optimal time allocation mode. When $\tau_t = 1$, work organization is specialized, whereas when $\tau_t < 1$ work organization is based on multi-tasking.

Firms determine the optimal share of workers' time devoted to task 1 (τ_t) and task 2 ($1 - \tau_t$) and the optimal quantity of labor input that maximize profits³. The profits of a production unit employing N_t individuals with human capital level h_t are given by:

$$\pi_t = [y_t - w_t] \cdot N_t \quad (4)$$

where $w_t \equiv w(h_t)$ is the wage rate of a worker with human capital h_t .

The optimal work organization and quantity of labor input are the solutions of the following program:

$$\begin{aligned} \max_{\tau_t, N_t} \pi_t &= [y_t - w_t] \cdot N_t \\ \text{s.c. } y_t &= A_t \tau_t h_t^\alpha + B_t \tau_t (1 - \tau_t) h_t^\beta \end{aligned}$$

- The first order condition on τ_t writes⁴:

$$A_t h_t^\alpha + B_t h_t^\beta (1 - 2\tau_t) \leq 0$$

The optimal time allocation is therefore given by:

$$\begin{cases} \tau_t = 1 & \text{if } h_t \leq \bar{h}_t \equiv \left(\frac{A_t}{B_t}\right)^{\frac{1}{\beta-\alpha}} \\ \tau_t = \frac{1}{2} \left[1 + \frac{A_t}{B_t} h_t^{\alpha-\beta}\right] & \text{if } h_t > \bar{h}_t \equiv \left(\frac{A_t}{B_t}\right)^{\frac{1}{\beta-\alpha}} \end{cases} \quad (5)$$

³Lindbeck and Snower (2001) consider that employees have discretion over the proportions in which different tasks are performed (i.e. the task mix) and that, in the absence of centralized bargaining, the firm can offer a different wage to worker at each task. The employees' freedom to decide upon the task mix, that is the employees' autonomy, would indeed be adapted to organizations with pay plans based on individual performance measures (see, for instance, Holmström and Milgrom, 1991). This leads them naturally to focus the relationships between centralized bargaining and reorganization. Our ambition is different and the issue of unionization and imperfectly competitive wage setting rules is beyond the scope of our paper. Indeed, relying on a competitive wage setting rule, we analyze on employees' education decisions in a dynamic context, given organizational choices at the employer level. This leads us to focus on the interactions between human capital accumulation and reorganization.

⁴The second order condition is always satisfied: $-2B_t h_t^\beta < 0$.

- The first order condition on N_t is:

$$w_t = y_t \tag{6}$$

Given the optimal work organization (5), we get:

$$\begin{cases} w_t = A_t h_t^\alpha & \text{if } h_t \leq \bar{h}_t \\ w_t = \frac{h_t^{-\beta}}{4B_t} \left[A_t h_t^\alpha + B_t h_t^\beta \right]^2 & \text{if } h_t > \bar{h}_t \end{cases} \tag{7}$$

2.3 The workers' behavior

The economy is populated by overlapping generations of individuals who live for two periods. They decide to invest in human capital in the first period and they work in the second period. To simplify, individuals do not consume during the first period. We denote by $t + 1$ the generation born in t . The utility function of a member of this generation is given by⁵:

$$u_{t+1} = \ln(1 - e_t) + \ln c_{t+1}$$

where e_t denotes time spent on education in the first period. Total time being normalized to 1, $(1 - e_t)$ represents leisure time. c_{t+1} denotes second period's consumption. Given that individuals do not consume in the first period, the budget constraint writes $c_{t+1} \leq w_{t+1}$ where the wage rate is defined by equation (7).

The level of human capital of a member of generation $t + 1$, h_{t+1} , depends on two elements: the time spent acquiring education in the first period, e_t , and human capital of the previous generation h_t : $h_{t+1} = h(e_t, h_t)$ where $h(., .)$ is increasing in both arguments, differentiable and concave. To obtain analytical results, we rely on the specific functional form

$$h_{t+1} = E_t \cdot (e_t)^a \cdot (h_t)^{1-a} \tag{8}$$

⁵Lindbeck and Snower assume that reservation wages express the preferences of workers for specialization or multi-tasking. This induces a non convexity in the disutility of effort. Our model is different since we model preferences in an intertemporal framework where there is a trade-off between education and consumption.

where E_t is an efficiency parameter and $0 < a < 1$.

Individual decisions hence are made according to the following program:

$$\begin{aligned} & \max_{e_t} \ln(1 - e_t) + \ln(w_{t+1}) \\ & \text{s.t. } h_{t+1} = E_t \cdot (e_t)^a \cdot (h_t)^{1-a} \end{aligned}$$

This program leads to the following condition:

$$\frac{1}{1 - e_t} = \frac{\partial(\ln w_{t+1})}{\partial h_{t+1}} \cdot \frac{\partial h_{t+1}}{\partial e_t} \quad (9)$$

Given (7), we get:

$$e_t = \frac{a\phi(h_{t+1})}{1 + a\phi(h_{t+1})} \quad (10)$$

where $\phi(\cdot)$ is such that:

$$\begin{aligned} \phi(h_{t+1}) &= \alpha \quad \text{if } h_{t+1} \leq \bar{h}_{t+1} \\ \phi(h_{t+1}) &= \frac{(2\alpha - \beta)A_{t+1}(h_{t+1})^\alpha + \beta B_{t+1}(h_{t+1})^\beta}{A_{t+1}(h_{t+1})^\alpha + B_{t+1}(h_{t+1})^\beta} \quad \text{if } h_{t+1} > \bar{h}_{t+1} \end{aligned} \quad (11)$$

Given equation (8), the dynamics of human capital is governed by the following equation:

$$h_{t+1} = E_t \cdot \left(\frac{a\phi(h_{t+1})}{1 + a\phi(h_{t+1})} \right)^a \cdot (h_t)^{1-a} \quad (12)$$

When $h_{t+1} > \bar{h}_{t+1}$, the relationship between h_t and h_{t+1} is still functional, *i.e.* to each h_t corresponds a unique h_{t+1} . Equation (12) can indeed be rewritten as $h_{t+1} = h_t \cdot \left(E_t^{\frac{1}{a}} \cdot \frac{1}{h_{t+1}} \cdot \frac{a\phi(h_{t+1})}{1 + a\phi(h_{t+1})} \right)^{\frac{a}{1-a}}$, that is:

$$h_{t+1} = h_t \cdot (1 - G(h_{t+1}))^{\frac{a}{1-a}}, \quad G(h_{t+1}) = 1 - E_t^{\frac{1}{a}} \cdot \frac{1}{h_{t+1}} \cdot \frac{a\phi(h_{t+1})}{1 + a\phi(h_{t+1})}$$

We show in Appendix (6.1) that function $G(\cdot)$ is strictly increasing. Using the implicit function theorem, h_{t+1} therefore is monotonic and strictly increasing in h_t . For each h_t corresponds a unique h_{t+1} .

3 Stationary equilibria

We first study the existence of solutions under a stationary environment. In particular, we assume that A_t , B_t and E_t are constant, equal to A , E and B . The threshold human capital value is therefore constant equal to $\bar{h} = \left(\frac{A}{B}\right)^{\frac{1}{\beta-\alpha}}$. This stationary threshold value defines two possible steady state regimes: specialization below this value, and multi-tasking above. Let e_s (respectively e_m) and $h_s < \bar{h}$ (respectively $h_m > \bar{h}$) denote the steady-state values of education investments and human capital in the specialization regime (respectively in the multi-tasking regime). We shall study the existence and uniqueness of these equilibrium values.

To get an immediate idea about how the model works in this respect, notice that given equations (8), (10), and (11) we have:

$$e_s = \frac{\alpha a}{1 + \alpha a}, \quad h_s = E^{\frac{1}{\alpha}} \cdot \frac{\alpha a}{1 + \alpha a} \quad (13)$$

However, this stationary value of human capital under specialization only makes sense if $h_s < \bar{h}$. This conditions imposes the following restriction on the environment:

$$E^{\frac{1}{\alpha}} \cdot \frac{\alpha a}{1 + \alpha a} < \left(\frac{A}{B}\right)^{\frac{1}{\beta-\alpha}}. \quad (C1)$$

Condition (C1) can be interpreted in two ways. For fixed “organizational parameters”, A , B , α and β , the specialization equilibrium exists if and only if the education productivity variable E is small enough. In other words, specialization is an equilibrium organization of work when the productivity of the education technology is too low to allow reaching the threshold value of human capital above which firms would choose multi-tasking. Another interpretation is that for fixed education parameters, condition (C1) implies a lower bound for the ratio $\frac{A}{B}$, which implies that the specialization equilibrium exists if A is large enough with respect to B , which is a very natural outcome. Intuitively, specialization is an equilibrium organization of work when the relative technological productivity of labor services in such a case (A compared to B) is high enough. Does a multi-tasking equilibrium exist in such a case? Notice that if such an equilibrium exists, then the multi-tasking equilibrium effort and human capital are respectively:

$$e_m = \frac{a\phi(h_m)}{1 + a\phi(h_m)}, \quad h_m = E^{\frac{1}{\alpha}} \cdot \frac{a\phi(h_m)}{1 + a\phi(h_m)} \quad (14)$$

where $\phi(h_m) = \frac{(2\alpha - \beta)A(h_m)^\alpha + \beta B(h_m)^\beta}{A(h_m)^\alpha + B(h_m)^\beta}$.

We assume that parameters α and β are such that

$$\alpha < \beta < 2\alpha \tag{A1}$$

Assumption (A1) is a sufficient condition for the multi-tasking equilibrium to be unique. The interpretation of this assumption is the following. The optimal work organization, combined to the stationary level of human capital accumulated by workers, leads to a unique multi-tasking equilibrium as long as the contribution of human capital to the returns to labor services is higher in the multi-tasking organization than in the specialization-based structure ($\beta > \alpha$), but it should not be not too high for a stationary level of human capital to exist ($\beta < 2\alpha$).

The analysis is much less trivial in the case of multi-tasking. The following proposition summarizes the findings regarding these issues.

Proposition 1: Steady states

Under assumption A1, the model has a unique steady state. If condition (C1) is fulfilled, the specialization equilibrium prevails. If not, the multi-tasking equilibrium does.

Proof:

The existence and uniqueness of the steady-state with specialization is immediate from equation (13) under condition (C1). The existence of the multi-tasking equilibrium amounts to solving the equation $G(h) = 0$ with $G(h) = 1 - E^{\frac{1}{a}} \cdot \frac{1}{h} \cdot \frac{a\phi(h)}{1+a\phi(h)}$.

We have: $\lim_{h \rightarrow 0} \phi(h) = (2\alpha - \beta)$, $\lim_{h \rightarrow +\infty} \phi(h) = \beta$ and therefore, under assumption A1:

$$\lim_{h \rightarrow 0} G(h) = -\infty, \quad \lim_{h \rightarrow +\infty} G(h) = 1$$

We show in Appendix (6.1) that function $G(\cdot)$ is strictly increasing on \mathbb{R}_+ . Hence, there exists a multi-tasking equilibrium if and only if $G(\bar{h}) < 0$. Notice that this condition is exactly the opposite of (C1) since $\phi(\bar{h}) = \alpha$. So under (C1), we cannot have a multi-tasking equilibrium.

Assume now that (C1) does not hold, namely that:⁶

$$E^{\frac{1}{a}} \cdot \frac{\alpha a}{1 + \alpha a} > \left(\frac{A}{B}\right)^{\frac{1}{\beta - \alpha}}.$$

⁶We disregard the equality case, $h_s = \bar{h}$, because it does not make economic sense.

In such a case, the specialization equilibrium cannot exist. In contrast, since $G(\bar{h}) < 0$ if (C1) is violated, a multi-tasking equilibrium exists and is unique. \square

It follows that the values of the exogenous variables A , B and E are crucial in the nature of the long term organizational regime. If the education effort is efficient enough and/or if the multi-tasking regime is profitable enough (relatively to specialization), the unique possible stationary equilibrium is multi-tasking, and *vice versa*. Of course, it remains to study if the obtained stationary equilibria are stable.

4 Dynamics and transition from specialization to multi-tasking

We shall now study the global dynamics. As announced in the introduction section, we will also identify the cases where a transition from specialization to multi-tasking takes place.

4.1 Global dynamics under condition (C1)

Consider a situation where the environment is stationary, *i.e.* with constant A_t , B_t and E_t , and where condition (C1) holds. Hence, by Proposition 1, the specialization regime is the unique prevailing stationary equilibrium. Suppose that the initial value of human capital is bigger than h_s : $h_s < h_0$. The following proposition gives the exact dynamics in such a case.

Proposition 2. Transition dynamics when $h_s < h_0$

Under assumptions A1, provided (C1) holds, if $h_s < h_0$, the equilibrium sequence h_t , $t \geq 0$, decreases to the specialization human capital stationary value h_s .

Proof.

We will prove that the human capital sequence is decreasing and bounded from below by h_s ; hence it is converging necessarily to the fixed point h_s .

We start with the case $h_s < h_t < \bar{h}$. Then, either $h_{t+1} > \bar{h}$ or $h_{t+1} < \bar{h}$. In the latter case: $h_{t+1} = E (e_t)^a \cdot (h_t)^{1-a}$, and $e_t = \frac{\alpha a}{1+\alpha a}$.

Since $h_s < h_t$, we get: $h_{t+1} > E (e_t)^a \cdot (h_s)^{1-a}$, so that:

$$\frac{h_{t+1}}{h_s} > E (e_t)^a \cdot (h_s)^{-a}.$$

Given that $e_s = e_t$ for every t when $h_t < \bar{h}$, and as $h_s = E^{\frac{1}{a}} e_s$, it follows that $\frac{h_{t+1}}{h_s} > 1$. The human capital sequence is bounded from below by the fixed point of the sequence h_s . Moreover, we have: $\frac{h_{t+1}}{h_t} = E (e_t)^a \cdot (h_t)^{-a}$, and provided that $h_t > h_s$, it follows that: $\frac{h_{t+1}}{h_t} < E (e_t)^a \cdot (h_s)^{-a}$.

Again, we use the relations $e_s = e_t$ and $h_s = E^{\frac{1}{a}} e_s$ since when $h_t < \bar{h}$, and we get immediately $\frac{h_{t+1}}{h_t} < 1$.

Hence if $h_{t+1} < \bar{h}$, we have $h_s < h_{t+1} < h_t < \bar{h}$.

Suppose now that $0 < h_t < \bar{h}$ and $h_{t+1} > \bar{h}$. Then, $e_t = \frac{a \phi(h_{t+1})}{1+a \phi(h_{t+1})}$, and $h_{t+1} = E \left(\frac{a \phi(h_{t+1})}{1+a \phi(h_{t+1})} \right)^a \cdot (h_t)^{1-a}$.

We can rewrite the equation just above as:

$$\frac{h_{t+1}}{h_t} = \left(\frac{E^{\frac{1}{a}} a \phi(h_{t+1})}{h_{t+1} (1 + a \phi(h_{t+1}))} \right)^{\frac{a}{1-a}},$$

we then have: $\frac{h_{t+1}}{h_t} = [1 - G(h_{t+1})]^{\frac{a}{1-a}}$.

Since condition (C1) is fulfilled, $0 < G(x) < 1$ for every $x \geq \bar{h}$. As $h_{t+1} > \bar{h}$, it follows that $\frac{h_{t+1}}{h_t} < 1$, which contradicts the assumption $h_t < \bar{h}$ and $h_{t+1} > \bar{h}$.

It follows that whence $h_t < \bar{h}$, h_{t+1} is necessarily below the threshold, and $h_s < h_{t+1} < h_t$. Convergence follows.

Consider now the case where $h_t > \bar{h}$. Then either h_{t+1} is below the threshold and we come back to the previous case, or h_{t+1} is above the threshold, and in such a case we have the relation: $\frac{h_{t+1}}{h_t} = [1 - G(h_{t+1})]^{\frac{a}{1-a}}$, with $0 < G(x) < 1$ for every $x \geq \bar{h}$.

The sequence is in any case strictly decreasing. At some point in time, it should go below the threshold value, \bar{h} , and it then converges to the unique fixed point under (C1), namely h_s . \square

By a similar argument, we can prove that the same monotonic behavior arises when $0 < h_0 < h_s$.

Proposition 3. Transition dynamics when $0 < h_0 < h_s$

Under assumptions A1, provided condition (C1) holds, if $0 < h_0 < h_s$, the equilibrium sequence $h_t, t \geq 0$, increases to the specialization human capital stationary value h_s .

Using the same arguments as before, we prove that the human capital sequence is increasing and bounded from above by the fixed-point h_s . It therefore converges to this value. Figure 1 in Appendix (6.2) depicts the dynamical system when condition (C1) holds. We now study the dynamics when condition (C1) is violated.

When condition (C1) holds, the returns to specialization and wages are equal: $w_t = A_t h_t^\alpha$ and $s(\tau = 1, h_t) = A_t h_t^\alpha$ if $h_t \leq \bar{h}_t$. Wage is an increasing function of human capital ($\partial w_t / \partial h_t = \alpha A_t h_t^{\alpha-1} > 0$). Since wages are competitive, an increase in the efficiency units of labor supplied due to rising human capital, raises wages. Figure 3a in appendix (6.3) depicts this human capital effect on wages.

4.2 Global dynamics when condition (C1) does not hold

If (C1) does not hold, the multi-tasking equilibrium is the unique steady state. Moreover in such a case, $G(x) < 0$ for $\bar{h} < x < h_m$ and $G(x) > 0$ for $x > h_m$. This allows us to establish the following characterization of the global dynamics in such a case.

Proposition 4. Transition dynamics when $h_0 > h_m$

Under assumptions A1, if condition (C1) does not hold, and $h_0 > h_m$, the equilibrium sequence $h_t, t \geq 0$, decreases to the multi-tasking human capital stationary value h_m .

Proof.

Suppose that $h_t > h_m$. Then, we have either $h_{t+1} > \bar{h}$ or $h_{t+1} < \bar{h}$.

Consider first the case where $h_{t+1} > \bar{h}$ so that $\frac{h_{t+1}}{h_t} = [1 - G(h_{t+1})]^{1-\alpha}$.

We have two possible sub-cases: either $h_{t+1} > h_m$ or $h_{t+1} < h_m$. The second sub-case is impossible. Indeed, as $G(x) < 0$ for $x < h_m$, we have $\frac{h_{t+1}}{h_t} > 1$, which contradicts $h_t > h_m$ and $h_{t+1} < h_m$. In contrast, if $h_{t+1} > h_m$, we get no contradiction. Because $1 > G(x) > 0$ for $x > h_m$, it follows that: $h_m < h_{t+1} < h_t$.

This is indeed the unique possible case since the alternative $h_{t+1} < \bar{h}$ is also impossible. Indeed, in such an alternative case, we have

$$h_{t+1} = E \left(\frac{\alpha a}{1 + \alpha a} \right)^a \cdot (h_t)^{1-a},$$

and because $h_t > h_m > \bar{h}$ and $E^{\frac{1}{a}} \cdot \frac{\alpha a}{1 + \alpha a} > \bar{h}$ (condition (C1) violated), it follows that:

$$h_{t+1} > (\bar{h})^a \cdot (\bar{h})^{1-a} = \bar{h}. \quad \square$$

It remains to study the dynamics in the case where $h_0 < h_m$.

Proposition 5. Transition dynamics when $h_0 < h_m$

Under assumptions A1, if condition (C1) does not hold, and $h_0 < h_m$, the equilibrium sequence h_t , $t \geq 0$, increases to the multi-tasking human capital stationary value h_m .

Proof.

Let us first consider the case $\bar{h} < h_t < h_m$. We can prove exactly as in the end of the proof of Proposition 4, that $h_{t+1} \leq \bar{h}$ is impossible in such a case. Thus $h_{t+1} > \bar{h}$.

A priori two sub-cases are still possible: either $h_{t+1} > h_m$ or $h_{t+1} < h_m$. Again we use the law of motion, $\frac{h_{t+1}}{h_t} = [1 - G(h_{t+1})]^{\frac{a}{1-a}}$, to discriminate. Indeed, notice that since $1 > G(x) > 0$ when $x > h_m$, we have $\frac{h_{t+1}}{h_t} < 1$ if $h_{t+1} > h_m$, which contradicts $h_t < h_m$. Therefore: $h_{t+1} < h_m$. It follows that when the sequence starts below h_m (and above the threshold value), it converges monotonically to h_m .

We now end our analysis by solving the case of an initial condition below the threshold value, $h_t < \bar{h}$. We have either $h_{t+1} > \bar{h}$, and in such a case, it is trivial to show using the same argument just above that necessarily $h_{t+1} < h_m$, and we end up with the same story as before. Less trivially, the case $h_{t+1} < \bar{h}$, is solved by noticing that since the evolution of capital is given by:

$$h_{t+1} = E \left(\frac{\alpha a}{1 + \alpha a} \right)^a \cdot (h_t)^{1-a},$$

we have:

$$\frac{h_{t+1}}{h_t} > E \left(\frac{\alpha a}{1 + \alpha a} \right)^a \cdot (\bar{h})^{-a},$$

which implies since $E^{\frac{1}{\alpha}} \cdot \frac{\alpha a}{1+\alpha a} > \bar{h}$ (condition (C1) violated), that is $\frac{h_{t+1}}{h_t} > 1$. The sequence is increasing, and at some point in time, it should go above the threshold value, \bar{h} , and converge to the unique fixed point under (C1), namely h_m . \square

Figure 2 in Appendix (6.2) depicts the dynamical system when condition (C1) does not hold. We now turn to the determinants of organizational change, that is the transition from specialization to multi-tasking.

When condition (C1) does not hold, the returns to multi-tasking and wages are also increasing functions of human capital⁷. This human capital effect is however higher in the multi-tasking than in the specialization regime. Indeed, in the former case, returns to human capital are the sum of returns to specialization and returns to multi-tasking, while in the latter case returns to human capital are uniquely composed of returns to specialization. Hence, in addition to the human capital effect, there is also a multi-tasking effect on wages. Figure 3b in appendix (6.3) depicts this characteristics. This property has been documented by Chaudhury (2002) who shows that the trend towards multi-tasking implies steeper individual age-wage profiles.

4.3 Transition from specialization to multi-tasking

We have shown that under a stationary environment, the steady-state regime is either the specialization regime (condition (C1) fulfilled) or the multi-tasking regime (condition (C1) violated). To analyze the conditions for a transition from the specialization regime to the multi-tasking regime, we consider two different types of shock: a shock on the efficiency parameter of the education technology E , or a shock on the parameters of the returns to specialization and multi-tasking, A and B . Given the structure of our model, the transition dynamics from one organizational form to another is endogenous.

Following Autor, Levy and Murnane (2001), we may interpret time spent on task 1 as time spent on routine cognitive and manual task, and time spent on task 2 as activities requiring non-repetitive tasks. Hence, our analysis of the transition from specialization to multi-tasking decomposes two kinds of shocks generating work reorganization. On the one hand, we consider technological advances embedded into information technologies that increase the relative returns of non-routine problem solving and interactive tasks, which corresponds to an increase in the technological

⁷When $w_t = \frac{h_t^{-\beta}}{4B_t} [A_t h_t^\alpha + B_t h_t^\beta]^2$ and under A1, $\partial w_t / \partial h_t = \frac{w_t}{h_t} \cdot \frac{(2\alpha - \beta)A_t h_t^\alpha + \beta B_t h_t^\beta}{A_t h_t^\alpha + B_t h_t^\beta} > 0$.

ratio B/A . On the other hand, we consider advances in the education system that improve the ability of individuals to learn how to perform various activities, that is how to become more versatile, which corresponds in the model to an increase in the efficiency of education E .

Proposition 6. Transition from specialization to multi-tasking

An increase in the efficiency of the education technology E or an increase in the relative returns to multi-tasking B/A generates a transition from a specialization stationary regime to a multi-tasking regime.

Proof.

Let consider an initial situation in which condition (C1) is fulfilled and such that the specialization regime prevails. The stationary value of human capital under specialization is such that: $E^{\frac{1}{a}} \cdot \frac{\alpha a}{1+\alpha a} < \left(\frac{A}{B}\right)^{\frac{1}{\beta-\alpha}}$. We have to show that after an increase in E or in B/A , the multi-tasking regime prevails and is such that $h_m > E^{\frac{1}{a}} \cdot \frac{\alpha a}{1+\alpha a}$.

Consider first an increase in the efficiency parameter of the education technology from E to \tilde{E} , high enough and such that

$$\tilde{E}^{\frac{1}{a}} \cdot \frac{\alpha a}{1+\alpha a} > \bar{h} = \left(\frac{A}{B}\right)^{\frac{1}{\beta-\alpha}}.$$

Let $\tilde{h} = \tilde{E}^{\frac{1}{a}} \cdot \frac{\alpha a}{1+\alpha a}$. Given that function $\phi(\cdot)$ is strictly increasing (see Appendix 6.1) and the fact that $\phi(\bar{h}) = \alpha$, we have

$$\begin{aligned} \tilde{h} &= \tilde{E}^{\frac{1}{a}} \cdot \frac{\alpha a}{1+\alpha a} > \bar{h} \Leftrightarrow \frac{a\phi(\tilde{h})}{1+a\phi(\tilde{h})} > \frac{a\phi(\bar{h})}{1+a\phi(\bar{h})} \\ &\Leftrightarrow \frac{a\phi(\tilde{h})}{1+a\phi(\tilde{h})} > \frac{a\alpha}{1+a\alpha} \\ &\Leftrightarrow 1 - \frac{1+\alpha a}{\alpha a} \cdot \frac{a\phi(\tilde{h})}{1+a\phi(\tilde{h})} < 0 \end{aligned}$$

Using the fact that $\frac{1+\alpha a}{\alpha a} = \frac{\tilde{E}^{\frac{1}{a}}}{\bar{h}}$ we finally have:

$$\tilde{h} > \bar{h} \Leftrightarrow G(\tilde{h}) = 1 - \frac{1}{\bar{h}} \cdot \tilde{E}^{\frac{1}{a}} \cdot \frac{a\phi(\tilde{h})}{1+a\phi(\tilde{h})} < 0$$

The stationary value of human capital is such that $G(h_m) = 0$, and given that function $G(\cdot)$ is strictly increasing, we therefore have the following inequality:

$$\bar{h} < \tilde{h} < h_m.$$

Consider now an increase in the relative returns to multi-tasking from $\frac{B}{A}$ to $(\frac{B^*}{A^*})$, high enough and such that

$$E^{\frac{1}{a}} \cdot \frac{\alpha a}{1 + \alpha a} > \bar{h}^* = \left(\frac{A^*}{B^*}\right)^{\frac{1}{\beta - \alpha}}.$$

Using the same argument as above, we show that

$$\begin{aligned} \hat{h} &= E^{\frac{1}{a}} \cdot \frac{\alpha a}{1 + \alpha a} > \bar{h}^* \Leftrightarrow \frac{a\phi(\hat{h})}{1 + a\phi(\hat{h})} > \frac{a\phi(\bar{h}^*)}{1 + a\phi(\bar{h}^*)} \\ &\Leftrightarrow \frac{a\phi(\hat{h})}{1 + a\phi(\hat{h})} > \frac{a\alpha}{1 + \alpha a} \\ &\Leftrightarrow 1 - \frac{1 + \alpha a}{\alpha a} \cdot \frac{a\phi(\hat{h})}{1 + a\phi(\hat{h})} < 0 \\ &\Leftrightarrow G(\hat{h}) = 1 - \frac{1}{\hat{h}} \cdot E^{\frac{1}{a}} \cdot \frac{a\phi(\hat{h})}{1 + a\phi(\hat{h})} < 0 \\ &\Leftrightarrow \bar{h}^* < \hat{h} < h_m. \end{aligned}$$

The transition dynamics from the initial specialization regime to multi-tasking follow from Proposition 5. \square

While an increase in E or B/A leads to the same transition from specialization to multi-tasking, the mechanisms at work are slightly different. On the one hand, an increase in the efficiency of education E increases the incentives to acquire education. For a given level of technological parameters, as the efficiency of education rises, the specialization equilibrium becomes a sub-optimal work organization. This mechanism captures an efficiency effect: an increase in the parameter E makes workers more able to perform a wider variety of tasks, since it increases the efficiency of education. Education systems improving cognitive abilities to become versatile, which translates in our model into an increase in the productivity of the education technology, hence appears to be one major source of organizational change. For Lindbeck and Snower (2000), an important determinant of organizational change indeed is the steady growth of human capital per worker generated by education systems which made workers improve their performance of particular skills and increase their ability to acquire a variety of skills. Such an evolution motivates firms to

reorganize work in favor of multi-tasking. For Acemoglu (1999) as well, an increase in the productivity of education makes it more profitable for skilled workers to work in reorganized firms (separately from unskilled workers).

On the other hand, a shock on B/A reduces the threshold level above which firms choose to allocate workers to several tasks. Such a shift in the threshold level of human capital means that, for a given level of human capital, the ability of workers to perform various tasks is enhanced when B/A increases. This mechanism captures an allocation effect: an increase in B/A makes workers more easily allocated to multi-tasking. Intuitively, ICT usage provide workers with more information, both within firm and about customers, permitting employees to be more involved in multi-tasking. Autor, Levy and Murnane (2001) indeed document that the adoption of ICT alters job content. Computer-based technologies substitute for routine tasks and complement non-routine activities, suggesting that workers using such technologies are required to become more versatile. An increase in the relative returns to multi-tasking due to ICT is in our model a second major force stimulating the transition from specialization to multi-tasking.

The novelty of our approach is to highlight, like Autor, Levy and Murnane (2001), the predominant role of the task content of employment. While the traditional skill-biased technical change literature emphasizes computerization and ICT as a source of a demand shift favoring better-educated labor and increasing wage inequality, we focus on the changing nature of jobs as technological change and education systems improve the ability of workers to perform a variety of new tasks, that is to become more versatile.

Considering technological adoption in a historical perspective, there are several examples of innovations favoring successively specialization and multi-tasking during the twentieth century. Automobile production is a good illustration for this (see Goldin and Katz, 1998). It began in large artisanal shops where automobiles were assembled by highly skilled and versatile artisans. Technological advances associated with the emergence of assembly lines led to standardized and interchangeable parts that were assembled in factories by scores of less-skilled and specialized workers. Our model can account for such reverse transitions from multi-tasking to specialization. Indeed, while ICT that have contributed to increase the returns to versatility, complementing non-routine activities and relying on higher human capital levels, the emergence of assembly lines in the first part of the twentieth century increased the returns to task specialization leading to wide-scale division of labor. This would translate in our model into an increase in the ratio A/B , which leads, by symmetry with an increase in B/A , to a transition from multi-tasking to specialization.

5 Conclusion

This paper provides theoretical foundations to the apparent complementarity between organizational change, ICT investment and human capital. In deciding whether workers should specialize or perform multiple tasks, firms face a trade-off between the returns from specialization and the returns from multi-tasking. The optimal time allocation mode involves multi-tasking when the workers' level of human capital is sufficiently high. The model has a unique steady state (specialization or multi-tasking) which is globally stable.

Organizational change taking the form of a the transition from specialization to multi-tasking occurs following two kinds of shocks: an increase in the productivity of the human capital technology or an increase in the relative returns of multi-tasking. The increase in the productivity of education, as well as the productivity effects of ICT in terms of informational and technological task complementarity favor the adoption of multi-tasking organizations, thereby explaining the contemporaneous increase in computer usage, human capital accumulation and multi-tasking observed in many OECD countries during the 1990s.

6 Appendix

6.1 Steady-state with multi-tasking

Deriving $G(\cdot)$ implies:

$$G'(h) = E^{\frac{1}{a}} \cdot \frac{1}{h} \cdot \frac{a\phi(h)}{1+a\phi(h)} \cdot \left[\frac{\phi(h)(1+a\phi(h)) - h\phi'(h)}{h\phi(h)(1+a\phi(h))} \right]$$

In turn,

$$G'(h) > 0 \Leftrightarrow \phi(h)[1+a\phi(h)] - h\phi'(h) > 0$$

Deriving $\phi(\cdot)$ yields:

$$\phi'(h) = \frac{2AB(\alpha - \beta)^2 h^{\alpha+\beta-1}}{[A(h)^\alpha + B(h)^\beta]^2} > 0$$

Hence,

$$G'(h) > 0 \Leftrightarrow [1+a\phi(h)] \cdot \frac{1}{h\phi'(h)/\phi(h)} > 1$$

We have:

$$h\phi'(h)/\phi(h) = \frac{(2\alpha - \beta) \alpha A(h)^\alpha + \beta^2 B(h)^\beta}{(2\alpha - \beta) A(h)^\alpha + \beta B(h)^\beta} - \frac{\alpha A(h)^\alpha + \beta B(h)^\beta}{A(h)^\alpha + B(h)^\beta}$$

Thus, after some calculations:

$$\begin{aligned} h\phi'(h)/\phi(h) &\leq 1 \\ \Leftrightarrow (2\alpha - \beta) [x(h)]^2 + \beta [y(h)]^2 + [\alpha(1 - \alpha) + \beta(2\alpha - \beta)] [x(h)y(h)] &\geq 0 \end{aligned}$$

where $x(h) \equiv A(h)^\alpha$ and $y(h) \equiv B(h)^\beta$.

Hence, under assumption A1, we have $2\alpha - \beta > 0$ and therefore $h\phi'(h)/\phi(h) < 1$.

In turn, since $1 + a\phi(h) > 1$ and $\frac{1}{h\phi'(h)/\phi(h)} > 1$, we have $G'(h) > 0$.

6.2 Phase diagrams

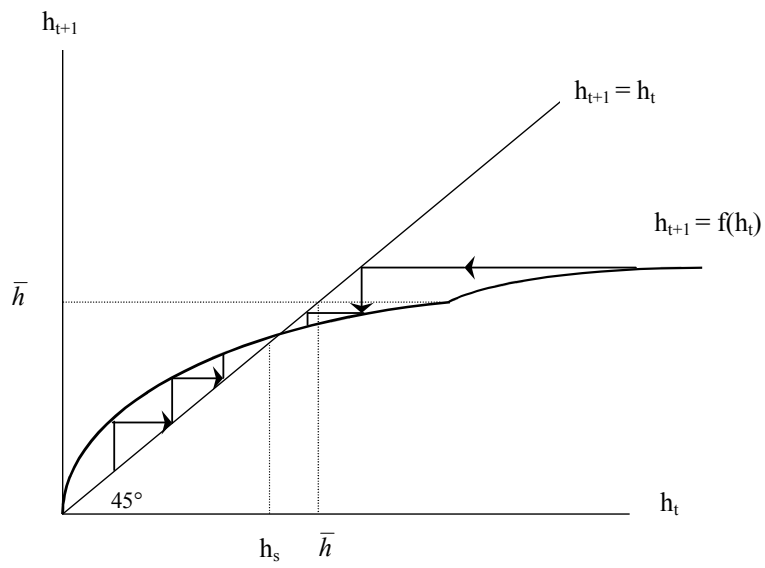


Figure 1: Dynamics of human capital when condition (C1) holds.

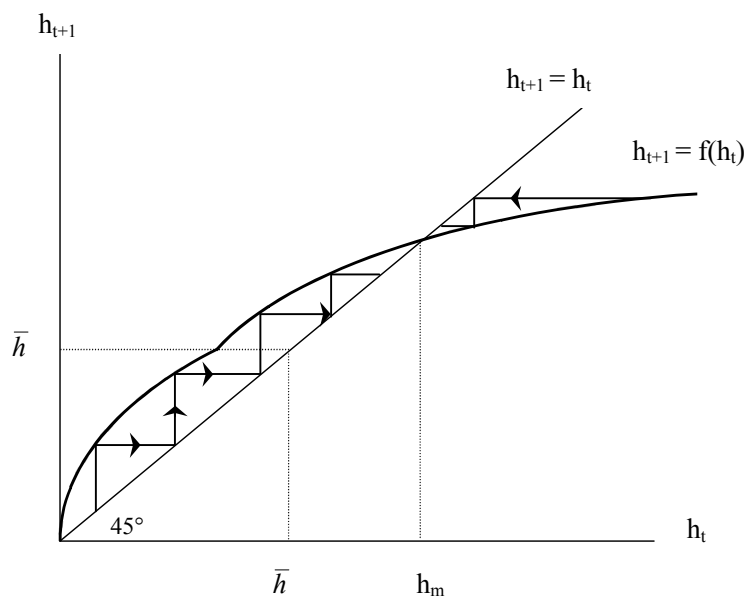


Figure 2: Dynamics of human capital when condition (C1) does not hold.

6.3 Returns to human capital and wages

When condition (C1) holds, that is in the specialization stationary regime, the returns to specialization and wages are equal: $w_t = A_t h_t^\alpha$ and $s(\tau = 1, h_t) = A_t h_t^\alpha$ if $h_t \leq \bar{h}$. Figure 3 reproduces simulations of the evolution of wage as human capital accumulates (that is when the sequence h_t is increasing). The parameters values are the following: $\alpha = 0.4$, $\beta = 0.7$, $a = 0.3$, $A = 1.8$, $B = 2$, $E = 1.2$ (these values are such that both assumption A1 and condition (C1) are satisfied).

In such a case, the stationary values of \bar{h} and h_s are: $\bar{h} = 0.703842$, $h_s = 0.196744$.

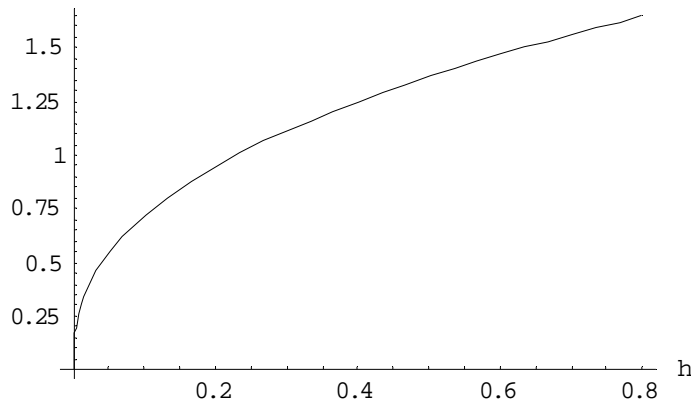


Figure 3a: Wages and returns to specialization when condition (C1) holds

Notice that by symmetry, when the sequence h_t is decreasing, wages are decreasing.

When condition (C1) is violated, that is in the multi-tasking regime, figure 3b reproduce simulations of the wages (thick line) and returns to multi-tasking (dashed line) as human capital accumulates. The parameter values are the following: $\alpha = 0.4$, $\beta = 0.7$, $a = 0.3$, $A = 1.8$, $B = 4$, $E = 1.2$ (these values are such that assumption A1 is satisfied and condition (C1) is violated).

In such a case, the stationary values of \bar{h} and h_m are: $\bar{h} = 0.0698299$, $h_m = 0.218795$ (notice that the stationary value h_s would be $h_s = 0.196744$, which is consistent with the fact that in this case condition (C1) is violated).

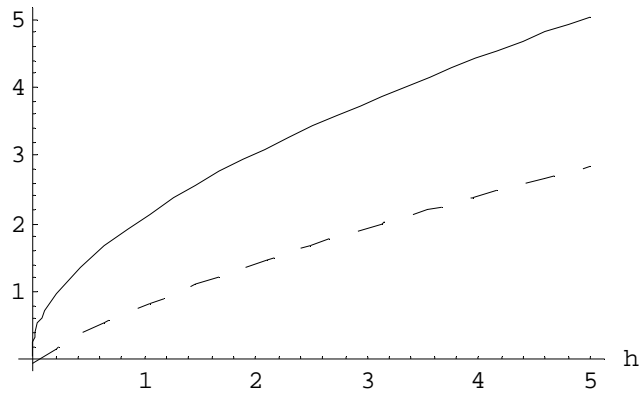


Figure 3b: Wages and returns to multi-tasking when condition (C1) is violated

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