Human Capital Theory, Returns to Education and on-the-Job Learning: Evidence from Canadian Data

Mohsen Bouaissa
Labour Market Research & Forecasting
HUMAN RESOURCES AND SKILLS DEVELOPMENT CANADA

[Preliminary and incomplete version]
June 16, 2009

1 Introduction

The return to education has been a topic of considerable interest for economists,[1] public policy makers and analysts, and even simple individuals over the last four decades and it is still attracting a lot of attention. Knowing how much a specific education program or degree would yield is a key factor for an individual's decision to enroll in that program rather than get another training or immediately join the labour market. Any one of these decisions determines his labour and skills supply, on which will depend his consumption and saving decisions, and eventually his well-being level. At the economy-wide level, individual decisions on education and training determine the aggregate supply of labour and skills, labour productivity and technological progress rate, which in turn determine the overall productivity level and economic growth, as well as the demand for goods and services (especially demand for education and training), and their contributions to public finance. For all these considerations, the public policy actors are naturally concerned with the issues related to the education and learning returns, and especially since policies to foster human capital accumulation are perceived as a means to stimulate economic growth and reduce income inequalities. [2]

Most of the information on this issue comes from studies based on Mincer regressions[3] (Mincer, 1974), which consist in regressing, for a sample of individual observations, the log wage on the number of years of education, years of work experience, its square along with a constant term. The return to education is then measured by the estimated coefficient of the years of education variable in the regression. Simple and easy to apply, this approach has become very pop-

[1]According to Belzil (2007), "the return to education is one of the most investigated parameters in modern economics."

[2]Polachek (2008) summarizes very well this point of view by noting that: "Understanding individual earnings gets at the very core of social science because it answers questions regarding the very foundations behind human well-being. Indeed comprehending the determinants of earnings helps policy makers develop tactics to promote wealth, to help ease poverty and eventually put countries on a path to increased growth and prosperity."

[3]Recent research on this topic approaches the issue of the return to education in a dynamic structural framework, by developing and estimating education choice models with stochastic dynamic programming. A detailed review of the origins, developments and results of this literature is presented by Belzil (2007).

ular, and many of its variants have been used in the literature, by adding explanatory variables other than education and work experience measures, higher order terms of these variables or by applying more elaborate estimation methods than linear regressions. A detailed review of this approach, its foundations, variants and results is presented in the series of papers by Heckman et al. (2003, 2006, 2008).

Much has been said about this approach, from praising its capacity to address adequately the issue and its ability to overcome conceptual (e.g. self-selection, non observed heterogeneity) and empirical problems (e.g., measurement errors, omitted variables, specification errors) and produce the most accurate measures for the return to education (Polachek, 2008), to entirely questioning its capacity to provide any appropriate measure for this return (Heckman et al., 2006, 2008). The aim of this work is not to question once more the Mincer regressions, but rather to opt for another measurement perspective for the returns to education and training.

The approach adopted here is to start from the basics of the human capital theory and build a dynamic structural model of individual education and on-the-job (OTJ) learning choices, to solve it, and estimate its parameters with a suitable dataset. These estimates are then used to calculate the relevant model aggregates and evaluate the returns to education and OTJ learning. The rationale behind this approach is that education and learning allow the individual to develop a durable productive asset that, when rent to firms, generates a stream of labour income over all his career; as these gains are spread out over the whole career, the return to education should be evaluated over the same horizon.

The model we analyze in this paper is a simple version of the basic model of human capital theory, where this asset is accumulated through schooling and OTJ learning. Specifically, individuals in this model join the labour market, after a formal education period, with different schooling levels and then allocate their time between work and learning in order to maximize the present value of their life-long labour income, earned by renting their human capital to firms. The main focus is on the after-school time allocation between work and learning, taking the decisions about the schooling level as predetermined. The return to OTJ learning is measured as the percentage difference between the present value of life-long labour income of those who devote time to learning and that of those who do not, and the return to education is estimated by the percentage difference between the present values of life-long labour income of individuals with different levels of education, taking into account schooling costs and the effect of OTJ learning on the labour income. We also use the model results to examine the dynamics of the individuals human capital level over their careers, and to evaluate the contribution of education and on-the-job learning to this level, and to the individuals labour income, in each period and over the whole career.

The estimation results obtained with the Canadian data show that a high school or postsecondary degree (less than a university BA) increases the individual's initial human capital (the level with which he joins the labour market) by nearly 27%, while a university degree (BA and higher) increases this level by nearly 83%. Human capital acquired through educational turns out to be the main source of labour income earned over all the career; depending on the schooling level, between 83% and 96% of this income is generated by the initial human capital while the contribution of the human capital accumulated through learning to labour income is marginal. With optimal allocation of time to OTJ learning, high school and postsecondary graduates get a present value of labour income nearly 23% higher than that obtained by school droppers, and university graduates get a present value of earnings 54% higher than that of high school and postsecondary graduates. With no OTJ learning at all, the present value of labour income of high school and postsecondary graduates is 18% higher than that of high school droppers, while the present value of labour income of university graduates is 78% higher than that of high school and postsecondary graduates. Taking schooling costs at the level of 10% of present value of labour income (a fairly high approximation), a high school or postsecondary degree increases individual's net whole career earnings by more than 13% if he optimally allocates time to learning, and by 6% more without learning, while a university degree yields a further 40% of net earnings with learning, and by nearly 60% more without learning.

The rest of this paper is organized as follows: the structure of the model studied and its solution are presented in Section 2, the issue of the returns to education and to on-the-job learning return is discussed in Section 3. Section 4 presents the methodology and data used to estimate the model of Section 2, estimation results, and model predictions for labour income and other relevant measures used to evaluate education and learning returns. The conclusion sums up the main findings and discusses the limits of this work.

2 The Model

The model considered here is a simplified, discrete-time version of the standard human capital accumulation model through OTJ learning (or post-school investment in human capital), developed by Ben-Porath (1967), and studied among others by Ben-Porath (1970), Brown (1976), and more recently by Heckman et al, (1998a, 1998b, 1998c, 1999), and used by Huggett et al. (2006, 2009) to study the income distribution dynamics and life-cycle income inequalities. The economic environment is taken to be stationary, without uncertainty nor unemployment, and we look at the decisions of individuals, with different schooling levels, to allocate time between work, which generates immediate income, and learning, which increases human capital and future gains. The differences in schooling levels, taken as predetermined, and the length of the career (number of work periods before retirement) are the only form of heterogeneity observed between individuals, and there is no unobserved heterogeneity. Despite its simplicity, this framework is rich enough to examine the issue of interest, that of determining how much education and learning yield to an individual over his all career.

2.1 Model Structure

In this model, a typical individual is assumed to choose, early in his active life, a schooling level s among a set of possible levels $\{1, 2, ..., S\}$, which, once schooling is over and for a cost C^s (measured in welfare), allows him to join the labour market with a human capital stock $h_1^s > 0$, and work for the following T^s periods (the period length is normalized to one), which yields a well-being level noted V^s. The individual is supposed to choose the education level $\hat{s}$ that maximizes his net gain, i.e.:

$$\hat{s} = \text{argmax}_{s \leqslant S} \left\{ V^s - C^s \right\}$$

The human capital acquired through schooling is taken as homogeneous, and different schooling levels result in different human capital levels with which the individuals start their careers.[4]

[4]The schooling level chosen by the individual will determine his initial human capital as well as his labour supply, which will determine the dynamic of his human capital and income, thus determining his well-being level. The idea

After schooling, the individual starts working and rents his human capital in each period t of his career ($t = 1, 2, ..., T^s$) to firms at the wage rate R_t. His human capital depreciates in each period at the exogenous rate δ_t^s $(0 \leqslant \delta_t^s < 1)$, but can be increased through OTJ learning. The time devoted to learning, denoted by e_t^s afterwards, combined with the current human capital level h_t^s, generates an increment to human capital at the end of the period equal to $g^s(e_t^s, h_t^s)$. Since time spent in learning is not available for work, learning results in a labour income loss equal to $R_t e_t^s h_t^s$. We assume that this is the unique cost associated with learning.[5] As the individual devotes a fraction l_t^s $(0 \leqslant l_t^s \leqslant 1)$ of the period to work, his labour income for period t will correspond to:

$$W_t^s = R_t h_t^s l_t^s. \tag{1}$$

Given that human capital depreciates over time, the individual ends the period t with the non-depreciated fraction of the human capital he started with, $(1-\delta_t^s)h_t^s$, plus the increment $g^s(e_t^s, h_t^s)$. He then starts the following period with a human capital level h_{t+1}^s corresponding to:

$$h_{t+1}^s = (1-\delta_t^s)h_t^s + g^s(e_t^s, h_t^s). \tag{2}$$

The individual is assumed to not value leisure, so at each period, the available unit of time is divided between work l_t^s and learning e_t^s, resulting in the time constraint:

$$l_t^s + e_t^s = 1. \tag{3}$$

Under these assumptions, the individual will choose the work time l_t^s and learning time e_t^s that maximize the present value of his career-long labour income, corresponding to the well-being measure V^s, and is equal to:

$$V^s = \sum_{t=1}^{T^s} (1+r)^{-t} W_t^s, \tag{4}$$

where r is the constant and known interest rate. We focus in what follows on the choice of work and learning time, assuming that the decision on the schooling level has already been made by the individual.

2.2 Model Solution

Solving the model of the previous section amounts to determining the individual's optimal choice of the learning time sequence $\{e_t^s\}_{t=1}^{T^s}$. This choice will determine the dynamics of his human capital over his career, his labour supply and income in every period, and hence the present value of his earnings. We follow this same sequence to solve the model.

We start solving the model by writing down the associated optimization problem. To that end, we combine the equations (1)–(4) to rewrite the problem in the following form (omitting the schooling index s for simplicity):

$$\max_{\{e_t\}_{t=1}^{T}} \sum_{t=1}^{T} \left[(1+r)^{-t} R_t (1-e_t) h_t \right]$$

is that by choosing the level s, the individual places himself on the corresponding life path, *which determines the rest.*

[5] A more general formulation would imply direct learning costs d_t^s that would be included in the production function of the human capital, i.e. $g^s(e_t^s, h_t^s, d_t^s)$. Ignoring such costs is a common practice in the literature and is justified by the fact that, for all practical purposes, these costs are generally not observed and, for the usual specifications of the human capital production function, the results are qualitatively the same.

subject to:

$$h_{t+1} = (1-\delta_t)h_t + g(e_t, h_t), \qquad h_1 > 0, \qquad e_t \in [0,1].$$

To further simplify the solution and ensure a unique interior optimum, we assume that $g(e_t, h_t) = g(e_t h_t)$, a positive, increasing and strictly concave function, with continuous derivative, such that $g(0) = 0$. The current value Hamiltonian associated to this problem is then the following:

$$H_t = R_t(1-e_t)h_t + \lambda_{t+1}\left[-\delta_t h_t + g(e_t h_t)\right],$$

where λ_{t+1} is the Lagrange multiplier associated with the human capital dynamics constraint. The necessary (and sufficient in this case) first order conditions for an optimum are: for $t = 1, 2, ..., T$

$$\begin{aligned}
\frac{\partial H_t}{\partial e_t} &= -R_t h_t + \lambda_{t+1} g'(e_t h_t) h_t \leqslant 0, \qquad e_t \geqslant 0, \qquad e_t \frac{\partial H_t}{\partial e_t} = 0, && (5)\\
\frac{\partial H_t}{\partial h_t} &= -\left[\lambda_{t+1} - \lambda_t(1+r)\right] = R_t - \lambda_{t+1}\delta_t - \left[R_t - \lambda_{t+1} g'(e_t h_t)\right] e_t, && (6)\\
\lambda_{T+1} &= 0. && (7)
\end{aligned}$$

The last condition is simply the result of the fact that h_{T+1} is free. Conditions (5) and (6) imply that $e_T = 0$, which reflects the intuitive idea that the individual has no interest to spend time in learning at the last period of his career simply because no time is left to get the return on this investment. For all the other periods $t \leqslant T-1$, the first condition of equation (5) holds with equality, implying that:

$$R_t = \lambda_{t+1} g'(e_t h_t). \tag{8}$$

The condition $e_t\left(\partial H_t / \partial e_t\right) = 0$ allows to simplify the equation (6) to:

$$\lambda_t = \frac{R_t}{1+r} + \lambda_{t+1}\left(\frac{1-\delta_t}{1+r}\right), \qquad t \leqslant T, \tag{9}$$

and to conclude that since $\delta_t \in [0,1)$, the series $(\lambda_t)_{t=1}^{T}$ is positive and decreasing and, given the condition of equation (7), converges to $\lambda_T = R_T/(1+r)$.

Equation (8) is the condition characterizing the optimal learning time, and states the familiar condition that at the optimum, the current marginal cost (R_t) is equal to the marginal benefit $[\lambda_{t+1} g'(e_t h_t)]$. It also shows that the optimal learning time is a function of the interest rate r, the current human capital cost R_t, its production technology (through g') and its depreciation, as well as the future marginal value λ_{t+1} of human capital. To determine this future value, we solve the first order difference equation (9) to get[6] :

$$\lambda_t = \sum_{\tau=t}^{T}\left[\prod_{j=t}^{\tau-1}\left(\frac{1-\delta_j}{1+r}\right)\right]\frac{R_\tau}{1+r}, \qquad t \leqslant T. \tag{10}$$

It is worth noting here that λ_t, the expected marginal value of human capital, depends only on the sequence of human capital prices and depreciation rates $(R_\tau, \delta_\tau)_{\tau=t}^{T}$, the interest rate r, but is totally independent from the human capital level (current and future). Given the interest rate r and the sequence $(R_\tau, \delta_\tau)_{\tau=t}^{T}$, the human capital marginal value is entirely determined

[6] If $\delta_t = \delta$ for all t, the expression of λ_t simplifies to $\lambda_t = \sum_{\tau=t}^{T}\left(\frac{1-\delta}{1+r}\right)^{\tau-t}\frac{R_\tau}{1+r}$.

by the equation (10) for all $t \leqslant T$, so that the optimal learning time sequence $(e_\tau)_{\tau=t}^{T-1}$ is determined by solving equation (8), e_T being zero. In fact, since the period t human capital level h_t is given, solving for e_t is equivalent to solving for $q_t \equiv e_t h_t$, the optimal input for the human capital production. Once the optimal input q_t is determined, the optimal learning time e_t is recovered simply by computing the ratio q_t/h_t. This remark allows to rewrite equation (8) as follows:

$$R_t = \lambda_{t+1} g'(q_t), \qquad t \leqslant T-1,$$

and applying the inverse function of g'gives:

$$q_t = g'^{-1}\left(R_t/\lambda_{t+1}\right), \qquad t \leqslant T-1, \tag{11}$$

and $q_T = 0$ since $e_T = 0$.

Given the assumptions on the function g, the last equation shows that the optimal input to the production of human capital q_t is decreasing in the current price of human capital R_t, the interest rate r and the human capital depreciation δ_t (R_t increases the marginal learning cost, while r and δ_t reduce the marginal benefit), and increases with future prices R_τ, $\tau > t$ prices (which increase marginal benefit of learning). These properties are quite intuitive and easy to understand. What is less intuitive, however, is the fact that, for the same technology of human capital production and price sequence, the optimal input q_t is independent of the individual human capital level. Facing the same technology and the same prices, individuals with different levels of human capital will have to adjust their learning time to provide the same input q_t given by equation (11); those who have more human capital will spend less time learning, and those who have less human capital will have to put more time on learning. This immediately implies that the amount of time devoted to learning is decreasing in the human capital level, which generates labour income differences among individuals. As for the variation of the input q_t over time, it is not quite clear that, as intuition suggests, this input will decrease as the individual gets closer to the end of his career. To make a precise statement on this, we rewrite equation (11) as follows:

$$q_t = g'^{-1}\left((\lambda_{t+1}/R_t)^{-1}\right), \qquad t \leqslant T-1.$$

and note that since $g'^{-1}(\cdot)$ is decreasing and positive (since g is increasing and strictly concave), a sufficient condition for q_t to be decreasing over time is that the sequence of λ_{t+1}/R_t is decreasing. Denoting by γ_t the growth rate of human capital price at period t (i.e. $R_t/R_{t-1} = 1+\gamma_t$), equation (9) may be written as:

$$\frac{\lambda_t}{R_{t-1}} = (1+\gamma_t) + \frac{(1+\gamma_t)(1-\delta_t)}{1+r}\frac{\lambda_{t+1}}{R_t},$$

so the term λ_{t+1}/R_t will be smaller than λ_t/R_{t-1} if the following condition is satisfied:

$$(1+\gamma_t)\frac{1-\delta_t}{1+r} < 1,$$

or, in a more explicit form, if:

$$\gamma_t < r + \delta_t + \delta_t\gamma_t \approx r + \delta_t,$$

which states that the input q_t in period t will decrease if the observed increase in human capital price is not high enough to compensate for the depreciation and discounting.

Substituting for q_τ for $\tau < t$ in the human capital dynamics equation gives for $t = 2, 3, ..., T$:

$$h_t = \left[\prod_{\tau=1}^{t-1}(1-\delta_\tau)\right] h_1 + \sum_{\tau=1}^{t-1}\left[\prod_{j=\tau+1}^{t-1}(1-\delta_j)\right] g(q_\tau), \tag{12}$$

which characterizes the time path of the individual's human capital level when he chooses the optimal sequence $(q_t)_{t=1}^T$ (the optimal learning time is given by the ratio q_t/h_t). Given the $(q_t)_{t=1}^T$ and $(h_t)_{t=1}^T$ sequences, it is easy to determine the resulting individual's labour income dynamics. The labour income of the individual W_t corresponds to:

$$W_t = R_t(1-e_t)h_t = R_t(h_t - h_t e_t),$$

so, if the individual chooses the optimum $q_t = h_t e_t$, his wage will be equal to

$$W_t = R_t(h_t - q_t), \tag{13}$$

which, after substituting for the expression of h_t from equation (12), gives the wage predicted by the model:

$$W_t = R_t\left\{\left[\prod_{\tau=1}^{t-1}(1-\delta_\tau)\right]h_1 + \sum_{\tau=1}^{t-1}\left[\left(\prod_{j=\tau+1}^{t-1}(1-\delta_j)\right)g(q_\tau)\right] - q_t\right\}, \tag{14}$$

where the terms $(q_\tau)_{\tau\leqslant t}$ are given by equation (11).

Summing up the previous results, the model predicts that, at each period t of his career, the individual, with a human capital h_t, should devote a fraction $e_t = q_t/h_t$ of the period to learning, where q_t is given by equation (11), and $(1-e_t)$ for work in order to maximize the present value of labour income value he receives over all his career. When choosing the optimal sequence, this present value will be equal to:

$$\sum_{t=1}^{T}\tilde{R}_t(h_t - q_t),$$

where $\tilde{R}_t = (1+r)^{-t}R_t$ is the period t price of human capital, discounted to the first period, and the human capital level for each period will be given by equation (12). All things equal, the time devoted to learning will be decreasing in the current level and price of human capital, its depreciation rate, the interest rate, and increasing in the future prices of human capital capital , and will be zero at the last period of the work career.

3 Return to Education and OTJ Learning

Besides characterizing the optimal path of OTJ learning, labour supply, human capital and income, the results of the last section are useful in addressing issues related to the contribution of education and OTJ learning to human capital formation and the returns to these forms of investment. To look at these issues, we consider an individual who has chosen the education level s, and suppose that we want to know what fractions of his human capital and income are due to education and what other fractions are due to OTJ learning, and what would have been his situation had he chosen a lower education level s'.

The answer to the first question is given by equation (12), reproduced here,

$$h_t^s = \left[\prod_{\tau=1}^{t-1}(1-\delta_\tau^s)\right]h_1^s + \sum_{\tau=1}^{t-1}\left[\prod_{j=\tau+1}^{t-1}(1-\delta_j^s)\right]g^s(q_\tau^s), \tag{15}$$

which shows that the individual human capital for period t has two components corresponding to the terms on right hand side of the preceding expression; the first is the non-depreciated fraction of his initial human capital, and the second is the sum of later additions due to OTJ learning. Clearly, the first component is due to education, while the second represents the OTJ learning contribution to the human capital.

In a similar way, the individual's labour income, for each period and cumulated over his career, may be split between education and learning. To see that, note that the expression for current wage W_t^s given by equation (14) can be rewritten as follows:

$$W_t^s = R_t \left[\prod_{\tau=1}^{t-1} (1-\delta_\tau^s) \right] h_1^s + R_t \left[\sum_{\tau=1}^{t-1} \left(\prod_{j=\tau+1}^{t-1} (1-\delta_j^s) \right) g^s(q_\tau^s) - q_t^s \right], \tag{16}$$

which shows that the first term at the right hand side is the fraction of the wage for human capital acquired by education and the second term corresponds to the remuneration of human capital acquired through learning. Similarly, the present value of the individual's career-long labour income V^s can be decomposed into education and learning components. Using equations (4) and (16), this present value can be reexpressed as:

$$V^s = h_1^s \sum_{t=1}^{T^s} \tilde{R}_t \left[\prod_{\tau=1}^{t-1} (1-\delta_\tau^s) \right] + \sum_{t=1}^{T^s} \tilde{R}_t \left\{ \sum_{\tau=1}^{t-1} \left[\prod_{j=\tau+1}^{t-1} (1-\delta_j^s) g^s(q_\tau^s) \right] - q_t^s \right\}, \tag{17}$$

where $\tilde{R}_t$ is the discounted price of human capital. The first right hand side term of the preceding expression is the fraction of the present value of earnings paid for the human capital acquired by education, while the second term is the fraction of that present value paid for human capital accumulated by learning.

The return to OTJ learning can be evaluated in different ways, depending on the period it takes place and the period at which it is evaluated. Here, we only evaluate, at the first period, the return to the learning done in a subsequent period $k \geqslant 1$. As it can be checked, if the individual decides not to devote time to learning at period k ($e_k = 0$), the present value of his labour income will correspond to:

$$V_{e_k=0}^s = h_1^s \sum_{t=1}^{T^s} \tilde{R}_t \left[\prod_{\tau=1}^{t-1} (1-\delta_\tau^s) \right] + \sum_{t=1}^{T^s} \tilde{R}_t \left\{ \sum_{\tau=1}^{t-1} \left[\prod_{j=\tau+1}^{t-1} (1-\delta_j^s) g^s(\hat{q}_\tau^s) \right] - \hat{q}_t^s \right\},$$

where $\hat{q}_\tau^s = q_\tau^s \left(1 - \mathbf{1}_{(k=\tau)}\right)$, with $\mathbf{1}_{(z)}$ an indicator variable equal to one if the condition z is true, and zero otherwise. The return to learning done in period k then corresponds to:

$$\eta_k^s = \frac{V^s - V_{e_k=0}^s}{V_{e_k=0}^s},$$

which shows that the return to learning depends on the period it takes place and the schooling level of the individual who is learning. If the individual chooses to not devote any time to learning, the present value of his career-long earnings will be equal to:

$$V_0^s = h_1^s \left[\sum_{t=1}^{T^s} \left(\prod_{\tau=1}^{t-1} (1-\delta_\tau^s) \right) \tilde{R}_t \right], \tag{18}$$

and the return to learning made over all his career will correspond to:

$$\eta_0^s = \frac{V^s - V_0^s}{V_0^s}. \tag{19}$$

It can be easily checked that if $\delta_t > 0, V^s > V_0^s$, so that $\eta_0^s > 0$,, which says that if the individual's human capital does depreciate over time, he is always better off by devoting some time to learning.

We now turn to the issue of the return to education by considering the case of an individual who chooses a schooling level s', taken to be inferior to level s. According to equation (17), by choosing the schooling level s' and if allocates optimally his time to work and to OTJ learning , the individual would obtain a present value of earnings $V^{s'}$ equal to:

$$V^{s'} = h_1^{s'} \sum_{t=1}^{T^{s'}} \tilde{R}_t \left[\prod_{\tau=1}^{t-1} (1-\delta_\tau^{s'}) \right] + \sum_{t=1}^{T^{s'}} \tilde{R}_t \left\{ \sum_{\tau=1}^{t-1} \left[\prod_{j=\tau+1}^{t-1} (1-\delta_j^{s'}) g^{s'}(q_\tau^{s'}) \right] - q_t^{s'} \right\},$$

and taking account of the schooling cost $C^{s'}$, the net value of this option would be $\hat{V}^{s'} = V^{s'} - C^{s'}$. With the choice of the schooling level s and under optimal allocation of time between labour and OTJ learning, the net value of the individual's choice is $\hat{V}^s = V^s - C^s$. The corresponding return would then be equal to[7] :

$$\rho^{s,s'} = \frac{\hat{V}^s - \hat{V}^{s'}}{C^s + \hat{V}^{s'}}. \tag{20}$$

Obviously, this measure includes an OTJ learning component, which reflects the indirect effect of education on the learning activity: the individual's education level determines his initial human capital level, which determines his level of human capital in every period of his career (equation 12), which, in turn, determines his learning choice (equation 12). The OTJ learning component in the return to education can even be made apparent by rewriting the expression of $\rho^{s,s'}$ as a function of the return rate to learning (equation 19), as follows:

$$\rho^{s,s'} = \frac{(\hat{V}_0^s - \hat{V}_0^{s'}) + (\eta_0^s V_0^s - \eta_0^{s'} V_0^{s'})}{C^s + \hat{V}_0^{s'} + \eta_0^{s'} V_0^{s'}}, \tag{21}$$

where $\hat{V}_0^s = V_0^s - C^s$, $\hat{V}_0^{s'} = V_0^{s'} - C^{s'}$, and $\eta_0^{s'}$ is the return rate on learning for the individual with a schooling level s'. The learning component appears in the numerator of the fraction on the right hand side of the expression (21) through the difference of the contribution of OTJ learning to the present value of labour income at the two schooling levels $(\eta_0^s V_0^s - \eta_0^{s'} V_0^{s'})$, and in the denominator of this expression through the term $\eta_0^{s'} V_0^{s'}$. This learning component may be eliminated, if we want so, to evaluate the return to education level s relative to level s' with and without learning at each schooling level. Expression (21) is particularly useful for this purpose: to evaluate the return to the education level s, relative to level s', without learning at the schooling level s (s' respectively), we just need to set $\eta_0^s = 0$ ($\eta_0^{s'} = 0$, respectively) and evaluate the corresponding expression for $\rho^{s,s'}$.[8] However, under optimal choices of education level and learning time, the economically relevant concept to measure the return to education is certainly the rate $\rho^{s,s'}$ given by equation (21) above.

We now turn to the empirical evaluation of the previous results by estimating the model of Section 2 on a dataset from the Canadian Survey of Labour and Income Dynamics (SLID).

[7] By choosing the schooling level s, the individual will have to assume the associated cost C^s and will obtain the present value V^s. By giving up the level s', he gives up the present value $V^{s'}$ and avoids the cost $C^{s'}$. His opportunity cost then corresponds to $C^s + V^{s'} - C^{s'} = C^s + \hat{V}^{s'}$. So, the net gain of this option corresponds to $V^s - (C^s + \hat{V}^{s'}) = \hat{V}^s - \hat{V}^{s'}$, and the expression of the return rate follows immediately.

[8] One may also wish to evaluate the return to education under the assumption of equal rates of return to learning at the two schooling levels. In such a case, one just needs to set $\eta_0^s = \eta_0^{s'}$.

4 Empirical Application

For the estimation needs, we specify the functions of accumulation and depreciation of the human capital as follows:

$$
\begin{aligned}
g(e_t h_t) &= A(e_t h_t)^{\alpha}, \qquad 0 < A, \quad 0 < \alpha < 1, && (22)\\
\delta_t &= \delta_0 + \delta_1 \left[1 - \exp\{-(t/\bar{a})^2\}\right], \qquad 0 \leqslant \delta_0 < 1, \quad 0 \leqslant \delta_0 + \delta_1 < 1, \quad 0 < \bar{a}. && (23)
\end{aligned}
$$

The specification (22) for the function $g(\cdot)$, the same as that used by Huggett et al. (2006), is a simplification of the one used by Heckman et al.[9] (1998a-c, 1999), where parameters A and α are interpreted as the learning ability and the degree of diminishing returns to scale in this activity. The human capital depreciation rate δ_t in (23) is specified as a function of time to capture the potential variability of this parameter with the individual's age.[10] Since age is exogenous, the expressions for optimal learning input q_t and human capital h_t level obtained with this specification are almost identical to those obtained with a constant depreciation rate, while allowing for variable depreciation of individual's human capital over his career. More specifically, when the parameter $\bar{a}$ is near 0, the depreciation rate δ_t approaches $(\delta_0 + \delta_1)$, and if $\bar{a}$ is very large, δ_t will be close to δ_0, while for intermediate of values $\bar{a}$, δ_t will lie between these two bounds. A convenient feature of the specification (23) is its parsimony and great flexibility: the function δ_t may be concave, convex or even change concavity depending on the values of the parameters $\delta_1$and $\bar{a}$.

With the specification (22) for the function $g(\cdot)$, the expression for optimal input to learning given by equation (11) simplifies to:

$$q_t \equiv e_t h_t = (\alpha A \lambda_{t+1}/R_t)^{\frac{1}{1-\alpha}}, \qquad t \leqslant T, \tag{24}$$

with the value of the multiplier λ_t given by equation (10). Substituting for the expression of q_t in equation (13), the human capital expression becomes:

$$h_t = h_1 \left[\prod_{\tau=1}^{t-1}(1-\delta_\tau)\right] + A \sum_{\tau=1}^{t-1} \left[\prod_{j=\tau+1}^{t-1}(1-\delta_j)\right](q_\tau)^{\alpha}. \tag{25}$$

Estimating the model will produce estimates for the parameters A and α of function $g(\cdot)$, for the parameters δ_0, δ_1 and $\bar{a}$ of the function δ_t, as well as the initial human capital level of individual h_1, and these values can be used, jointly with equations (24), (25), (16)–(21), to evaluate the individual's wage at each period t in his career, the present value of his all labour earnings, and the return to education and learning. The estimation strategy, the dataset used and the estimation results are discussed in what follows.

4.1 Estimation Strategy

Let us assume that we have available a dataset of observations on N individuals, and that for each one of these individuals, we observe the age a_t, the earned wage w_t and the schooling

[9] Heckman et al. (1998a-c, 1999) adopted the Cobb-Douglas function $g(e_t h_t) = A h_t^{\alpha} e_t^{\beta}$, but based on their estimation results, were not able to reject the equality of coefficients α and β.

[10] If the individual ends his schooling at age a_0 (given), and at period t in his career, his age is a_t, then we have $a_t = a_0 + t$. When substituting this in the specification (23), the depreciation rate δ_t appears explicitly as a function of age, of the form: $\delta_t = \delta_0 + \delta_1 \left[1 - \exp - \left\{[(a_t - a_0)/\bar{a}]^2\right\}\right]$.

level. Then, to estimate the model, we would proceed as follows. First, we group individuals according to their schooling levels into sub-samples of respective sizes $N^s, s = 1,2,,S$, and take the human capital production technology to be the one specified by equations (22) and (23) for all groups, but each group has its own parameter vector $\theta^s \equiv (h_1^s, A^s, \alpha^s, \delta_0^s, \delta_1^s, \bar{a}^s)$. We then estimate each one of these parameter vectors by nonlinear least squares, by minimizing the sum, over all individuals of the group, of squared errors between the observed wages and wages predicted by the model. More specifically, if $W_{i,t}^s$ is the wage predicted by the model for individual i with a schooling level s at period t according to equation (14), it is clearly a function of the parameter θ^s, i.e. $W_{i,t}^s = W_{i,t}(\theta^s)$. If $w_{i,t}^s$ is the observed wage of the same individual at the same date, the idea is to estimate vector θ^s with the value that makes the predicted wage $W_{i,t}^s$ closest (in the least squares sense) to the observed wage $w_{i,t}^s$. Formally, the estimate $\hat{\theta}^s$ of θ^s is such that:

$$\hat{\theta}^s = \text{argmin} \sum_{i=1}^{N^s} \sum_{t=1}^{T^s} \left[w_{i,t}^s - W_{i,t}(\theta^s) \right]^2 .$$

For each group of individuals, the estimation proceeds according to the following order: given the interest rate r, price vector $R_t, t = 1,2,...,T$, a candidate parameter value θ, equation (23) is used to determine the series $(\delta_t)_{t=1}^T$, which is then used to determine the series $(\lambda_t)_{t=1}^{T+1}$ according to equation (10). The series of λ_t and equation (24) are then used to determine the series $(q_t)_{t=1}^T$. This series is then used with equation (25) to generate sequence $(h_t)_{t=1}^T$, and both are combined according to equation (13) to generate the individual's wage for all periods of his career. The predicted wage series $(W_{i,t})_{t=1}^T$ thus obtained is used to evaluate the sum of squares $\sum_{i,t} \left[w_{i,t}^s - W_{i,t}(\theta) \right]^2$. The procedure is repeated for all possible values of parameter θ until the value $\hat{\theta}$ that minimizes the sum of squares is found. Standard deviations of these estimates are then calculated by the delta method.

4.2 Data

The data we use for the estimation is from the 1996–2005 waves of the Survey of Labour and Income Dynamics (SLID) of Canada. Among all individuals sampled by this survey, a sub-sample was selected according to the assumptions and framework of the model presented in Section 2. Specifically, the model deals with the individuals decisions on work and learning time once schooling is over, it precludes unemployment and going back to school, and wage variations are only due to changes in human capital level. Consequently, individuals selected for the sample are salaried employees (other than those working in the agricultural sector), who completed their education, did not go back to school or changed job during the whole period and who declared a positive labour income. Assuming that retirement is at age 65, only individuals aged 16 to 65 who declared having worked less than 6,570 hours per year (equivalent to 18 hours per day) were retained. These individuals were then grouped by education level into three groups: school droppers (HS– group), high school or postsecondary (less than BA) graduates (HS/PS group), and university graduates (BA+ group). For each group, the nominal annual wages were converted in real terms using the consumer price index, and outliers in each group were then eliminated by excluding individuals with real wages lower than the 0.5th percentile or superior to the 99.5th percentile of the real wage distribution. Table 1 presents summary statistics on the number of observations, the age and wage characteristics of the retained sample and its three sub-groups. For estimation purposes, the human capital price R_t was normalized at 1 in all periods and the interest rate was fixed at 5%.

Table 1. Summary statistics of the sample

Education group.	Sample size	Age					Real wage*				
		min	mean	median	max	st.-error	min	mean	median	max	st.-error
1 (HS–)	17848	16	44.56	45	65	10.99	1962.52	29357.14	26451.40	97158.87	16013.72
2 (HS/PS)	89280	17	40.40	41	65	10.12	3738.79	35757.77	32424.30	124897.20	18574.34
3 (BA+)	22198	21	40.69	40	65	9.57	5759.58	52267.96	47752.33	231813.10	27321.34
Total	129326	16	41.03	41	65	10.53	1962.52	37708.30	33860.75	231813.10	21220.74

* in 2005 dollars

4.3 Estimation Results

The estimated values for parameters $(h_1, A, \alpha, \delta_0, \delta_1, \bar{a})$ for each of the three schooling groups are reported in Table 2.

Table 2. Estimation results

Education Group	Parameters*						
	H_1^*	A	α	δ_0	δ_1	$\bar{a}$	R^2
Group 1	23947.18	1.8331	0.6843	0.004672	0.01287	26.4739	0.9250
(HS–)	(1727.49)	(3.1265)	(0.1483)	(0.01333)	(0.0062)	(5.9818)	
Group 2	30347.47	2.1735	0.6847	0.01233	0.009571	30.4238	0.9949
(HS/PS)	(718.12)	(1.0981)	(0.04305)	(0.00389)	(0.00171)	(2.8875)	
Group 3	43844.29	0.3787	0.8246	$2.22e{-}14$	$2.23e{-}14$	28.6395	0.9711
(BA+)	(576.83)	(0.1668)	(0.0405)	$(9.33e{-}4)$	$(5.007e{-}3)$	$(5.531e12)$	

* Standard errors between parentheses.
* Evaluated in 2005 dollars.

For the initial human capital level, the results indicate, as expected, that more educated individuals join the labour market with more human capital.More precisely, the initial human capital level of high school and postsecondary graduates is 26.73% higher than that of school droppers, but 44.47% lower than that of university graduates. For the human capital production technology, results are somewhat mitigated, even though they are essentially in line with what we may expect. The estimated value of learning ability (parameter A) is higher for high school and postsecondary graduates than for school droppers, but it is the lowest for university graduates, even though we expect it to be the highest for this group. The estimated value of the degree of diminishing returns to scale in the production of human capital α increases with the schooling level as expected, but is almost the same for high school and postsecondary graduates and school droppers. For the depreciation of human capital, the results suggest that it occurs at a low, yet positive, time-varying rate (0 to 2.19%), and its time variation is rather well approximated when related to the individual's age. Intuitively, one expects that the human capital depreciation rate would increase with the education level, which is the case for school droppers and high school and postsecondary graduate groups, but the university graduate group is a notable exception. In terms of the estimated values, human capital depreciation rate for school droppers is 0.47% in early career, and it increases progressively and stabilizes at 1.75%. The same trend is observed among high school and postsecondary graduates with a 1.24% depreciation rate in early career, increasing with age and stabilizing at 2.19%. Among university graduates, the estimated depreciation rate is practically zero for all periods, which causes the non identifiability of parameter $\bar{a}$ for this group. In terms of the quality of fit, the use of a concave human capital accumulation function along with a variable depreciation rate allows the model to fit the data fairly well, with coefficients of determination at 92.5% and more for the three groups. This result is seen clearly in Figure 1 below, which presents the average age profiles of observed and estimated wages for the three groups. *Inspection of the observed wage profiles allows to better understand the underlying mechanics of the model ...*

[insert Figure 1 about here]

4.4 Model Predictions

Using the estimated values of the model parameters jointly with equations (10) and (23)–(25), the age profiles of human capital depreciation rate δ_t, optimal learning time $\hat{e}_t$ and human capital level are easily obtained for each education group. These profiles are reproduced, respectively, in figures 2, 3 and 4 below.

Figure 2 presents the human capital depreciation rate by age for the three groups. It can be seen that the human capital of school droppers depreciates at a lower rate than that of high school and postsecondary graduates (between 0.47% and 1.75% for the first group and between 1.24% to 2.19% for the second group), but at a faster rate, and that for both groups the depreciation rate increases monotonically up to its maximum and then stabilizes at that value. This maximum is reached at age 39 for school droppers, and later at age 48 for the high school and postsecondary graduates. For university graduates, there is practically no human capital depreciation, and this is due to the non-decreasing profile of their wage (see Figure 1).

Figure 3 presents the age profile of optimal learning time for the three groups. Overall, the time devoted to learning decreases monotonically with age, a result due to the (assumed) zero growth rate of the human capital prices, which does not offset for the joint effect of depreciation and discounting. Among the three groups, high school and postsecondary graduates devote the biggest amount of time to OTJ learning, school droppers spend less time to learning, and university graduates are those who invest the least in learning during their career. This result is consistent with the estimated abilities to learning (parameter A): those with higher ability to learn spend more time in learning, and conversely. Here again there is an exception for school droppers group who devote the least time to learning in early career than university graduates, although we expect the contrary given the lower level of initial human capital and greater learning ability of the first group. However, since this parameter is estimated with a quite low precision for this group (see Table 2), this result may be due to data measurement errors on early career wages of school droppers. Overall, the optimal learning time predicted by the model seems relatively high at all levels of education, at least in the first 20 to 30 years of career compared to what is regularly observed in real data.

Figure 4 shows the age profile of human capital level for the three schooling groups. The overall pattern of these profiles is in line with what we may expect: human capital level increases with schooling level and in most of the career, it then stabilizes or decreases progressively until retirement age. For school droppers and high school and postsecondary graduates, the human capital reaches its maximum at age 42, it then decreases monotonically under the effect of depreciation. For university graduates, because there is no depreciation at any age, the human capital of this group keeps increasing, but at a slower rate, until retirement age.

4.5 Life-long Earnings and the Return to Education and Learning

Given the average age profile of wages predicted by the model for each education group, one can evaluate the present value of earnings over the whole career, decompose it into education and learning components, and obtain estimates of the return to learning. Table 3 below shows the details of this decomposition.

Tableau 3. Decomposition of the present value of life-long earnings and the return to OTJ learning

Education Group	Present value of earnings*,⋆		Education component⋆	OTJ learning component⋆	Return to OTJ learning⋆
	V	V_0	(V_0/V)	$(1-V_0/V)$	$(\eta_0 = V/V_0 - 1)$
Group 1	431.5649	369.5250	0.85624	0.14376	0.16789
(HS–)	(4.7769)	(50.1659)	(0.11663)	(0.11663)	(0.15908)
Group 2	528.4493	437.5497	0.82799	0.17201	0.20775
(HS/PS)	(1.6908)	(19.8017)	(0.03757)	(0.03757)	(0.05480)
Group 3	811.9242	779.2914	0.95981	0.04019	0.04188
(BA+)	(8.5309)	(10.2527)	(0.01616)	(0.01616)	(0.01754)

* In thousands of 2005 dollars.
⋆ Standard errors between parentheses.

Looking first at columns 2 and 3 shows that, for all education levels, the present value of earnings is higher with learning than without learning, as predicted by the model. Since without learning the individual's labour income is due to human capital acquired through education only, the fraction of this income in the present value of all earnings measures the education component, and the remaining fraction measures the learning component. The fourth column of the table indicates that this education component accounts for the major part of earnings: 85.6% for school droppers, 82.8% for high school and postsecondary graduates, and 96.0% for university graduates. The learning contribution to earnings is thus relatively marginal (see column 5 of the table), even though the model over predicts investment in this activity. In terms of return rates, the increase in the present value of earnings due to learning varies with the level of education, with 16.8% for school droppers, 20.8% for high school and postsecondary graduates, and only 4.2% for university graduates.

When comparing the different schooling groups, the preceding table shows that the present value of earnings, with optimal learning, for high school and postsecondary graduates is 22.5% higher than for school droppers, and for university graduates this value is 53.6% higher than that of high school and postsecondary graduates. Overall, these values suggest that, with optimal allocation of time to OTJ learning, a secondary or postsecondary degree (less than BA) would yield to an individual 22.5% more of earnings present value than he would get by leaving school before graduating, and a university degree would yield 53.6% more of earnings present value than he would get by joining the labour market with a high school or postsecondary degree. These values, although measuring the effect of more education on the present value of all career labour income, do not measure the net return to education, since they do not take into account of the schooling costs. To obtain a measure of the net return to education, we can use equation (20) since it expresses the net return rate $\rho^{s,s'}$ to choosing the education level s rather than the lowest level s' as a function of the earnings present values and schooling costs (V^s, C^s) and $(V^{s'}, C^{s'})$:

$$\rho^{s,s'} = \frac{(V^s - C^s) - (V^{s'} - C^{s'})}{C^s + (V^{s'} - C^{s'})}.$$

and rearrange it as follows:

$$\rho^{s,s'} = \frac{(V^s/V^{s'} - 1) - \xi^{s,s'}}{1 + \xi^{s,s'}}, \tag{26}$$

with $\xi^{s,s'} \equiv (C^s - C^{s'})/V^{s'}$ denoting the fraction of the present value $V^{s'}$ of earnings at level s' that pays the additional schooling cost associated with moving from level s' to level s. Equation (26) expresses the net return rate of choosing the schooling level s instead of level s' as a function of the resulting growth in the present value of earnings $(V^s/V^{s'} - 1)$, and the associated additional schooling cost, measured as a fraction $\xi^{s,s'}$ of the forgone present value $V^{s'}$. This expression is particularly useful since it allows to get around the problem of non or partial observability of schooling cost (the monetary portion of theses costs is hardly observable and the non-monetary portion is just not observed). Figure 5 below uses the expression in equation (26) and the increase of present values due to moving from the non graduate level to the high school or postsecondary level, and from the latter level to that of university graduate to represent the net rate of return to education as a function the additional schooling cost. The overall pattern seen in this figure is that the return to education (net of schooling costs) is high and increases with the level of education. For example, at an additional schooling cost of 10% of the present value of all career earnings of a non graduate (i.e. 43,167 dollars of 2005), a high school or postsecondary degree yields 11.3% , and for an additional schooling cost of 10% of the present value of earnings of a high school or postsecondary graduate (that is 52,845 dollars of 2005), a university grade yields 39.7%.

[insert Figure 5 about here]

5 Conclusion

In this paper, we use data from the Survey of Labour Income and Dynamics to evaluate the return to education and on-the-job learning within the framework of the basic model of human capital formation though on-the-job learning. We explicitly solve the problem of time allocation between labour and OTJ learning faced by individuals in the model, derive their labour supply and the corresponding wage, and estimate the model parameters by minimizing the deviations between model predicted and observed wages. Using the estimated parameters values for three education levels (school droppers, high school and postsecondary graduates, and university graduates), we evaluate the age profiles of wages, learning time, depreciation rate and levels of human capital for each group. We then evaluate, for each group, the present value of labour income earned over the whole career, and decompose it into two components: an education component (income earned from human capital acquired by education) and learning (income earned from human capital accumulated through learning). We finally use these results to evaluate the return to education and the return to on-the-job learning.

Our results indicate that human capital acquired through education is the major source of labour income earned over the whole career (between 83% and 96% of this income depending to education level) and that the human capital acquired through OTJ learning contributes only marginally to this income. The return to OTJ learning, as measured by the growth rate of the present value of labour income when time is allocated optimally to this activity, varies with the education level, ranging from 4% to 21%. When ignoring the schooling cost, the gross return to education, as measured by the growth rate of the present value of labour income with a higher education level, is evaluated at 22.5% for a high school degree (compared to non graduates) and at 53.6% for a university degree (compared to high school graduates). When taking schooling costs into account, the net return to education is obviously lower, but also more difficult to evaluate (because these costs are usually not observed), and so we represent it as a function of these costs. Considering that a high school (or postsecondary lower than BA) degree would cost an individual 10% of the present value of labour income of a non graduate, this degree would yield more than 11%, while for a cost of 10% of the present value of labour income of a high school graduate, a university degree would yield nearly 40%. These estimates suggest that the return on education is high, increases with the schooling level and is certainly higher than the 7% per year of additional schooling regularly reported in the Mincer regressions with Canadian data. (*add references and relate the two results*).

Finally, a word of caution is in order when one interprets the results presented here. The model we studied and estimated to get these results is particularly simple, a feature that simplified considerably the solution of the individuals choice problem, the estimation of the parameters, and the evaluation of earnings and returns to education and learning. However, this simplification came at the cost of strong and restrictive assumptions, which inevitably limit the scope of the results. Most notably, assuming that individuals make their choices to maximize the present value of their earnings is far from the standard microeconomic practice where the individual's objective is to maximize utility derived from consumption and leisure. Also, by considering a certainty environment, precluding any form of individual heterogeneity other than through education levels, and taking these as predetermined choices, the model ignored many essential features of the dynamic analysis of individual choices of labour supply and investment in skill acquisition. These simplifications possibly introduced biases in the estimates obtained, and these should be taken into account when interpreting the results of this study.

With these considerations in mind, it is clear that a more detailed model, where heterogeneous individuals decide on their consumption, leisure, education, labour supply, job search and training activities, in a world of uncertainty with individual and aggregate shocks occurring regularly, would be a more appropriate setting to study the issues related to the return to education, training, and work experience. While working on such a model, we wished to show through this essay that, if one agrees with the idea that education and other forms of training develop individual's innate abilities into a stock of productive capacities, i.e. the human capital, that generate gains over the whole career (if not the whole life), then the returns of these different forms of human capital acquisitions should be evaluated over the same horizon, i.e. the entire the life cycle. The analysis of the basic model of human capital development through in on-the-job learning presented in this paper is best perceived as an example that this approach can be easily applied and can be very informative, rather than an effort to produce accurate estimates of the returns to education and on-the-job learning for Canadian workers.

References

Becker, G., 1962, "Investment in Human Capital: A Theoretical Analysis", *Journal of Political Economy*, 70(5): 9–49.

Becker, G., 1964, "*Human Capital*", Columbia University Press, New York.

Belzil, C., 2007, "The Return to Schooling in Structural Dynamic Models: A Survey", *European Economic Review*, 51(5): 1059–1105.

Ben-Porath, Y., 1967, "The Production of Human Capital and the Life Cycle Earnings", *Journal of Political Economy*, 75(4): 352–365.

Ben-Porath, Y., 1970, The Production of Human Capital over Time, in *Education, Income, and Human Capital*, edited by W. Lee Hansen, NBER, New York.

Brown, C., 1976, "A Model of Optimal Human Capital Accumulation and the Wages of the Young High School Graduates", *Journal of Political Economy*, 84(2): 299–316.

Heckman, J., L. Lochner, C. Taber, 1998a, "Explaining Rising Wage Inequility: Explorations with a Dynamic General Equilibrium Model of Earnings with Heteogeneous Agents", *Review of Economic Dynamics*, 1(1): 1–58.

Heckman, J., L. Lochner, C. Taber, 1998b, "General Equilibrium Treatment Effects: A Study of Tuition Policy", *American Economic Review,* 88(2): 381–86.

Heckman, J., L. Lochner, C. Taber, 1998c, "Tax Policy and Human Capital Formation", *American Economic Review,* 88(2):293–97.

Heckman, J., L. Lochner, C. Taber, 1999, "Human Capital Formation and General Equilibrium Treatment Effects: A Study of Tax and Tuition Policy", *Fiscal Studies*, 20(1): 25–40.

Heckman, J., L. Lochner, P.E. Todd, 2003, "Fifty Years of Mincer Earnings Regressions", *NBER* Technical Report no. 9732, Cambridge, Massachusets.

Heckman, J., L. Lochner, P. Todd, 2006, "Earnings Regressions and Rates of Return: The Mincer Equation and Beyond", in *Handbook of the Economics of Education,* edit. E.A. Hanushek and F. Welsh, Elsevier, Amsterdam.

Heckman, J., L. Lochner, P. Todd, 2008, "Earnings Functions and the Rates of Return", *Journal of Human Capital*, 2(1): 1–31.

Huggett, M., G. Ventura, A. Yaron, 2006, "Human Capital and Earnings Distribution Dynamics", *Journal of monetary Economics*, 53(2): 265–290.

Huggett, M., G. Ventura, A. Yaron, 2009, "Sources of Lifetime Inequality", mimeo, Georgetown University.

Mincer, J., 1974, "*Schooling, Experience and Earnings*", Columbia University Press, New York.

Polachek, S.W., 2008, "Earnings Over the Life Cycle: The Mincer Earnings Function and Its applications", *Foundations and Trends in Microeconomics,* 4(3): 165–272.

Figure 1. Observed vs. predicted wage profiles

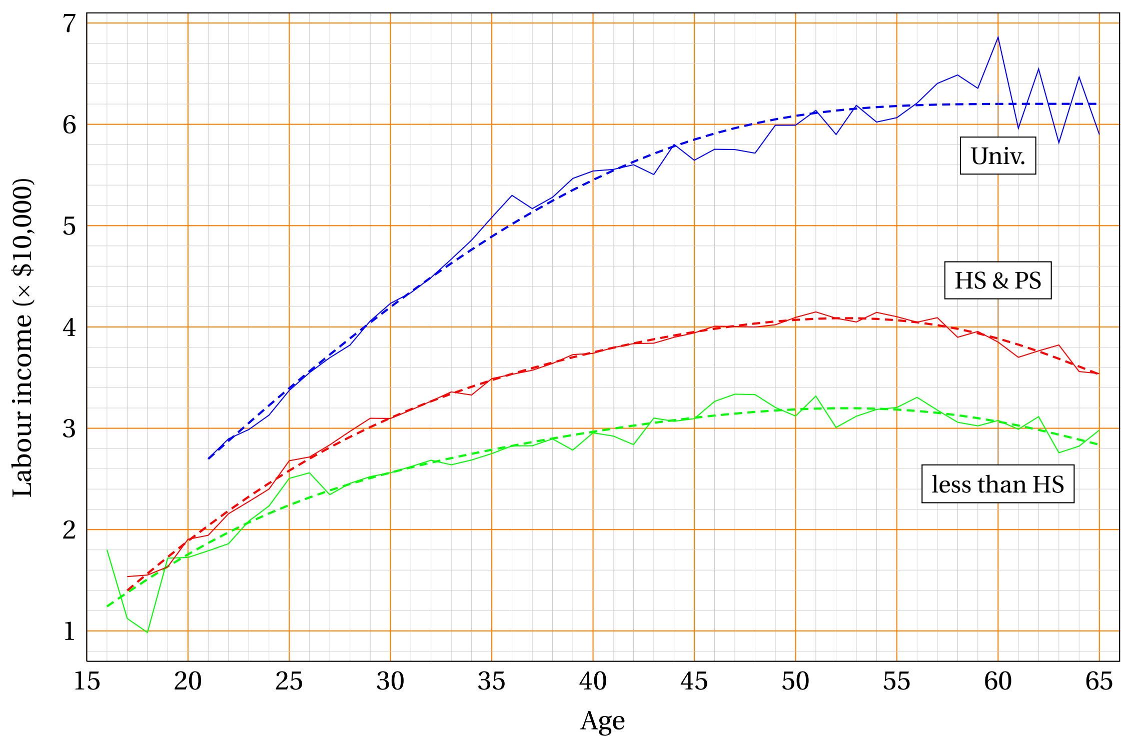

Figure 2. Human capital depreciation rate

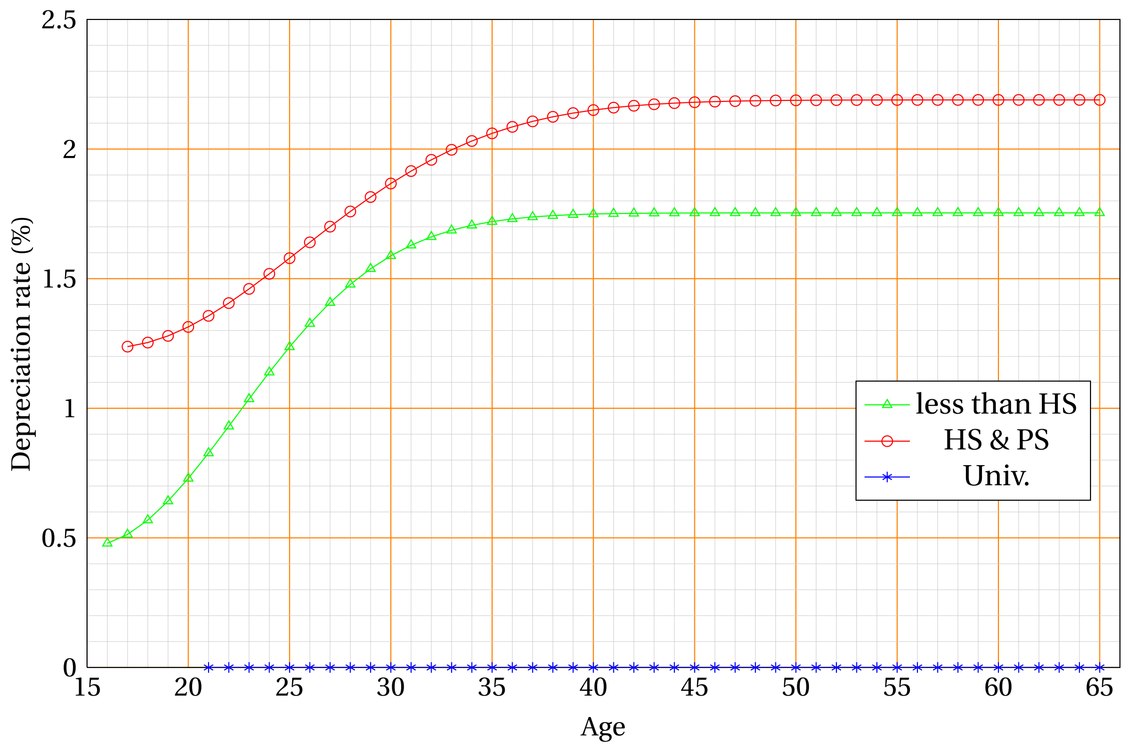

Figure 3. Time devoted to on-the-job learning

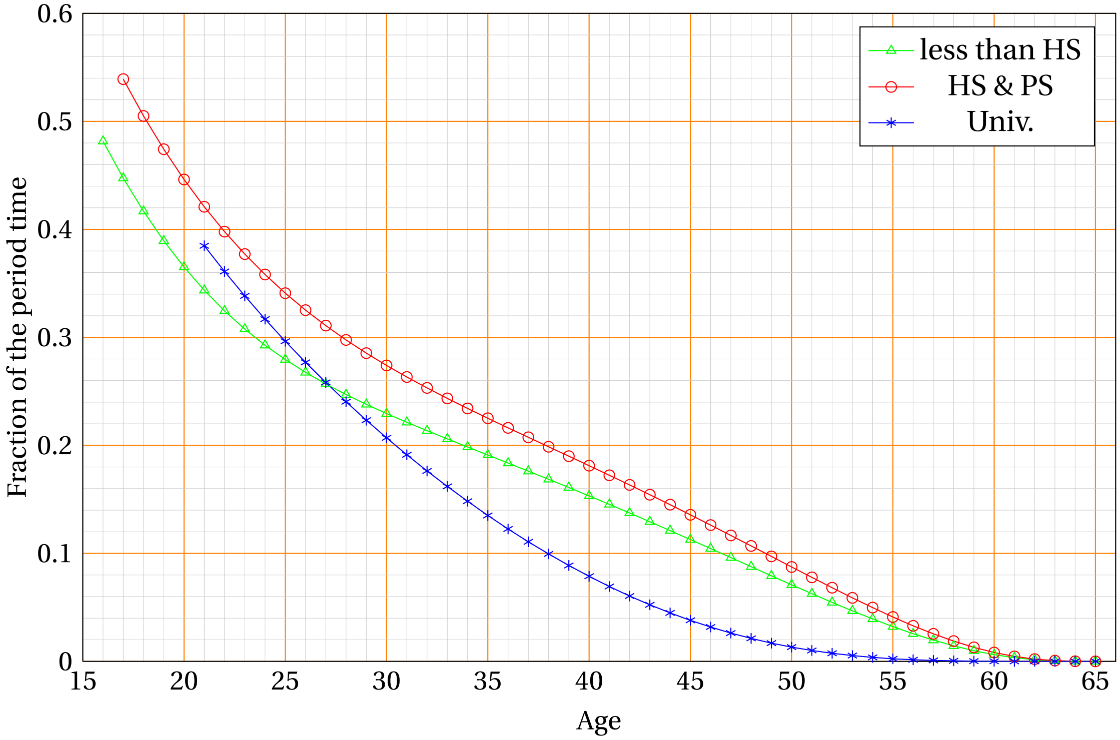

Figure 4. Predicted time profile of human capital

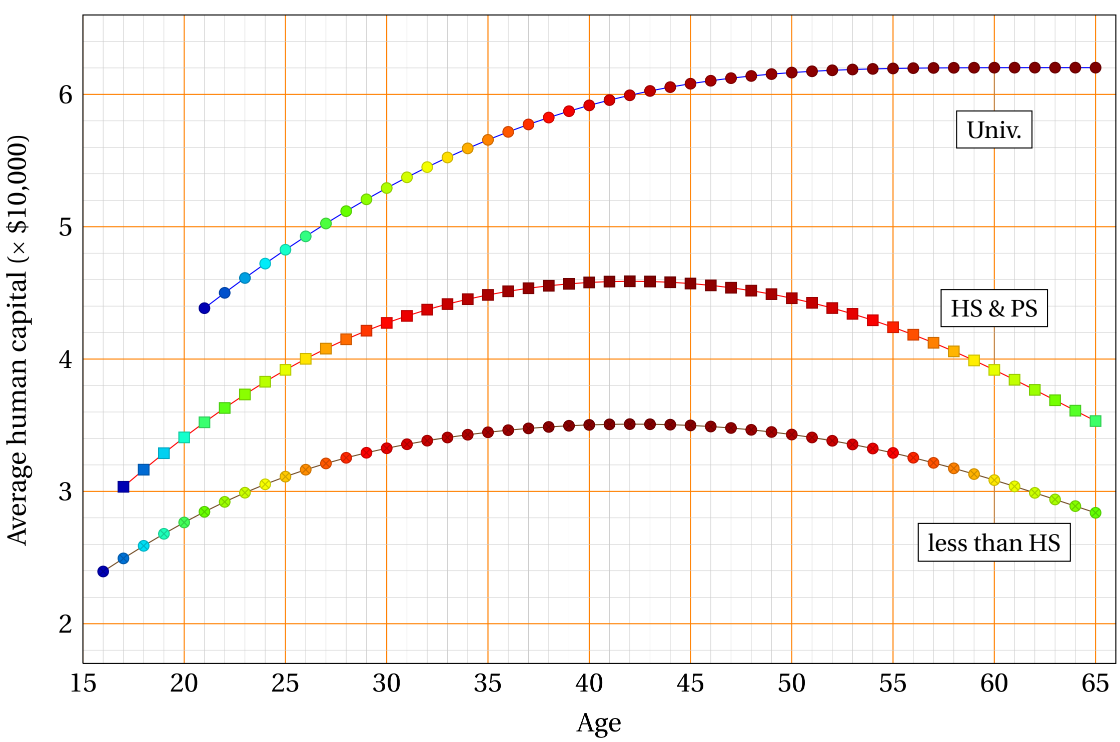

Figure 5. The net return to education