Available online at www.sciencedirect.com
ScienceDirect
Labour Economics 14 (2007) 913–925
LABOUR ECONOMICS
www.elsevier.com/locate/econbase

Real options and human capital investment

Bas Jacobs *

Universiteit van Tilburg, CentER, Netspar, Universiteit van Amsterdam, and Tinbergen Institute, Department of Economics, Roetersstraat 11, 1018 WB Amsterdam, The Netherlands

Received 23 January 2006; received in revised form 16 May 2007
Available online 16 June 2007

Abstract

This paper extends the standard human capital model with real options. Real options influence investment behavior when risky investments in human capital are irreversible and individuals can affect the timing of the investment. Option values make individuals more reluctant to invest in human capital and, as a result, required returns on the investment increase. Real options may help to explain a larger human capital premium for higher education, smaller responsiveness of higher educational investments to financial incentives, and larger sensitivity of higher educational investments to low-return outcomes and human capital risks. Higher tax rates (or lower subsidies) depress human capital investments, but to a lesser extent than in the standard human capital model if not all direct costs are tax-deductible. A flat income tax remains neutral if education expenditures are fully deductible.

JEL classification: G1; H2; I2; J2
Keywords: Human capital; Higher education; Risk; Irreversible investment; Real options; Progressive taxation; Education subsidies

1. Introduction

> "The long time required to collect the return on an investment in human capital reduces the knowledge available, for knowledge required is about the environment when the return is to be received. […] The desire to acquire additional knowledge about the return and about alternatives provides an incentive to postpone any risky investment […]." Becker (1964, pp. 91–92, 94).

* Tel.: +31 20 525 4367 / 4252; fax: +31 20 525 4252.
E-mail address: b.jacobs@uva.nl.

0927-5371/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.labeco.2007.06.008

Observed returns to human capital are typically larger than the risk-free rate as Palacios-Huerta (2004, 2006) has shown in a novel finance approach. High returns are also consistently found in the empirical labor literature (Card, 1999; Ashenfelter et al., 1999; Harmon et al., 2003). This begs the question why the private returns to education are so high. Capital markets may not make sufficient borrowing available due to enforcement and information problems (Stiglitz and Weiss, 1981). Liquidity constraints increase required returns on human capital. The empirical plausibility of liquidity constraints is controversial, however. Carneiro and Heckman (2003), Cameron and Taber (2004), Plug and Vijverberg (2004) and others find that liquidity constraints only have a slight impact on enrolment in higher education and seem to be insufficient to explain high observed rates of return to education.[1]

Income risk may also justify a high rate of return. Risk averse individuals want to be compensated for income risks. Indeed, Palacios-Huerta (2004, 2006) finds that human capital returns include a substantial risk premium. Many papers find evidence for risk compensation in wages, see the overview by Hartog (2005). Nevertheless, the high return on human capital is suggestive of a human capital premium puzzle, just like in the finance literature (see e.g., Mehra and Prescott, 2003). Palacios-Huerta (2006) has shown that risk alone cannot explain the difference between the real return on human capital and the risk-free interest rate. Only implausibly large coefficients of relative risk aversion, ranging from 30–60, generate a risk-premium on human capital investments that is consistent with the data. Judd (2000) argues that, if idiosyncratic income risks are so important, governments or markets would look for institutions to insure these risks. Apparently, neither is the case. Both private and public insurance are not likely to emerge if moral hazard renders the income risks endogenous rather than idiosyncratic, see also Judd (2000) and Sinn (1995).

Another empirical puzzle is that the covariance between earnings or employment and the marginal investment in education appears to be negative, see also Gould et al. (2000), Hartog and Diaz-Serrano (2002), and Belzil and Hansen (2004). Also, Palacios-Huerta (2004, 2006) empirically finds that the human capital premium is lowered as workers become more educated. This suggests that, although human capital investment is risky on average, higher levels of human capital hedge against labor market risks on the margin, cf. Levhari and Weiss (1974). Rubinstein and Tsiddon (2001) show that the negative correlation between education and unemployment or earnings risk vanishes, once controls for parental education are included in the analysis. Earnings and unemployment risks could then be driven mainly by parental or even genetic transfers of skills, rather than market risks. Indeed, Cunha et al. (2005) demonstrate that a large part of risk in labor market outcomes can be traced back to non-observed heterogeneity, not to market risk. These empirical findings also substantially weaken the case for a substantial risk premium for human capital investments.

This paper demonstrates that real options could provide another explanation as to why returns are high for higher educational investments. Real options are present in irreversible and risky investments in which there is a possibility to influence the timing of the investment. Human capital is generally regarded as a non-liquid asset (e.g., Friedman, 1962). It is impossible to recover forgone earnings and tuition expenses by selling the asset after the investment has been made. Investments are therefore sunk. Individuals can, however, influence the timing of the decision to invest in risky higher education. They have an option to wait for better information regarding the returns (or costs) of the investment. If they invest immediately in higher education,

[1] Palacios-Huerta (2006) suggests that borrowing and solvency constraints may explain up to fifty percent of the human capital premium if these were indeed the main frictions in the capital market.

they give up a valuable option to wait, which must be compensated with higher returns. In equilibrium, the option value of postponing the investment drives up returns to investment in human capital, which could explain why returns are high. Moreover, high returns are an equilibrium outcome in the presence of perfect capital and insurance markets. Palacios-Huerta (2006) shows that about two-thirds of the observed human capital premium could be the result of the illiquidity of human capital if short-sale constraints would be the relevant market imperfection. These findings can, however, also suggest that option values are important. Indeed, the illiquidity of the investment is the prime reason why the real option emerges. Therefore, even with risk neutral individuals, rates of return to human capital investments would increase when investments in human capital are illiquid and subject to short-sale constraints.

The option value of postponing investment is relevant whenever individuals can influence the timing of the investment. From a theoretical perspective, it would therefore apply to all types of investment in human capital. In practice, however, it is relevant mainly for higher education where, by the nature of voluntary choice, there is indeed a possibility to influence the timing of the investment. It is not likely that waiting options could explain a human capital premium for lower, compulsory levels of education. Nevertheless, there is potentially also a waiting option associated with education levels below obligatory school entrance ages when parents have the possibility to decide when to send their children to kindergarten, preschool or early childhood programs. This paper nevertheless confines the analysis to higher education only.

As a side step, this paper also analyzes the effects of (progressive) income taxes and education subsidies when options in higher educational investments are important. Investment in higher education will be less elastic to taxes and subsidies when waiting options are more valuable. However, the neutrality of flat income taxes with full deductibility of investments in the standard human capital framework remains (cf. Heckman, 1976).

This paper is organized as follows. Section 2 briefly describes some earlier papers and how this paper relates to the literature. Section 3 describes the model of irreversible investment in higher education. Section 4 derives the main results and performs comparative static analysis. Section 5 concludes.

2. Earlier literature

Comay et al. (1973), Heckman et al. (2006), Hogan and Walker (2007-this issue), and Leuven and Oosterbeek (2001) have earlier pursued the option approach in a human capital framework. Comay et al. (1973) and Heckman et al. (2006) analyze so called growth options in human capital investments. Education is seen as a sequential multi-stage investment process in which some uncertainty is resolved after each stage. In Comay et al. (1973) the uncertainty at each stage is generated by an exogenous probability to drop-out, while there are no income risks in the remainder of the life-cycle. Heckman et al. (2006) endogenize this probability to drop out by explicitly deriving the decision to enter the next stage from a human capital investment model. In equilibrium, individuals would be willing to accept lower rates of return on their human capital investments than real rates of return on financial investments with similar risk characteristics if growth options to enter the next stage are valuable. Consequently, growth options cannot resolve the human capital premium puzzle.

Hogan and Walker (2007-this issue) and the current paper analyze timing options in human capital investment. Hogan and Walker (2007-this issue) study waiting options. The decision to stop learning, and to start working is irreversible, because utility benefits of staying in education are given up when entering the labor market. The student gives up his option to enter the labor market a later date, only when the returns to human capital are sufficiently high. Their findings could be criticized for a number of reasons. First, in practice students can re-enter education at a later age which suggests that the option to go to work is not really irreversible. Second, the most important results of Hogan and Walker (2007-this issue) are quite sensitive to the assumption of positive utility benefits of education. The option value would disappear when non-monetary utility benefits are zero, or even negative, and everyone would immediately start to work. Although utility benefits could indeed be relevant, opportunity and direct costs are probably more important sunk costs associated with educational investments. The reason is that a large human capital premium is rather difficult to reconcile with non-monetary benefits being more important than non-monetary costs. High returns should compensate for high (net) non-monetary costs (Judd, 2000).[2] Third, the fact that non-pecuniary benefits are untaxed explains why (progressive) income taxes boost human capital investments. Education is implicitly subsidized under a flat income tax, because the total (monetary and non-monetary) returns are subject to a lower effective tax rate than the total costs (forgone earnings), see also Bovenberg and Jacobs (2005). This is not counterintuitive and has little to do with options. Options only tend to make the investment decision less responsive to taxation, but they do not change the sign of the tax impact on human capital investments. Fourth, also the model of Hogan and Walker (2007-this issue) goes in the wrong direction in explaining a high human capital premium because individuals are willing to accept a lower rate of return on their investments when the option to enter the labor market at a later date becomes more valuable.

In contrast to Hogan and Walker (2007-this issue), this paper starts from the premise that the decision to start learning is the irreversible decision, not the decision to start working. The returns (or costs) of the investment in human capital are uncertain. Waiting to enroll in higher education has the benefit of gaining more information on the returns (or costs) of the investment. The option value stems from the fact that one could wait to enroll and only do so when the returns are sufficiently large. The sunk cost of the investment is not the lost benefit of staying in education, but the forgone labor earnings and tuition costs while in school.

One other option type has been analyzed in the human capital literature. Leuven and Oosterbeek (2001) consider real options to terminate a worker-employer relationship in a setting with firm specific investments in on-the-job training, as in Becker (1964). Uncertainty on returns from irreversible firm-specific investments in OJT gives option values if the firm can lay off the worker so as to avoid a bad outcome. This option value raises the firm's returns and the bargained wage will rise. Further, under uncertainty, the firm would not bear all the costs of specific investments in OJT, in contrast to the certainty case studied by Becker (1964).

3. Model

The model of Dixit and Pindyck (1994, ch.2) forms the basis of this paper. A risk neutral individual considers the discrete decision to make a risky investment in higher education. Capital and insurance markets are perfect, although the latter assumption is not needed with risk neutral individuals. The investment in higher education is completely irreversible. Investments in higher education mainly consist of forgone labor earnings and tuition costs. It is quite reasonable to

[2] See the substantial evidence in Carneiro and Heckman (2003) for the importance of non-monetary costs, especially for lower education levels and minority groups. Findings by Palacios-Huerta (2004, 2006) are consistent with this. Further, drop-out rates in higher education are around 20-60% in Western countries, see the OECD-figures in Jacobs and van der Ploeg (2006). Apparently, studying entails substantial non-monetary costs in the form of effort.

assume that there is not a way of getting your money back once working time is forgone and tuition fees have been paid. The investment in education is therefore a sunk cost.

The individual may decide to enrol in higher education directly or he may postpone the investment for one year and work in the labor market during this year. Therefore, the individual has the option to wait. After one year, all uncertainty is revealed. Using the terminology of Levhari and Weiss (1974), this model is probably more suited to describe the effects of input uncertainty (on ability) because it is less likely that all output uncertainty (on labor market conditions) is fully revealed after one year. This is the simplest set-up possible to analyze the consequences of options in human capital investments. All qualitative results will nevertheless carry over to more general continuous time case in which uncertainty is never fully revealed and the individual can always decide to invest in higher education at later dates (see also Dixit and Pindyck, 1994).[3]

The total investment consists of forgone labor earnings and the direct costs of higher education while enrolled. Forgone earnings are gross earnings per year net of taxes $(1-\tau)w$ where δ is the tax rate and w is the gross yearly wage. There are also direct costs such as tuition fees, books, materials and computers. Direct costs are $(1-s)k$ where k is the monetary cost of one year of higher education and s is the flat subsidy rate. Both forgone labor earnings and tuition costs are not time-varying for simplicity. It takes T years to graduate, hence the present value of total costs I of investing in higher education at the date of graduation, $t=0$, equals

$$I \equiv \sum_{t=-T}^{t=0} \frac{(1-\tau)w+(1-s)k}{(1+r)^t} = (1-\tau)\omega + (1-s)\kappa, \tag{1}$$

where r is the real interest rate. $\omega \equiv \sum_{t=-T}^{t=0} \frac{w}{(1+r)^t}$ and $\kappa \equiv \sum_{t=-T}^{t=0} \frac{k}{(1+r)^t}$ denote the present value of gross forgone earnings and direct costs of education, respectively. Perfect capital markets are assumed so that the individual can always borrow at rate r to finance investments in education I.

The time-horizon for the individual is assumed to be infinite for analytical simplicity. The qualitative results readily extend to the case with a finite horizon, however. When the individual invests with graduation at time $t=0$, the expected return to the investment in higher education is R_0 each year from $t=0$ to $t=\infty$. The future return is uncertain. At time $t=1$ the return either increases to $R_1 \equiv (1+\upsilon)R_0$ with probability q and the expected return decreases to $R_1 \equiv (1-\delta)R_0$ with probability $(1-q)$. After $t=1$ all uncertainty is revealed and the return remains fixed at R_1 from $t=1$ to $t=\infty$. υ is the upward swing and δ is the downward swing in the returns on the investment. The return on the investment is taxed at marginal rate θ which may be higher than the marginal rate τ. In that case, marginal tax rates are increasing with income.

If it is only possible to invest immediately (and graduate at $t=0$), the prospective student invests in higher education if the present value of labor earnings V_0 is larger than the total costs of the investment in higher education I. Otherwise, the student does not go to higher education. The net-present value rule is equivalent to the standard human capital model.

The present value of labor earnings of investing with graduation at time $t=0$ is

$$V_0 \equiv \frac{(1-\theta)R_0(1+r+q(\upsilon+\delta)-\delta)}{r}. \tag{2}$$

[3] The option to postpone the investment is analogous to a financial call option. The student has the right but not the obligation to buy an asset, i.e., human capital, at some future date. When the student decides to enroll immediately, he exercises his option to buy the asset and gives up the opportunity to wait and see whether the returns to the investment have improved.

Ω_0 equals the net pay-off from the investment in higher education. $\Omega_0 \equiv \max\{V_0 - I, 0\}$ is the net present value of the investment if the investment is undertaken or zero if the net present value is negative and the investment is not undertaken. Formally, it can be written as

$$\Omega_0 = \max\left\{\frac{(1-\theta)R_0(1+r+q(v+\delta)-\delta)}{r} - I, 0\right\}. \tag{3}$$

If investment with graduation at $t=1$ is also possible, the individual has the option to wait one year and see whether returns have gone up or down because uncertainty is revealed. Waiting one year, and thereby foregoing a one-year return, only makes sense if one can avoid a bad outcome which generates a lower net present value when the investment is made.

If the investment is postponed and human capital earns a *high* return at graduation date $t = 1$, the net present value of the investment in education with graduation at $t=1$, $\overline{F}_1 \equiv \max\{\overline{V}_1 - I, 0\}$, can be written as

$$\overline{F}_1 = \max\left\{\frac{(1-\theta)(1+\upsilon)R_0(1+r)}{r} - I, 0\right\}, \tag{4}$$

where the upper bar denotes a high return outcome. If the investment is postponed and human capital earns a *low* return at graduation date $t=1$, the net present value of the investment in education with graduation at $t=1$, $\underline{F}_1 \equiv \max\{\overline{V}_1 - I, 0\}$ can be written as

$$\underline{F}_1 = \max\left\{\frac{(1-\theta)(1+\delta)R_0(1+r)}{r} - I, 0\right\}, \tag{5}$$

where the lower bars denote outcomes when the return is low.

Now, the whole investment opportunity, i.e., investing either now or tomorrow has a value $F_0 \equiv \max\left\{\Omega_0, \frac{q\overline{F}_1 + (1-q)\underline{F}_1}{1+r}\right\}$ which is equal to the maximum return of the investment when the individual invests directly and, the discounted value of the returns when waiting:

$$F_0 = \max\left\{\max\{V_0 - I, 0\}, q\frac{\max\{\overline{V}_1 - I, 0\}}{1+r} + (1-q)\frac{\max\{\underline{V}_1 - I, 0\}}{1+r}\right\}, \tag{6}$$

where $\frac{\overline{V}_1}{1+r} \equiv \frac{(1-\theta)(1+\upsilon)R_0}{r}$, and $\frac{\underline{V}_1}{1+r} = \frac{(1-\theta)(1-\delta)R_0}{r}$.

The value of the option to wait O is the difference between the value of the investment opportunity F_0 which covers the choice between investing now or next year and the net present value of investing Ω_0 directly: $O \equiv F_0 - \Omega_0$. To derive simple analytical results, the formal analysis is restricted to the case in which immediate investment has a positive present value, i.e., $\max\{\underline{V}_0 - I, 0\} = V_0 - I > 0$, the good outcome yields a positive present value, so that $\max\{\overline{V}_1 - I, 0\} = \mathrm{V}_1 - I$, and the bad outcome yields a negative present value, so that $\max\{\underline{V}_1 - I, 0\} = 0$.[4] With these restrictions, the option to wait has value

$$O = \max\left\{V_0 - I, q\left(\frac{\overline{V}_1 - I}{1+r}\right)\right\} - (V_0 - I). \tag{7}$$

[4] Little generality is lost by imposing these restrictions. All analytical results can be shown to be robust using graphical analysis of the general model without restrictions.

As long as $V_0 - I > q\left(\frac{V_1 - I}{1+r}\right)$ the option to wait is of no value and $O = 0$. In that case, it is optimal to go enrol in higher education directly if the present value of direct investment is positive. If, however, $V_0 - I < q\left(\frac{V_1 - I}{1+r}\right)$ the option to wait generates sufficient value and the investment will be postponed for one year. In that case, the individual will only invest if the returns turn out to be high and the individual will not invest at all if the returns turn out to be low.

4. To invest or not to invest in higher education?

This section derives the comparative statics of changing the parameters of the model on the willingness to invest in higher education, and the willingness to postpone investment in higher education. The value of the option (W) depends on the probability of an upswing (q), the costs (I), the interest rate (r), and the gross present values of the investment in higher education now or tomorrow (V_0 and V_1). These costs and present values are, in turn, determined by the return on the investment (R_0), the sizes of the up- and downswings in the returns (υ and δ), the costs of forgone earnings and tuition (ω and κ), the interest rates, the taxes (τ, θ), and the subsidy (s).

4.1. Options values and returns

R_0^* is the critical value of the average return to the investment in higher education at which individuals are indifferent between directly going to higher education or postponing one year, and only going to higher education if the return turns out to be high. R_0^* follows from setting $V_0 - I = q\left(\frac{V_1 - I}{1+r}\right)$:

$$R_0^* = \frac{(1 + r - q)}{(r + (1 - q)(1 - \delta))} \frac{rI}{(1 + r)(1 - \theta)}. \tag{8}$$

Recall, $I \equiv (1 - \tau)\omega + (1 - s)\kappa$.

There is also a critical lower bound on the return $\underline{R}_0$ below which the individual will never consider to enroll in higher education, not even if the individual has the option to wait. $\underline{R}_0$ follows from setting $q\left(\frac{V_1 - I}{1+r}\right) = 0$, and is given by

$$\underline{R}_0 = \frac{1}{(1 + v)} \frac{rI}{(1 + r)(1 - \theta)}. \tag{9}$$

The required return at which the student will never invest is lower than the return at which the student postpones the investment: $\underline{R}_0 < R_0^*$.

The minimum required return $\underline{R}_0$ can be compared with the required return $\hat{R}_0$ that would make the net-present value of investing higher education non-negative if the option to delay the investment was not available, i.e., when $V_0 - I = 0$:

$$\hat{R}_0 = \frac{1 + r}{(1 + r + q(v + \delta) - \delta)} \frac{rI}{(1 + r)(1 - \theta)}. \tag{10}$$

This return is larger than the return if the option to wait is available, i.e., $\hat{R}_0 > \underline{R}_0$. Having the option to wait has positive value, and it reduces the required return to consider the investment in higher education. At the same time, the return at which individuals invest directly can be shown to be larger than the return which would induce investments when options are not available: $R_0^* > \hat{R}_0$. As a result, individuals are more reluctant to invest directly in the option model than in the standard human capital model.

The value of the opportunity to go to higher education F_0 is a piecewise-linear function of the average return R_0 to the investment:

$$F_0 = \max\left\{\frac{(1-\theta)(1+r+q(\upsilon+\delta)-\delta)}{r}R_0 - I, \frac{q(1-\theta)(1+\upsilon)}{r}R_0 - \frac{qI}{1+r}\right\}. \quad (11)$$

If we subtract the value of immediate investment without the option Ω_0 (assumed to be positive) we get the value O of the option to wait:

$$O = \max\left\{\frac{(1-\theta)(1+r+q(\upsilon+\delta)-\delta)}{r}R_0 - I, \frac{q(1-\theta)(1+\upsilon)}{r}R_0 - \frac{qI}{1+r}\right\} - \left(\frac{(1-\theta)(1+r+q(\upsilon+\delta)-\delta)}{r}R_0 - I\right). \quad (12)$$

As long as the option O has positive value, i.e., when $R_0 < R_0^*$, the value of the option declines when the return to higher education R_0 increases: $\frac{\partial O}{\partial R_0} < 0$.[5] When the present value of direct investment is positive, the option becomes less valuable as returns increase because the individual looses positive returns of immediate investment. The value of immediate investment $\left(\frac{\partial V_0}{\partial R_0} = \frac{(1-\theta)(1+r+q(\upsilon+\delta)-\delta)}{r}\right)$ increases more than the value of the investment opportunity $\left(\frac{\partial F_0}{\partial R_0} = \frac{q(1-\theta)(1+\upsilon)}{r}\right)$ when returns R_0 increase. Therefore, higher returns R_0 reduce the value of the option and investing directly becomes relatively more profitable. As the return passes the critical level R_0^* immediate investment takes place and the option to wait is given up. An increase in the financial rewards of the investment will induce smaller effects on the decision to invest when options are valuable than without, since $\partial V_0/\partial R_0 > \partial F_0/\partial R_0$. In other words, the option approach predicts smaller sensitivity of human capital investments with respect to the returns than the standard human capital model.

Note also that the value of the option O is positively related to the required return R_0^* to make immediate investment optimal (if $O > 0$). The required return R_0^* increases if the return of the whole investment opportunity F_0 increases, or if the return of direct investment Ω_0 decreases. In both cases, option values to wait with immediate investment increase. In other words, if the required return to make immediate investment in human capital optimal increases, the option value in the investment opportunity increases. This property will be useful later on when discussing the comparative statics.

4.2. Options values and the cost of investment

Higher costs of the investment in higher education I raise the critical return to induce immediate investment R_0^*. From Eq. (8) follows that $\frac{\partial R_0^*}{\partial I} = \frac{(1+r-q)}{(r+(1-q)(1-\delta))}\frac{r}{(1+r)(1-\theta)} > 0$. The intuition is that when the costs of investment increase, the opportunity costs of waiting (i.e., having a one year extra return) decrease more than the benefit of waiting (i.e., only invest if the return is high). Higher costs of education therefore increase the option value of waiting. Higher costs also raise the critical value of the return $\underline{R}_0$ below which the investment is not considered at all which follows from differentiating (9): $\frac{\partial \underline{R}_0}{\partial I} = \frac{1}{(1+\upsilon)}\frac{r}{(1+r)(1-\theta)} > 0$. This result is analogous to the impact of higher costs on a higher required

[5] If direct investment yields a negative present value, i.e., $\frac{(1-\theta)(1+r+q(\upsilon+\delta)-\delta)}{r}R_0 < I$, the value of the option increases with the return: $\frac{\partial O}{\partial R_0} > 0$. The intuition is that the option to wait increases in value when the returns increase because there are no opportunity costs of waiting to invest if the direct investment yields a negative present value, and the individual would not invest at $t=0$.

threshold return in the standard human capital model. Therefore, higher costs of investment result in lower investment in human capital, both because individuals would not consider the investment and, because they tend to be more reluctant to invest immediately as the option value of waiting increases.

4.3. Option values and the probability of high returns

Differentiation of the required return to invest immediately (8) with respect to the probability of success q gives $\frac{\partial R_0^*}{\partial q} = -\frac{r\delta}{(r+(1-q)(1-\delta))^2}\frac{rI}{(1+r)(1-\theta)} < 0$. Therefore, if the probability of success increases, the opportunity costs of waiting in terms of missed returns increase. At the same time, the option value of waiting diminishes because the benefit of avoiding the low return outcome is lower as the low return outcome is less likely to occur. For both reasons, the critical value R_0^* decreases if the probability of a success increases. A higher probability of success has no effect on the minimum required return to consider the whole investment opportunity: $\frac{\partial \underline{R}_0}{\partial q} = 0$. The intuition is that option values are only determined by the probability of a downswing, not an upswing, see also below.

4.4. Option values and riskiness in returns

Increasing the probability q of a good outcome both increases the return and reduces the risk of the investment at the same time. To isolate the effect of larger risk without changing the expected return, mean preserving increases in the spread of returns are considered. To keep mean returns fixed, the downswing and the upswing are linearly related, i.e., $q(1+\upsilon) = -(1-q)(1-\delta)$. Note that (8) only depends on the downswing δ. Differentiation gives the effect of larger risk on the required return to induce immediate investment in human capital: $\frac{\partial R_0^*}{\partial \delta} = \frac{(1-q)(1+r-q)}{(r+(1-q)(1-\delta))^2}\frac{rI}{(1+r)(1-\theta)} > 0$. Therefore, increasing risk increases the return at which individuals want to invest directly. The intuition is that the option value of waiting O increases when the spread increases. The individual can reap the benefits of a higher potential upswing while avoiding the larger downward risks by not investing in that case. The required return for immediate investment (8) does not depend on the upward swing υ or the probability of a successful outcome q. Only the size of the bad outcome δ and the probability of the bad outcome $1-q$ determine whether individuals want to invest directly or not. This is the so called 'bad news principle', see also Dixit and Pindyck (1994). The option to wait is only valuable because it allows the individual to avoid the consequences of bad news.[6] A higher risk has a negative effect on the minimum required return to consider the whole investment opportunity: $\frac{\partial \underline{R}_0}{\partial \upsilon} = -\frac{1}{(1+\upsilon)^2}\frac{rI}{(1+r)(1-\theta)} < 0$ The intuition is that with a mean-preserving spread, the larger option value lowers the critical return to consider the investment.

4.5. Option values and income taxes

The effects of taxes on returns and forgone earnings on the required return to induce immediate investments follow from differentiation of (8) with respect to θ and τ. The effect of a higher tax rate on future returns is $\frac{\partial R_0^*}{\partial \theta} = \frac{(1+r-q)}{(r+(1-q)(1-\delta))}\frac{rI}{(1+r)(1-\theta)^2} > 0$. A higher 'top rate' θ makes students less willing to invest directly, both because returns are lower and because option values increase. A

[6] Eaton and Rosen (1980) also find that higher income risks have a negative effect on investments in human capital. In that paper, however, individuals are risk averse and therefore want a risk-premium on their investments in human capital. In the current set-up with risk neutral individuals, the individuals require a premium to give up a valuable option.

higher tax on future earnings increases the option value O because the returns on immediate investments decrease faster than the returns on postponed investments. As in the standard human capital model, the top rate increases the value of the return below which individuals do not want to consider the investment opportunity: $\frac{\partial R_0}{\partial \theta}=\frac{1}{(1+\upsilon)}\frac{rI}{(1+r)(1-\theta)^2}>0$.

A higher tax rate on forgone labor earnings τ decreases the threshold return above which immediate investments take place: $\frac{\partial R_0^*}{\partial \tau}=-\frac{(1+r-q)}{(r+(1-q)(1-\delta))}\frac{r\omega}{(1+r)(1-\theta)}<0$. The intuition is equivalent to lowering the costs of the investment I discussed previously. Higher taxes on forgone earnings increase the opportunity costs of waiting more than the benefit of waiting. The option value of waiting O decreases and the critical threshold for immediate investments R_0^* decreases. The required return to consider the investment in human capital also decreases as can be expected from the standard human capital model: $\frac{\partial R_0}{\partial \tau}=-\frac{1}{(1+\upsilon)}\frac{r\omega}{(1+r)(1-\theta)}<0$.

Suppose that there is a flat income tax ($\tau=\theta$) and all costs of education are effectively tax deductible ($s=\tau$). In the absence of option values, the tax system is neutral with respect to investments in human capital because all costs and returns of the investment are reduced at the same rate (see e.g. Heckman, 1976; Bovenberg and Jacobs, 2005). With option values this neutrality still holds because $\frac{\partial R_0^*}{\partial \tau}\big|_{\tau=\theta=s}=0$. Therefore, the classical neutrality of flat tax rates with complete deductibility of investment costs on human capital investments carries over to the current set-up with option values.[7]

With a flat tax and subsidies on education that are not equal to the tax rate ($s\neq\tau$), options do matter for the total impact of taxes on investments. The total effect of a flat tax on human capital investment consists of both an option effect and the standard positive impact on the required returns to invest. Indeed, if costs of education are not the same as the flat rate income tax ($s\neq\tau$) then we can find that a higher flat tax ($\theta=\tau$) increases the required return to induce immediate investment $\frac{\partial R_0^*}{\partial \tau}\big|_{\tau=\theta}=\frac{(1+r-q)}{(r+(1-q)(1-\delta))}\frac{r(1-s)\kappa}{(1+r)(1-\tau)^2}>0$. The costs of the investment are reduced less by a higher flat tax rate than the benefits, because the direct costs are not lowered by the tax rate. This is the standard effect in human capital models without options (Bovenberg and Jacobs, 2005). However, the presence of valuable options reduces the impact of the flat tax increase on the required return R_0^*. An increase in θ increases option values, and increase in τ decreases option values, see the earlier discussion. The combined effect is negative and option values decrease with a higher flat tax rate. Hence, individuals are more inclined to invest immediately. Due to the lower option values, the impact of flat taxes on human capital investments is typically smaller with options than without. An increase in the flat tax rate has the expected negative impact on the marginal return required to induce immediate investment: $\frac{\partial R_0}{\partial \tau}\big|_{\tau=\theta}=\frac{1}{(1+\upsilon)}\frac{r(1-s)\kappa}{(1+r)(1-\tau)^2}>0$.

4.6. Option values and subsidies on education

As a final exercise, the effects of larger education subsidies are analyzed. From differentiation of (8) follows that the marginal return to induce immediate investments diminisheswith the subsidy: $\frac{\partial R_0^*}{\partial s}=-\frac{(1+r-q.)}{(r+(1-q)(1-\delta))}\frac{r\kappa}{(1+r)(1-\theta)}<0$. Higher subsidies lower the costs of the investments. The

[7] This contrasts with Eaton and Rosen (1980) where distorting proportional taxes are optimally positive with risk-averse investors. A progressive tax system substitutes for missing insurance markets and thereby reduces the required risk-premium on human capital investments. Hogan and Walker (2007-this issue) find positive effects of taxes on human capital investment in their option approach. Their finding is the result of non-monetary benefits of education. A higher (flat) income tax boosts investment in human capital because total benefits (monetary and non-monetary) are subject to a lower rate of tax than forgone earnings (Bovenberg and Jacobs, 2005). Hence, a flat tax acts as an implicit subsidy on human capital investment. Options do make investment less responsive to tax incentives, but will not affect the sign of the tax impact on human capital investment.

marginal benefits of investing directly increase more than the marginal benefits of postponing the investments. Therefore, the option value of waiting O decreases and the return at which immediate investments are optimal decreases. This implies that the impact of education subsidies on individuals' decisions to consider the investment in human capital is partially off-set by lower option values. Therefore, the full impact of education subsidies on educational investment is again smaller than in the standard human capital model. The impact of lower costs on the investment is that individuals with lower $\underline{R}_0$ consider the investment: $\frac{\partial \underline{R}_0}{\partial s} = -\frac{1}{(1+\upsilon)} \frac{r\kappa}{(1+r)(1-\theta)} < 0$. Again, this is the standard human capital result.

5. Conclusions

This paper analyzed the consequences of real options in human capital investments. Human capital investments are both risky and largely irreversible. It is generally impossible to recover forgone labor earnings and paid tuition fees. If individuals can influence the timing of the investment, i.e., decide to go to higher education now or later, option values will influence investment behavior. This paper has shown that with perfect financial markets, the option to postpone investment could explain why returns to education are high, why investment in human capital is not very sensitive to returns, taxes and subsidies, and why students are rightly concerned with low return outcomes. These findings can be relevant in explaining various empirical findings.

Options may offer an explanation as to why skill-premia for higher educated workers are high. Returns should be high because they compensate for the lost option value of waiting once individuals make the irreversible investments in education. This is an equilibrium outcome which does not require incompleteness of financial markets.

This paper has shown that option values tend to make human capital investments less responsive to the net returns of the investments compared to the standard human capital model. This may help to explain findings that enrolment does not appear to be very price responsive. The empirical picture appears to be that doubling tuition costs will decrease enrolment rates with roughly 5–10%-points after controlling for selection effects, see recent estimates provided in Kane (1994, 1995), Hilmer (1998), Heckman et al. (1998), Card and Lemieux (2000), Cameron and Heckman (2001), and Dynarski (2003).

Option values may also help to explain why returns to education are larger in countries with larger income inequality, insofar as inequality reflects labor market risk.[8] In more risky labor markets, option values of postponing investments in education increase, and students need to be compensated for giving up the option to wait with higher returns. OECD (2006) data reveal that income inequality is typically larger in countries with high Mincer returns to education, as estimated by Harmon et al. (2003). Hence, the data are not inconsistent with the prediction that larger returns on education should be found in more risky labor markets.

Option values can be an important reason why students wait with enrolment in higher education. However, the vast majority of high school graduates immediately enrolls in higher education. The observation that many students do not wait to enroll may is not a direct refutation of the model presented in this paper. Students will enroll immediately as long as rates of return to education are high enough to give up their valuable waiting option to enroll later.

[8] If returns to education are higher, income inequality will also directly increase, so there is also a reverse causality problem involved here. Katz and Autor (1999), however, show that a large and increasing part of inequality cannot be explained by education alone.

The analysis of other types of options could be relevant for future research. No research exists on the option to *terminate* the investment in initial education, i.e., to drop out, when the investment turns out to be unprofitable. There could also be an option to *switch* from initial education to OJT investments or from general education to vocational education in case the latter becomes more profitable compared to the former. There can also be *compound* options when there is some combination of options involved in the investment in human capital. Furthermore, the model of this paper could be cast in a continuous time framework similar to examples in Dixit and Pindyck (1994). This would allow for an empirically grounded analysis to study the potential explanatory powers of the model. One could then also allow for a variety of stochastic processes describing the returns to the investment. A more in depth treatment of cost uncertainty could also be analyzed in more detail. This paper assumed that costs were exogenous and not time-varying. Cost uncertainty is equivalent to what Levhari and Weiss (1974) call 'input-uncertainty', i.e., the uncertainty about individual capacities. If cost uncertainty decreases when the project is undertaken, there may be reasons to start investing immediately even if the net present value is negative. This is related to the growth options in sequential investments as discussed in Comay et al (1973) and Heckman et al. (2006). Further, the impact of options on the distribution of wages would be interesting to investigate in a general equilibrium setting in which wages of skilled and unskilled workers are endogenously determined. Finally, interactions of options in human capital investment with various types of capital and insurance market failures may be a promising avenue for future research.

References

Ashenfelter, O., Harmon, C., Oosterbeek, H., 1999. A Review of Estimates of the Schooling/Earnings Relationship with Tests for Publication Bias. Labour Economics 6, 453–470.

Becker, G.S., 1993. Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education, Third edition. Chicago University Press, Chicago.

Belzil, C., Hansen, J., 2004. Earnings Dispersion, Risk Aversion and Education. Research in Labor Economics 23, 335–358.

Bovenberg, A.L., Jacobs, B., 2005. Redistribution and Education Subsidies are Siamese Twins. Journal of Public Economics 89, 2005–2035.

Cameron, S.V., Heckman, J.J., 2001. The Dynamics of Educational Attainment for Blacks, Hispanics, and Whites. Journal of Political Economy 109 (3), 455–499.

Cameron, S., Taber, C., 2004. Estimation of Educational Borrowing Constraints Using Returns to Schooling. Journal of Political Economy 112 (1), 138–182.

Card, D., 1999. The Causal Effect of Education on Earnings. In: Ashenfelter, O., Card, D. (Eds.), Handbook of Labor Economics, vol. 3A. Elsevier-North Holland, Amsterdam.

Card, D., Lemieux, T., 2000. Dropout and Enrollment Trends in the Post-War Period: What Went Wrong in the 1970's? NBER Working Paper, vol. 7658. NBER, Cambridge, MA.

Carneiro, P.M., Heckman, J.J., 2003. Human Capital Policy. In: Heckman, J.J., Krueger, A.B. (Eds.), Inequality in America: What Role for Human Capital Policies? MIT Press, Cambridge, MA.

Cunha, F., Heckman, J.J., Navarro, S., 2005. Separating Uncertainty from Heterogeneity in Life Cycle Earnings. Oxford Economic Papers 57 (2), 191–261.

Comay, Y., Melnik, A., Pollatschek, M.A., 1973. The option value of Education and the Optimal Path for Investment in Human Capital. International Economic Review 14 (2), 421–435.

Dixit, A.K., Pindyck, R.S., 1994. Investment Under Uncertainty. Princeton University Press, New Jersey.

Dynarski, S., 2003. Does Aid Matter? Measuring the Effect of Student Aid on College Attendance and Completion. American Economic Review 93 (1), 279–288.

Eaton, J., Rosen, H.S., 1980. Taxation, Human Capital and Uncertainty. American Economic Review 70 (4), 705–715.

Friedman, M., 1962. Capitalism and Freedom. Chicago University Press, Chicago.

Gould, E.D., Moav, O., Weinberg, B.A., 2000. Precautionary Demand for Education, Inequality, and Technological Progress. Journal of Economic Growth 6 (4), 285–316.

Harmon, C., Oosterbeek, H., Walker, I., 2003. The Returns to Education: Microeconomics. Journal of Economic Surveys 17, 115–155.

Hartog, J., 2005. Schooling as a Risky Investment. Proceedings of the Royal Dutch Academy of Sciences 68 (2).
Hartog, J., Diaz-Serrano, L., 2002. Earnings Risk and Demand for Higher Education: A Cross-Section test for Spain. IZA Discussion Paper, vol. 641. IZA, Bonn.
Heckman, J.J., 1976. A Life-Cycle Model of Earnings, Learning and Consumption. Journal of Political Economy 4, S11–S44.
Heckman, J.J., Lochner, L., Taber, C., 1998. Explaining Rising Wage Inequality: Explorations with a Dynamic General Equilibrium Model of Labor Earnings with Heterogeneous Agents. Review of Economic Dynamics 1, 1–58.
Heckman, J.J., Lochner, L.J., Todd, P.E., 2006. Earnings Functions, Rates of Return, and Treatment Effects: The Mincer Equation and Beyond. In: Hanushek, E., Welch, F. (Eds.), Handbook of the Economics of Education, vol. 1. Elsevier-North Holland, Amsterdam.
Hilmer, M.J., 1998. Post-Secondary Fees and the Decision to Attend a University or a Community College. Journal of Public Economics 67, 329–348.
Hogan, V., Walker, I., 2007. Education Choice under Uncertainty and Public Policy. Labour Economics 14, 894–912 (this issue).
Jacobs, B., van der Ploeg, F., 2006. Guide to Reform of Higher Education: A European Perspective. Economic Policy 47, 537–592.
Judd, K. (2000). Is Education as Good as Gold? Hoover Institute: mimeo.
Kane, T.J., 1994. College Entry by Blacks since 1970: The Role of College Costs, Family Background and the Returns to Education. Journal of Political Economy 102 (5), 878–911.
Kane, T.J., 1995. Rising public tuition and college entry: how well do public subsidies promote access to college. NBER Working Paper, vol. 5164. NBER, Cambridge, MA.
Katz, L.F., Autor, D.H., 1999. Changes in the Wage Structure and Wage Inequality. In: Ashenfelter, O., Card, D. (Eds.), Handbook of Labor Economics, vol. 3A. Elsevier-North Holland, Amsterdam.
Leuven, E., Oosterbeek, H., 2001. Firm-Specific Human Capital as a Shared Investment: Comment. American Economic Review 91 (1), 342–347.
Levhari, D., Weiss, Y., 1974. The Effect of Risk on the Investment in Human Capital. American Economic Review 64 (6), 950–963.
Mehra, R., Prescott, E.C., 2003. The equity premium in retrospect. NBER Working Paper, vol. 9525. NBER, Cambridge, MA.
OECD, 2006. Database Labor Force Statistics. OECD, Paris.
Palacios-Huerta, I., 2004. An Empirical Analysis of the Risk Properties of Human Capital Returns. American Economic Review 93 (3), 948–964.
Palacios-Huerta, I. (2006). Risk and Market Frictions as Determinants of the Human Capital Premium. Brown University: mimeo.
Plug, E.J.S., Vijverberg, W., 2004. Schooling, Family Background, and Adoption: Does Family Income Matter. Economic Journal 115, 880–907.
Rubinstein, Y., Tsiddon, D., (2001). Born to be Unemployed: Unemployment and Wages over the Business Cycle. mimeo: Tel Aviv University.
Sinn, H.-W., 1995. A Theory of the Welfare State. Scandinavian Journal of Economics 97, 495–526.
Stiglitz, J.E., Weiss, A., 1981. Credit Rationing in Markets with Imperfect Information. American Economic Review 71 (3), 393–410.