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Abstract

This review article examines the role of labor income risk in determining the value of a person's human capital. We draw on the existing literature to present a model that incorporates various types of shocks to earnings. Within this framework, we highlight the implications of different assumptions about the correlation between market returns and labor income growth for the value of human capital and its riskiness. Further, the article surveys other work that applies similar ideas to assess the value and risk of pension promises. Finally, we discuss how to enrich the environment with heterogeneity in preferences and stock market exposures; endogenous labor supply and retirement decisions; health shocks; and human capital investment.

1 Introduction

We broadly think of 'human capital' as the set of knowledge, skills, health, and values that contribute to making people productive (e.g., Becker 1964 and Rosen 2008). In a free society, any contract written against future labor services is not strictly enforceable, and ownership of human capital is restricted to the person who embodies it (labor income is a non-traded asset). Hence, any quantitative analysis of the value of human capital is necessarily based on the present value of a person's future labor income flows. While intuitive, this definition is hardly operational without sufficient knowledge of the flows of earnings and wages that an individual generates by 'renting' his services on the labor market and appropriate discount rates to translate those cash flows into a present value.

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To some extent individuals can control future earnings by adjusting labor supply. However, the ability to smooth labor income by changing working hours or moving retirement dates is limited by the presence of various shocks. For instance, deteriorating economic conditions could precipitate job loss and subsequently lower wages. Health problems could produce similar outcomes. Hence, human capital valuation typically relies on statistical models to determine the distribution of future labor income and its covariates.

Identifying appropriate discount rates for uncertain labor income flows also presents a challenge. Some labor income shocks contain an aggregate component. For instance, wages and employment rates are typically lower when the economy does poorly, especially during a long recession. Similarly, health problems in aggregate tend to increase during an extended economic downturn. These risks are likely to be priced in the economy with a premium that is pinned down by traded assets. Hence, given an estimate for the aggregate component of labor income shocks one can price these shocks at market values.

However, labor income contains also a big idiosyncratic component. For example, many health shocks that are unrelated to aggregate economic conditions could force a person out of the labor force. Similarly, a promotion could raise a worker's earnings regardless of the overall state of the economy. A person cannot fully insure such shocks. Hence, the private value of a worker's income may differ from the estimated market value of the income based on market discount rates. In other words, the market is incomplete, and to value human capital from the perspective of a worker one needs to posit the preference function being optimized, control variables, and the constraint set. In general, the set of control variables is quite rich. The agent faces saving vs. consumption decisions; moreover, he must choose how to allocate financial wealth across a variety of investment classes. As mentioned previously, endogenous labor supply and retirement decisions further complicate the optimization problem. Absent closed-form solutions, numerical methods generally are used to characterize optimal policies and the implied valuations.

In this review article, we discuss how the recent literature has tackled these issues. We begin by laying out a simple framework to study the implicit market value and risk of human capital. In Section 2, which draws on work by Benzoni, Collin-Dufresne, and Goldstein (2007), we sketch a model in which labor income is assumed to be an exogenous process subject to aggregate and idiosyncratic shocks. While stylized, the model is sufficiently general to match the main properties of labor income data, both at the aggregate and at the household level. It nests previous specifications in which the contemporaneous correlation of earnings and stock market shocks is the main source of of priced dependence between the labor market and the rest of the economy. It generalizes those previous specifications in that it allows for time-varying correlations between labor income and stock returns. In particular, the correlation between the growth rate in labor income and stock returns increases with the time horizon, consistent with economic intuition and empirical evidence. In this setting, we obtain a measure of human capital and identify its exposure to market-wide and idiosyncratic risks. Along the way, we relate this setup and its implications to the recent finance literature on life-cycle portfolio choice with stochastic labor income.

In Section 3, we discuss recent work that applies similar ideas to assess the value and risk of pension fund obligations, their funding, and the allocation of pension assets across different investment classes. Moreover, we extend the framework to incorporate various important ingredients. We touch upon heterogeneity in preferences; differences in the exposure to stock market risk across agents; endogenous labor supply and retirement decisions; health shocks; and human capital investment. We enrich this discussion with ideas for future work.

2 A Framework to Study the Value and Risk of Human Capital

Consider a person with constant relative risk aversion (CRRA) utility, who is endowed with initial wealth W_t and earns exogenous labor income $L(u)$ over his working life, $t \leq u \leq T$. At each point in time, he decides how much to consume and how to allocate savings between a safe bond and a risky asset, with the objective of maximizing the utility function,

$$J_t \equiv \max_{\{C,\pi\}} \mathrm{E}_t \left[\int_t^T du \, e^{-\psi u} \frac{(C(u))^{1-\gamma}}{1-\gamma} + \epsilon^\gamma e^{-\psi T} \frac{(W(T))^{(1-\gamma)}}{1-\gamma} \right], \tag{1}$$

where T is the retirement date, C denotes consumption, π is the fraction of financial wealth invested in the risky asset while $(1-\pi)$ is the fraction held in the risk-free bond. The second term in equation (1) captures the utility of wealth available to fund consumption during retirement and any bequest. This is similar to modeling the post-retirement consumption and investment decisions under the assumption that the agent receives a fixed income flow like, for example, a retirement annuity.

The budget constraint for the agent is

$$dW(t) = -C(t)\, dt + \Big(1 - \pi(t)\Big)\, W(t) \, \frac{dB(t)}{B(t)} + \pi(t)\, W(t) \, \frac{dS(t)}{S(t)} + L(t)\, dt\,, \tag{2}$$

where $\frac{dB(t)}{B(t)} = rdt$ is a constant risk-free rate and $\frac{dS(t)}{S(t)} = \frac{dP(t)+D(t)\,dt}{P(t)}$ is the cum-dividend return on the risky asset.

The first-order condition with respect to consumption yields $J_{_W} = U_{_C} = e^{-\delta t}\, C^{-\gamma}$. Thus, we obtain a key expression for the valuation of the agent's human capital, computed as the time-t present value of his labor income discounted at the inter-temporal marginal rate of substitution:

$$V(t) = \mathrm{E}_t \left[\int_t^T ds \, e^{-\delta(s-t)} \left(\frac{C(s)}{C(t)} \right)^{-\gamma} L(s) \right]. \tag{3}$$

To study the properties of human capital as defined in equation (3), we need to make additional assumptions about the labor income process L and its linkage with the factors affecting consumption and hence the pricing kernel.

2.1 A Model of Exogenous Long-Run Labor Income Risk

Statistical evidence suggests that individual labor income can be decomposed in two main parts (e.g., Carroll & Samwick 1997, Cocco et al. 2005, Gomes & Michaelides 2005, Gourinchas & Parker 2002, Jagannathan & Kocherlakota 1996). First, an aggregate stochastic component which captures the effect of economy-wide shocks on total workers' compensation. Second, an idiosyncratic component that embeds individual-specific shocks as well as a deterministic pattern due to life-cycle predictability in wages. Along these lines, we approximate the (logarithmic) household-level labor income, ℓ, with the sum of aggregate and idiosyncratic terms,

$$\ell = \ell_1 + \ell_2 \,. \tag{4}$$

2.1.1 The Aggregate Labor Income Component ℓ_1

To model a linkage between aggregate labor income and other economic variables that affect the pricing kernel, we follow much of the literature in assuming that the aggregate capital income process has the same statistical properties as the aggregate dividend process. We posit that the logarithmic dividend process $\hat{d}(t) \equiv \log\left[D(t)\right]$ follows a geometric Brownian motion,

$$d\hat{d}(t) = \left(g_{_D} - \frac{\sigma^2}{2}\right) dt + \sigma\, dz_{_3}. \tag{5}$$

It is convenient to consider a pricing kernel with a constant drift equal to the risk-free rate and a constant market price of risk. Then, the return on the investment strategy $S(t)$ which reinvests all proceeds (dividends and capital gains) in the stock market portfolio is:

$$ds = \left(\mu - \frac{\sigma^2}{2}\right) dt + \sigma\, dz_{_3}\,, \tag{6}$$

where $s(t) \equiv \log S(t)$ and μ is the total expected rate of return of the investment strategy. In this stylized model the dividend growth rate volatility σ is identical to the stock return volatility. This is counterfactual (stock returns fluctuate more than dividends) but inconsequential for life-cycle portfolio decisions and human capital valuation as long as σ is calibrated to match historical stock return volatility.

We then introduce a variable y which measures the (logarithmic) difference between aggregate labor income and dividends,

$$y(t) \equiv \ell_{_1}(t) - \hat{d}(t) - \overline{\ell d}\,, \tag{7}$$

where the constant $\overline{\ell d}$ is the long-run logarithmic ratio of aggregate labor income to dividends. To capture the notion of long-run dependence between aggregate labor income flow and dividends, we assume that the $y(t)$ process is mean-reverting,

$$dy(t) = -\kappa y(t)\, dt + \nu_{_1}\, dz_{_1}(t) - \nu_{_3}\, dz_{_3}(t)\,, \tag{8}$$

where $z_{_1}$ is a standard Brownian motion independent from $z_{_3}$. The coefficient κ measures the speed of mean reversion for the process y. Benzoni et al. (2007) provide evidence that

$\kappa > 0$, i.e., y is stationary, so that ℓ_1 and $\hat{d}$ are co-integrated. This result is economically intuitive. For instance, a model with a Cobb-Douglas production function predicts that returns to physical and human capital are perfectly correlated even in the short run (e.g., Baxter & Jermann 1997).[1]

2.1.2 The Idiosyncratic Labor Income Component ℓ_2

We assume that the idiosyncratic labor income component is subject to permanent shocks (e.g., Carroll & Samwick 1997, Cocco et al. 2005, Gomes & Michaelides 2005, and Gourinchas & Parker 2002):[2]

$$d\ell_2(t) = \left(\alpha(t) - \frac{\nu_2^2}{2}\right) dt + \nu_2 \, dz_{2,i}(t) \,, \tag{9}$$

where $z_{2,i}$ is a standard Brownian motion independent from both z_1 and z_3, and the ν_2 coefficient determines the standard deviation of the idiosyncratic shock. The subscript (i) denotes that this shock pertains to the i-th agent process. Further, we specify the time-dependent drift term $\alpha(t) = \alpha_0 + \alpha_1 t$, with coefficients α_0 and α_1 calibrated to match the hump-shape of earnings over the life cycle (e.g., Cocco et al. 2005).

2.2 Comparison with the Literature

Taken together, equations (5) and (7)-(9) yield the following dynamics for the total labor income process $\ell = \ell_1 + \ell_2$:

$$d\ell(t) = \left(-\kappa y(t) + g_D - \frac{\sigma^2}{2} + \alpha(t) - \frac{\nu_2^2}{2}\right) dt + \nu_1 \, dz_1(t) + \nu_2 \, dz_{2,i}(t) + (\sigma - \nu_3) \, dz_3(t) \,. \tag{10}$$

Equation (10) highlights that there are two possible sources of correlation between labor income and the risky asset return in the model. First, since z_1 and $z_{2,i}$ are orthogonal to the stock return shock z_3, equations (6) and (10) imply that the contemporaneous correlation between stock market and labor income shocks is

$$\text{corr}(ds, d\ell) = \frac{(\sigma - \nu_3)}{\sqrt{\nu_1^2 + \nu_2^2 + (\sigma - \nu_3)^2}} \,. \tag{11}$$

Second, co-integration generates non-zero long-run correlations between labor income and risky asset returns.

Previous research on life-cycle portfolio choice mainly focused on the first type of correlation (e.g., Campbell et al. 2001, Cocco et al. 2005, Davis & Willen 2000, Gomes & Michaelides

[1]Other previous studies have advocated specifications that produce high long-run correlations between labor income and stock returns, e.g., Baxter & Jerman (1997), Campbell (1996), Huggett & Kaplan (2013), Lucas & Zeldes (2006), and Santos & Veronesi (2006). For a dissenting voice, see, e.g., Lustig and Van Nieuwerburgh (2006); their results, however, are not robust to the presence of stochastic macroeconomic volatility, e.g., Bansal et al. (2013).

[2]It is straightforward to extend the model to include transient labor income shocks. We know however that such shocks do not affect the consumption-investment decision problem of the agent (e.g., Cocco et al. 2005). Hence we ignore them here for sake of parsimony.

2005, Haliassos & Michaelides 2003, and Viceira 2001). For instance, it is straightforward to show that the labor income dynamics of Campbell et al. (2001) are identical to those in equation (10) in the limit when the mean reversion parameter $\kappa \to 0$ (e.g., Benzoni & Chyruk 2009). In that case, the effect of co-integration is absent and the only source of correlation between labor income and stock returns is the contemporaneous correlation in their shocks. This channel, however, has limited support as most empirical studies have shown this correlation to be small or even zero. In contrast, in our more general setting labor income is contemporaneously uncorrelated with the stock market return when $(\sigma - \nu_3) = 0$, consistent with empirical evidence. Yet, co-integration generates non-zero long-run correlations between labor income and risky asset returns. Even though these two models are extremely difficult to distinguish econometrically for 'small' values of κ, Benzoni et al. (2007) show that they have substantially different predictions for the optimal portfolio choice of young agents. Moreover, co-integration has important implications for the analysis of human capital, as we discuss in more detail below.

This analysis is also useful to clarify the link with labor income models that allow for time varying idiosyncratic shocks. For instance, Storesletten et al. (2004) estimate that idiosyncratic risk is strongly counter-cyclical, and Storesletten et al. (2007) show that, due to this property, human capital acquires stock-like features and the life-cycle risky asset holding is hump shaped. In the context of this framework, fluctuations in the ν_2 coefficients over the business cycle would capture this feature. Lynch & Tan (2008) extend this work by showing that the conditional mean of the labor income flow also fluctuates at business cycle frequencies.

2.3 The Sources of Human Capital Risk

In the model, the expression for the agent's human capital V_t in equation (3) depends on three state variables, namely, y, L, and W. Hence, we can identify the sources of human capital risk in the stochastic component of dV as

$$\begin{aligned} dV_{stochastic} &= V_y dy_{stochastic} + V_L dL_{stochastic} + V_W dW_{stochastic} \\ &= \left(\nu_1 V_y + \nu_1 L V_L\right)\, dz_1 + \nu_2 L V_L\, dz_{2,i} \\ &\quad + \left(-\nu_3 V_y + (\sigma - \nu_3) L V_L + \pi \sigma W V_W\right)\, dz_3 \,. \end{aligned} \tag{12}$$

Since there are no traded securities that correlate with the z_1 and $z_{2,i}$ shocks, we follow Benzoni et al. (2007) and introduce two "pseudo-securities" X_j, $j = 1$ and 2, such that

$$\frac{dX_j(t)}{X_j(t)} = \left(r + \lambda_j(t)\sigma\right)\, dt + \sigma dz_{j,i}(t)\,, \quad j = 1 \text{ and } 2. \tag{13}$$

The coefficients $\lambda_j(t)$, $j = 1$ and 2, are the risk premia on these pseudo-securities. If these claims were traded, then markets would be complete and these risk premia would be determined by the observable price processes. In our case the pseudo securities are not traded. Still, the portfolio problem can be characterized by a complete markets problem in a fictitiously completed market in which the risk premia of the pseudo securities are such that, at the optimum, the agent does not want to hold them (He & Pearson 1991, Karatzas et al. 1991). The corresponding risk premia, given the optimal value function, are determined by $\lambda_j(t)\,dt = -\left(\frac{dX_j(t)}{X_j(t)}\right)\cdot\left(\frac{dJ_W(t)}{J_W(t)}\right)$.

Consider then a replicating portfolio consisting of an investment θ_S in the stock S, θ_B in the risk-free asset B, and θ_{X_j} in X_j, $j = 1$ and 2:

$$V^{Rep} = \theta_S S + \theta_B B + \theta_{X_1} X_1 + \theta_{X_2} X_2\,. \tag{14}$$

The stochastic component of dV^{Rep} is

$$dV^{Rep}_{stochastic} = \theta_S S\sigma dz_3 + \theta_{X_1} X_1 \sigma dz_1 + \theta_{X_2} X_2 \sigma dz_{2,i}. \tag{15}$$

Thus, by matching coefficients in (12) and (15) we conclude that the proportion of the agent's human capital implicitly tied up in the stock market is

$$\frac{\theta_S S}{V} = \frac{-\nu_3 V_y + (\sigma - \nu_3) L V_L + \pi\sigma W V_W}{\sigma V}\,. \tag{16}$$

Similarly, we obtain expressions for the shares implicitly invested in the risk-free bond and the two pseudo securities.

This approach also allows us to identify the correlation coefficient between returns to human capital and stock returns, which we denote by ρ. By combining (6) with (12), we obtain

$$\rho = \frac{-\nu_3 V_y + (\sigma - \nu_3) L V_L + \pi\sigma W V_W}{\sigma_V}\,, \tag{17}$$

where σ_V is an appropriately defined constant.

2.4 A Numerical Illustration

To illustrate the model properties, we calibrate the coefficients to the baseline values of Benzoni et al. (2007).[3] Figure 1, Panel A, shows the typical wealth, consumption, and labor income profiles averaged across model simulations. By design, the calibration produces realistic wealth accumulation as well as consumption and labor income patterns (e.g., Cocco et al. 2005, Cagetti 2003). Further, Panel B shows risky asset holdings that are hump shaped over the life cycle of the agent. This is also consistent with empirical evidence, which shows that most young investors hold very little financial wealth in stocks, they progressively increase their holdings during their middle age, and reduce their exposure to stock market risk as they approach retirement (e.g., Campbell 2006, Ameriks & Zeldes 2004, Benzoni & Chyruk 2009).

[3]Benzoni et al. (2007) use a 1929-2004 sample of data on total after-tax U.S. employee compensation and dividends on a U.S. stock index to estimate the coefficients of the co-integration relation (8). They calibrate the idiosyncratic labor income dynamics (9) to match the evidence in prior papers that have studied the properties of labor income using household-level data. The equity premium is fixed at 6% and the CRRA coefficient is 5. Further, they impose short-selling constraints on the stock and the bond and rule out any stock market entry cost.

To understand the intuition for these result, it is useful to turn to the valuation of the agent's human capital. When the investor is young, there is sufficient time for the co-integration effect to act. Thus, the young agent's human capital displays a high level of comovement with the stock market due to long-run labor income risk, i.e., human capital has stock-like features. Since much of a young investor's wealth is tied up in his human capital (financial wealth is relatively small when he is young), he finds herself over-exposed to stock market risk and therefore chooses to invest his financial wealth in the risk-free asset. This is illustrated in Figure 2, which shows the decomposition of the replicating portfolio for human capital into its various holdings of stock, pseudo-securities, and the risk-free money market.

We find the fraction of a 20-year old agent's human capital tied up in the stock market (equation 16) to be approximately one-half, while the implicit positions in the two pseudo-securities X_1 and X_2 are 13.9% and 87.6%, respectively. These evidence shows that human capital is mostly equivalent to a long position in the stock market portfolio and in permanent idiosyncratic risk, which is hedged with X_2.[4] Moreover, the human capital of a young agent is a highly leveraged security: his implicit holding in the risk-free asset is approximately -51%.

As the agent grows older, co-integration has less time to act so that idiosyncratic shocks become the prevalent source of human capital risk. Since these latter shocks are orthogonal to stock market fluctuations, the agent has an incentive to diversify them away via a larger position in stocks. This effect generates the increasing part of the portfolio holding profile (Figure 1, Panel B). When he approaches retirement, human capital has mainly bond-like features. However, the present value of future labor income flows shrinks to zero since there are few remaining years of employment. Thus, the agent reduces his position in the stock market to buy more of the risk-free asset.

This is also evident in Figure 3, Panel A, which shows how human capital V_t evolves over the life cycle. The fraction of the agent's labor income tied up in the risky asset is roughly constant at 50% throughout the first half of his life, and it rapidly goes to zero near retirement. Further, human capital has a hump-shaped profile. That is, although young agents face a larger stream of future labor income, they discount such cash flows more than older agents. There are three reasons for this. First, the predictable labor income component has a hump-shaped profile: Higher labor income cash flows occur at older ages, and therefore are subject to greater time discounting. Second, as the agent ages, he faces lower idiosyncratic labor income risk. Indeed we find the risk premium on the permanent idiosyncratic labor income shocks λ_2 to have a downward-sloping profile. This effect is common to other models with idiosyncratic labor income risk (e.g., Campbell et al. 2001, Cocco et al. 2005, Carrol & Samwick 1997, and Gomes & Michaelides 2005). Third, in our model human capital has pronounced stock-like features, and thus commands a higher discount rate, for young agents, whereas it acquires bond-like properties, and thus is discounted at a lower rate, for older

[4]The transient idiosyncratic shocks represent only a very small fraction of the replicating portfolio. Hence we do not report them in Figure 2.

agents. Due to this third effect, which is determined by the long-run cointegration of labor income and stock market performance, the value of human capital peaks at a later point in the agent's life compared to standard models considered in previous studies. This intuition is confirmed in Figure 3, Panel B, which shows that the correlation of stock returns and the returns to human capital remains high and basically constant over the first half of the agent's life, and it rapidly drops as the agent approaches retirement.

3 Future Directions

3.1 The Value and Risk of Pension Funds and Social Security

The methods for the valuation of human capital find direct application in the valuation of pension-plan obligations, their funding, and the allocation of pension assets across different investment classes. For instance, Lucas & Zeldes (2006) focus on the valuation and hedging of defined-benefit (DB) plans. A DB plan awards the employee deferred compensation in the form of future payments (typically a retirement annuity) linked to the length of his tenure with the firm and the salary received during the final year(s) of employment.[5] From a firm's point, a DB plan involves accrued benefit obligations (ABO) toward former and current workers, computed based on current years of employment and wages. More broadly, however, the firm's obligations include liabilities towards all employees (former, current, and expected future workers), computed based on past and projected future years of employment and wages. Lucas & Zeldes (2006) refer to this latter measure as an 'all-inclusive' projected benefit obligation (PBO).

ABOs are firm's obligations of a known amount and should be discounted and hedged accordingly. In contrast, the valuation and funding of PBOs should reflect the risk associated with these uncertain future payments. The problem is complicated by multiple factors, including taxes, the effect of the Pension Benefit Guarantee Corporation (PBGC) guarantees, accounting and tax regulations, corporate liquidity needs (funds tied up in the pension plan may not be easily redirected to other corporate needs), and other labor contracting considerations. Abstracting from some of these issues, Lucas & Zeldes (2006) argue that while the hedging of ABOs is best accomplished with a portfolio of bonds (see also Bodie 1990, 2006), the hedge portfolio for PBOs should contain a mix of stocks and bonds, with a share of stocks versus bonds that depends on firm and worker characteristics, e.g., the probability of bankruptcy, worker separation, and mortality. Moreover, the rate at which to discount uncertain PBOs is a function of similar macroeconomic, firm, and worker characteristics.

To better understand these results, consider that if wage growth correlates positively with stock returns over the long run, then future pension liabilities will also correlate positively with the performance of the stock market. Thus, stocks should be part of the hedge portfolio, and firms with a higher percentage of active workers should invest more heavily in stocks.

[5] In spite of much recent growth in defined-contribution (DC) plans, DB plans remain popular with a number of firms still offering them in the retirement package for their employees.

Moreover, firms should discount their projected PBOs at a rate that increases with the share of active workers relative to separated and retired employees. This is consistent with the discussion above, which shows that human capital has a stock-like component that is higher for younger workers. Thus, the PBO of a firm with a higher fraction of active (i.e., younger) workers also has stock-like properties. This feature determines a higher hedge position in stocks, increases the rate at which to discount the PBO, and reduces the PBO's present value.

Similar issues arise in the valuation of Social Security obligations. A key input to this problem is the rate at which to discount future liabilities. The traditional actuarial approach uses a risk-free rate to discount future expected cash flows. Geanakoplos & Zeldes (2010) argue that this approach underestimates the riskiness of such obligations. Social Security benefits depend on the realization of the future economy-wide wage level. If future wages and stock market performance correlate positively over the long run, then the appropriate discount rate for Social Security obligations toward active workers should exceed the risk-free rate. This risk adjustment reduces the present value of the obligation, which is relevant to assessing the projected burden of Social Security on the taxpayer. Moreover, there is much debate on the costs and benefits associated with investing a fraction of the Social Security fund in stocks (e.g., Abel 1999, 2001, Geanakoplos, Mitchell & Zeldes 1998, Heaton & Lucas 2005).[6] This problem resembles optimal asset allocation in private DB pension funds. Thus, as in Lucas & Zeldes (2006) the portfolio that hedges future projected Social Security obligations contains a share of stocks that depends on macroeconomic conditions and worker characteristics.

This discussion extends to the debate about the opportunity to replace part of the existing DB U.S. Social Security system with a system of defined contributions (DC) personal accounts. If such a reform were to occur, it is possible that the private sector would take over some of the obligations that are currently guaranteed by Social Security. Geanakoplos & Zeldes (2009) offer suggestions on how to structure and trade these securities. More broadly, much work is going in computing the present value of state and municipal government pension liabilities (e.g., Novy-Marx & Raugh 2011a, b) and in understanding the risk and valuation of Federal guarantees in student loans (e.g., Lucas & Moore 2010). We point the interested reader to the review articles by Lucas (2012) and Raugh (2014) for more discussion.

3.2 Cross Sectional Heterogeneity

There is a great deal of heterogeneity in stock market participation and risky asset holdings in the U.S. population (e.g., Ameriks & Zeldes 2004, Campbell 2006). Many reasons could explain this evidence, e.g., entry costs to the stock market that vary across agents due to different education levels, heterogeneity in borrowing constraints or attitude toward risk. An

[6] See also related work by Bovenberg et al. (2007) on the interaction between life-cycle portfolio choice and investment decisions by pension funds.

alternative, complementary explanation is that human capital risk varies across individuals depending on their degree of exposure to market-wide shocks. The model in Section 2 can accommodate this possibility by allowing the coefficient of cointegration κ to vary across agents. Smaller values of κ increase the correlation between labor income and stock market shocks. This raises the component of human capital implicitly tied up in the stock market and induces the agent to favor more conservative life-cycle stock holdings (Benzoni et al. 2007).

Recent empirical work by Betermier et al. (2012) suggests that this effect could be important. Using a panel data set on Swedish households that switched industries between 1999 and 2002, they conclude that households that go from an industry with low wage volatility to one with high volatility decrease their risky asset holdings. While more work is needed to better understand the sources of heterogeneity in human capital risk, the implications for optimal portfolio choice are evident. For instance, if workers in different industries are exposed to different degrees of aggregate risk, then financial advisers should tailor their recommendations accordingly (e.g., Bodie & Treussard 2007).

Moreover, this discussion has interesting implications for general equilibrium models that attempt to explain the equity premium puzzle. For instance, Basak & Cuoco (1998) take as given that a large proportion of investors do not participate in the stock market and conclude that, under this assumption, one need only attribute reasonable levels of risk aversion to those agents that invest in stocks to explain the historical equity premium.[7] Benzoni et al. (2007) show that it is optimal for a large proportion of agents to not participate in the equity market. While their analysis focuses on the individual's optimal portfolio and consumption choices taking the equity risk premium as given, their results suggest that the exogenous specification of Basak & Cuoco (1998) might be justifiable in a general equilibrium setting that considers two classes of agents that endogenously choose to participate in the stock market depending on their risk aversion and long-run exposures to aggregate risk.

3.3 Endogenous Labor Supply

The discussion so far assumed that labor income is an exogenous process. In particular, most of the finance literature on life-cycle portfolio choice relies on model calibrations that strive to match the empirical properties of labor income without explicitly modeling the work-leisure behavior, nor the retirement decision. These choices are the focus of much work in labor economics. For instance, Ríos-Rull (1996) and Heathcote et al. (2010) propose life-cycle models of labor supply and savings in which future wages are uncertain. French (2005) augments these models to include a retirement decision and uncertain health status. French & Jones (2011) and van der Klaauw and Wolpin (2008) extend this analysis to study the effect of uncertain medical expenses and health insurance on retirement decisions (see also related work by Casanova 2010, French & Benson 2011, and Low et al. 2010). These studies fit such structural models to individual-level data and use them to conduct fiscal policy

[7] See also Mankiw & Zeldes (1991).

experiments (e.g., the effect of Medicaid or Social Security System reforms on retirement choices and life-cycle labor supply).

On the other side, there is a growing finance literature that applies similar insights to the life-cycle portfolio choice problem of an agent who faces endogenous leisure/labor trade-off and retirement decisions, e.g., Bodie, Merton & Samuelson (1992), Bodie, Detemple, Otruba, & Walter (2004), Farhi, Emmanuel & Panageas (2007). A general conclusion is that the ability to vary labor supply ex post induces the agent to assume greater risks in his portfolio ex ante. This flexibility benefits especially the young, who can smooth consumption by buffering negative shocks in asset prices over a longer working life than the old. Effectively this means that by adjusting his labor supply the agent can hedge some of the stock market risk implicit in his human capital position.

These two branches of the literature present common elements, but also some differences. Labor economists abstract from the portfolio choice problem. On the other hand, finance studies of life-cycle portfolio choice with endogenous labor supply typically consider a narrower set of microeconomic shocks, and favor model calibrations over rigorous estimation of a structural model on individual level data. Blending these ideas together is an interesting area of future research. Moreover, most of this work focuses on the decisions of an individual agent, leaving open the question as to whether the results would change in a general equilibrium framework.

3.4 Health Shocks

Individual health has a broad effect on most life-time labor market outcomes including wages, earnings, labor force participation, hours worked, and retirement. As such, the literature views health as one of the human capital components (e.g., Becker 1964). While it is intuitive that a large negative health shock can lead to a decline in life-time earnings, numerous empirical studies have struggled to gauge the magnitude of these changes.

In their survey, Currie & Madrian (1999) discuss three main issues that are important to disentangle the effect of health status on labor market outcomes. First, it is difficult to measure health shocks. Thus, the estimates differ based on measures of health being used (e.g., mental health, heart diseases, external accidents). Second, there is a vast cross-disciplinary literature that argues that individual socioeconomic status (e.g., education and wealth) determines the investment in one's health, and thus, one's health capital (e.g., Smith 1999). Third, since health and labor market outcomes are endogenous variables, estimates of the effect of a health shock on wages, and vice versa, are sensitive to the identification assumptions (e.g., Lee 1982, Haveman et al. 1994, Riphahn 1999, Au et al. 2005, Disney et al. 2006)

In general, these studies focus on the adult population to determine the relationship between health and labor market activity. But there is also growing evidence that the early childhood environment significantly influences later life outcomes. Almond & Currie (2011) provide an extensive summary of recent work. The main finding of this literature is that shocks before the age of five years lead to significant long-run consequences. In particular, poor health in childhood affects both adult health status and investments in other forms of human capital (such as education). And even a compromised prenatal environment can have long-term negative effects on future health outcomes (e.g., Almond & Mazumder 2011, Barker & Osmond 1986, Kraemer 2000). Furthermore, there is evidence that poor health in childhood is associated with reduced educational attainment as well as lower wages and labor force participation (e.g., Grossman 1975, Perri 1984, Wolfe 1985, Wadsworth 1986, and Smith 2009).

The findings of the health economics literature have important implications for life-cycle consumption and investment decisions. For instance, Yogo (2007) builds on these ideas with a life-cycle model in which a retiree faces stochastic health depreciation, which affects his marginal utility of consumption and his life expectancy. The retiree receives income (including Social Security) and chooses consumption, health expenditure, and the allocation of wealth between bonds, stocks, and housing to maximize lifetime utility. In this context, he examines the cross-sectional variation in health expenditure and wealth. The model predictions are consistent with stylized empirical facts, e.g., out-of-pocket health expenditure, as a share of income, falls in health and rises in age; financial and housing wealth, as a share of total wealth, rises in both health and age; the portfolio share in stocks rises in health; and, finally, the portfolio share in housing falls in health for younger respondents and also falls in age. Key inputs to this analysis are the dynamics of health and health insurance coverage,[8] which affect the price of health care relative to non-health consumption. Related, Koijen et al. (2013) develop a pair of risk measures for the universe of life and health insurance products, which they use to assess whether the observed demand for insurance is close to the optimal demand, given the provision of public insurance through Social Security and Medicare. Finally, Cocco & Gomes (2012) examine the effect of secular trends in longevity on optimal portfolio choice and retirement decisions.

3.5 Human Capital Investment

The idea of human capital investment, in the form of education, training, and medical care, goes back to the seminal work of Becker (1964). Many studies have shown that people with more education have higher life-time income (e.g., Attanasio 1995, Hubbard et al. 1995, and Gourinchas & Parker 2002). While the returns of school and college education investment has been thoroughly studied (e.g., Lochner & Monge-Naranjo 2012), only recently the human capital literature has started to focus on the long-term effects of early childhood education (e.g., Almond & Currie 2011 and Cunha et al. 2006). This research finds that early childhood intervention among children with disadvantaged background leads to higher test scores, decreased grade retention, decreased time in special education, decreased crime and delinquency, and increased high school graduation. This new wave of work stresses the need for a better understanding of the life cycle skill formation process. It differentiates between

[8] See, e.g., De Nardi et al. (2013).

early and late investments in human capital. Moreover, it recognizes the role of both cognitive and noncognitive (e.g., perseverance, self-control, reliability, consistency, motivation, and optimism) abilities in determining the returns to human capital (Cunha & Heckman 2008, Cunha & Heckman 2010, and Cunha et al. 2010). In this setup, the skill production technology exhibits dynamic complementarity (early investments increase the productivity of later investments) and self-productivity (the skills acquired in the early stage augment the skills acquired in later periods). These two features produce multiplier effects as skills acquired today beget more skills in the future. According to this literature, effective public policies should focus on young children's human capital investments as they have the highest return compared to investments in later years. Moreover, such policies may potentially reduce lifetime inequality as differences in early life conditions have been found to explain a significant portion of the variation in lifetime earnings and wealth (Huggett et al. 2006, 2011).

Yet, some low-income families do not make the same investment in early childhood programs as higher-income households do. One possible explanation is the presence of borrowing constraints. Indeed, an increase in family income at early childhood ages has a greater effect on educational achievement than income received at later ages (e.g., Dahl & Lochner 2012). This finding is consistent with the dynamic complementarities discussed above: Higher early investment leads to higher returns for later investments in education, while it is difficult to amend inadequate levels of early investments with higher investments later in life (Keane & Wolpin 2001, Cameron & Heckman 1998). In an overlapping generation model of human capital production, Caucutt & Lochner (2012) show that relaxing credit constraints on young parents would increase both early investments in young children and late investments in older children. In contrast, a policy that focuses on subsidizing college eduction alone might not be as effective in increasing human capital investment, as the subsidy would come too late for a credit-constrained household. The effect on future generations, however, is more ambiguous. Increased borrowing causes higher debt levels that result in parents transferring less resources to their children in the long run. This in turn could limit the ability of future generations to sustain the same increased level of human capital investment.

This discussion underscores that the timing of the human capital investment over the life cycle is important. Moreover, human capital investment has significant implications for the agent's portfolio choice problem. Early childhood investment is critical, but it is highly illiquid and requires significant time and financial costs. Parents of young children often experience credit constraints. They anticipate higher income in the future (earnings are hump-shaped over the life-cycle), but they cannot borrow against it. A young college student could find herself in a similar predicament. He trades off uncertain returns to human capital investment against upfront tuition costs and opportunity costs in terms of forgone labor earnings. To further complicate the problem, the opportunity costs vary over the business cycle, as they are often higher during an economic expansion. In either example, absent appropriate public policies the outcome could be underinvestment in human capital. To attenuate this problem, the young agent might find it optimal to reduce his risky asset holdings in favor of a liquid position in the risk-free asset (Palacios-Huerta 2003, Saks & Shore 2005, Roussanov 2010, Athreya et al. 2013). This shift in his asset shares helps to explain why young people hold little or no financial wealth in stocks (Ameriks & Zeldes 2001, Campbell 2006).

4 Conclusions

Quantitative analysis of human capital relies on the valuation of the flows of earnings and wages that an individual generates by offering his services on the labor market. Hence, a natural definition of a worker's human capital is the present value of his future labor income stream. To make this measure operational, one needs a model for the agent's labor income as well as an appropriate rate to discount uncertain future earnings.

Much of the finance literature has treated labor income as an exogenous process subject to aggregate and idiosyncratic shocks and discounted future earning at the intertemporal marginal rate of substitution of an agent who solves his life-cycle consumption and investment problem. While intuitive, this approach is very sensitive to the specification of the labor income dynamics in the model.

Most previous studies of life-cycle portfolio choice assumed that the only source of correlation between aggregate labor income and the stock market are the contemporaneous shocks. This channel finds limited support in the data, where these correlations are small or even zero. Thus, the articles that evaluated human capital in this setting found it to be 'bond like,' i.e., the component of human capital implicitly tied up in the stock market is negligible. This result has counterfactual implications for portfolio choice, as the agent finds it optimal to hedge human capital risk with a significant position in the stock market (uncorrelated shocks trigger a desire for diversification). This effect is especially strong for the young, whose wealth consists mainly of human capital. In practice, however, people invest little or nothing in the stock market when they are young, and the risky asset share is humped shaped over the life cycle.

A more general approach accommodates long run correlations between aggregate labor income and the stock market. This assumption finds support in the data (e.g., Benzoni et al. 2007) and is economically intuitive. For instance, a model with a Cobb-Douglas production function predicts that returns to physical and human capital are perfectly correlated even in the short run (e.g., Baxter & Jermann 1997). This more general model has very different implications. In the presence of co-integration between the stock and labor markets, a big fraction of the agent's human capital is implicitly tied up in the stock market, especially for the young. Consistent with empirical evidence, this property generates hump-shaped risky asset holdings.

In this article, we provide an interpretive review of these developments in the context of the life-cycle portfolio choice literature. We then extend the discussion to recent work that applies similar ideas to assess the value and risk of pension fund obligations, their funding, and the allocation of pension assets across different investment classes. Moreover, we suggest how to enrich the environment to incorporate various important ingredients. We touch upon heterogeneity in preferences; differences in the exposure to stock market risk across agents; endogenous labor supply and retirement decisions; health shocks; and human capital investment. Along the way, we expand the review with ideas for future work.

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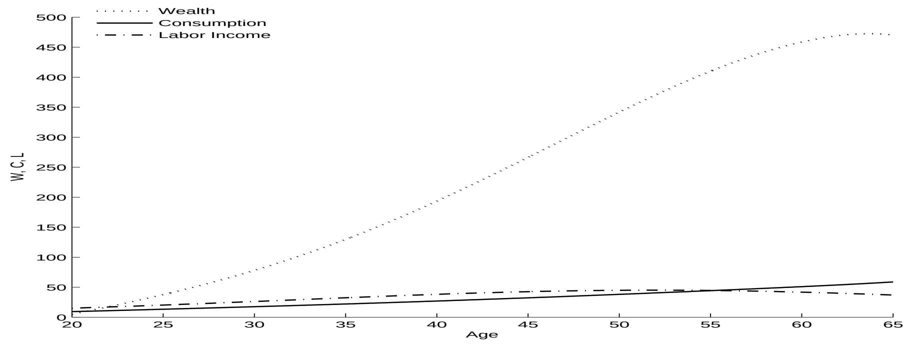
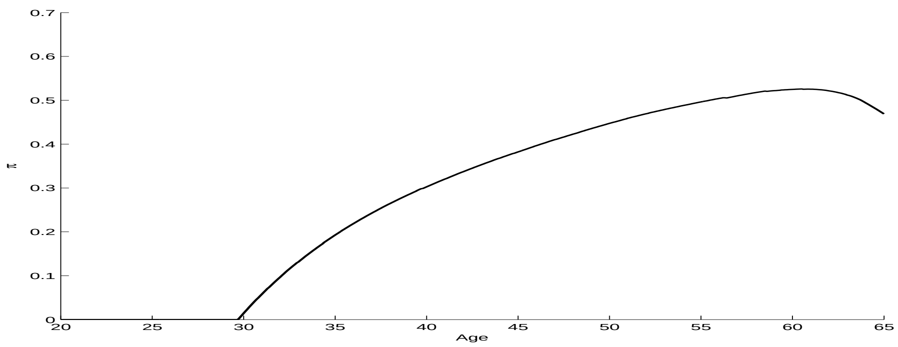


Panel A: Wealth, consumption, and labor income in 1992 USD



Panel B: Stock holdings

Figure 1: **Wealth, consumption, labor income, and stock holdings profile.** The plots depict wealth, consumption, labor income, and stock holdings over the life-cycle.

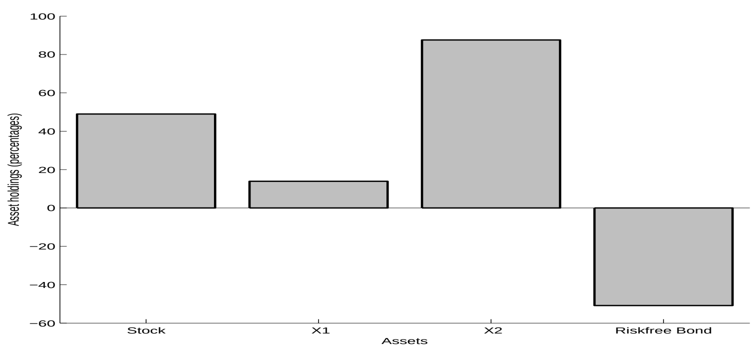
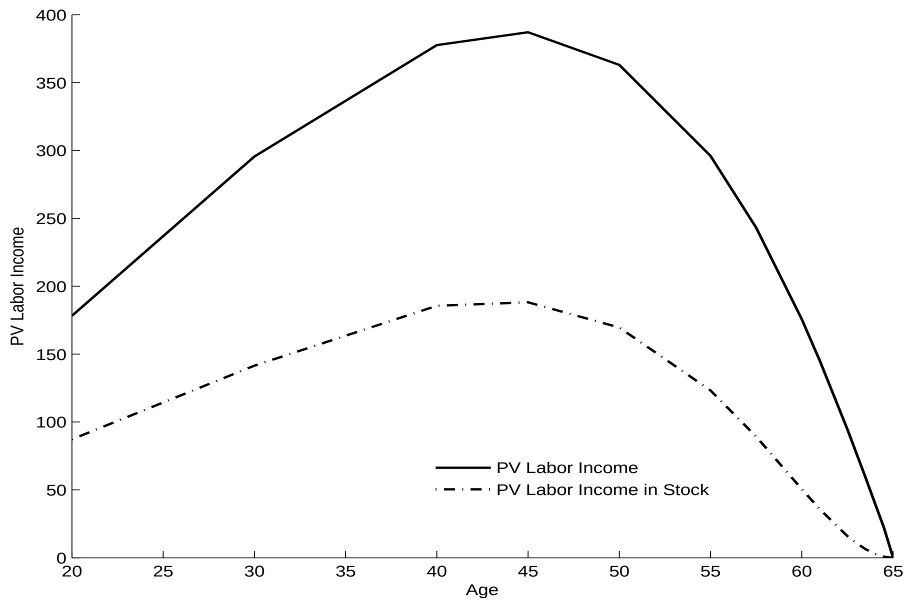
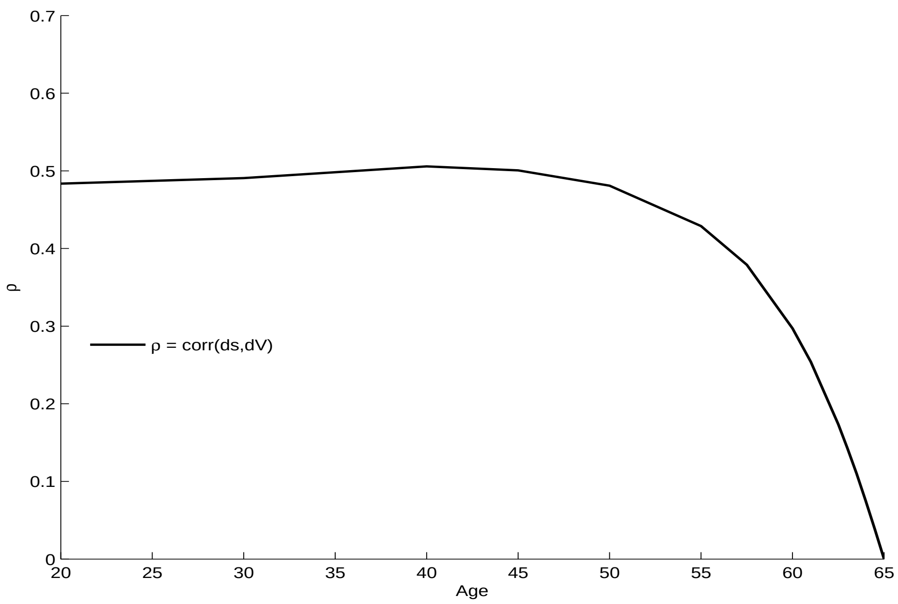


Figure 2: **The components of human capital.** The histogram depicts the investments in the various securities (risky asset S, pseudo-securities X_j, $j = 1, 2$, and risk-free money market B) that replicate the long position in human capital (that is, the present value of future labor income flows).



Panel A: Present value of labor income and present value of labor income tied up in stock



Panel B: Correlation of stock returns and returns to human capital

Figure 3: **Human capital.** The properties of human capital for the baseline case parameters.

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