THE CASE FOR INTENSIVE SKILL-BIASED TECHNOLOGICAL CHANGE

Stuart J. Fowler, Middle Tennessee State University
Jennifer J. Fowler, Belmont University

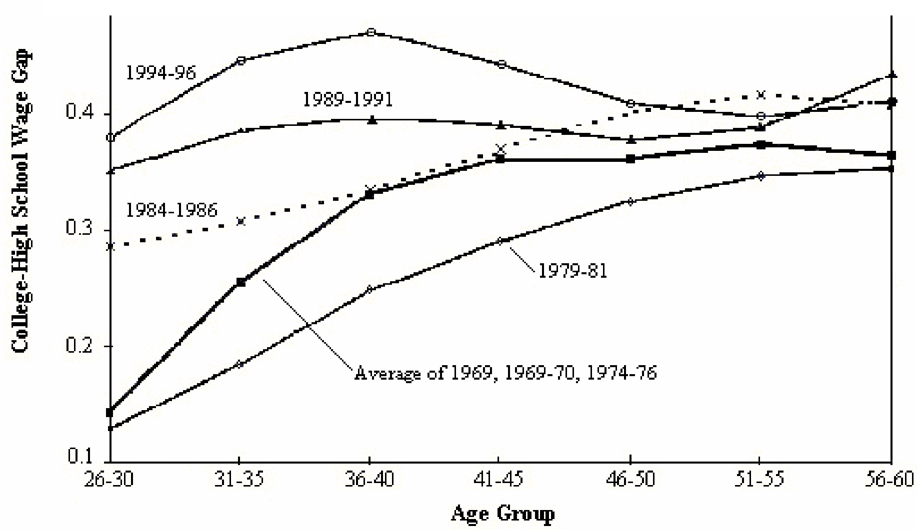
ABSTRACT

The skill-premium, defined as the relative wage of college to high-school graduates, has steadily increased over the past twenty years. Though skill biased technological change (SBTC) is generally considered to be the cause of the rise (Bound and Johnson 1992), little is known about the processes that have generated the improvements in technology. In this paper, we construct an intergenerational model of skill acquisition for the purpose of evaluating two theoretical alternative sources of SBTC. We find that intensive SBTC is necessary for the complete characterization of the observed changes in the wage premium profile. An example of intensive SBTC includes technological improvements in the actual acquisition of skills. In this case, an intertemporal substitution effect generates a reduction in the rate of skill acquisition by the old thereby replicating an important fact found in the data.

INTRODUCTION

The *skill-premium*, defined as the relative wage of college to high-school graduates, has steadily and remarkably increased over the past thirty years. Roughly, the premium has risen about 2% per year implying that the relative wage rate is three times as high as it was in 1980, the year the premium began to increase. *Skill biased technological change* (SBTC) is generally considered to be the cause (*e.g.*, Bound and Johnson, 1992; Autor, Katz, and Krueger, 1998; Guvenen and Kuruscu, 2010). In this case, technological advancements in the production of goods cause the relative marginal products of skilled to unskilled labor to rise. This form of SBTC has been examined in a dynamic general equilibrium framework by Heckman, Lochner, and Taber (1998) and has been found to explain the rising *average* skill premium reasonably well.

Figure 1: Changing Age Structure of the College-High School Wage Gap



Source: Card and DiNardo (2002), page 756.

Recently, however, the causality of SBTC has been called into question by Card and DiNardo (2002). Their argument can be found in Figure 1. They ask, why hasn't the *wage gap profile*, that represents the logged skill-premium by age, increased for every age group? Presumably, because SBTC necessarily predicts an equal change in the demand for all levels of skilled labor, Card and DiNardo (2002) label the behavior of the skill premium at cohort levels a puzzle. Though their empirics raise questions, a potential explanation can be theorized when SBTC is combined with life-cycle motives. For example, it could be the case that an increase in the return to skilled labor causes those with relatively more skills (middle to older aged workers) to economize on their skill acquisition activities thereby receiving a small wage premium. The younger workers, and therefore the less skilled, intertemporally substitute into the acquisition of skills and therefore receive a larger wage premium. The total effects of the combined lower skill acquisition rates by the old and higher skill acquisition rates by the young are a steeper skill acquisition profile and a flatter wage gap profile.

The purpose of this paper is twofold. First, we construct an intergenerational model of skill acquisition for the responses of life-cycle educational expenditures from a SBTC. The theoretical analysis employs a dynamic general equilibrium overlapping generations (OLG) model of skill acquisition drawing from Heckman (1976), Auerbach and Kotlikoff (1987), Heckman et al. (1998), Fowler and Young (2004), and Guvenen and Kuruscu (2010). The model represents an extension in one important way: the unskilled do not participate in risky capital markets. This feature replicates the well-known fact that equity ownership and education attainment are highly correlated (Haliassos and Bertaut, 1995; Bertaut and Starr-McCluer, 2002) and a large percentage of the population, roughly 43.1%, never hold risky equity assets (Mankiw and Zeldes, 1991; Guiso, Haliassos, and Jappelli, 2002).

An interesting feature that results from the model's skill acquisition sector and limited participation assumption is that biased technological improvements (in favor of skilled labor) can enter in two important ways: the final goods sector and the skill acquisition sector. If the relative productivity of skilled labor increases in the final goods sector, then the demand for skills is indirectly affected. Alternatively, if the labor's productivity in the acquisition of skills increases, then the demand for skills is directly affected. Technological change occurring through the demand for labor via the production of goods is labeled *extensive SBTC* and through the supply of labor via skill acquisition is denoted *intensive SBTC*.

Until now, extensive SBTC has been the focus of study within the literature. We find that the extensive margin alone cannot account for a flatter wage gap profile. Instead, a combination of extensive and intensive SBTC is required to replicate this puzzling empirical fact. In this case, the older aged workers economize on their skill acquisition activities while the younger workers substitute into the acquisition of skills. As predicted, the skill acquisition profile is steeper and the wage gap profile is flatter. Therefore, we make the case that intensive SBTC, and the effects it has on the acquisition of skills, is also a key for our understanding of the total effects of skill biased technological change.

The derivation of the theoretical higher education consumption profile also serves for a comparison to our second main purpose; to empirically examine the intertemporal substitution effect theory. More specifically, this paper uses the Consumer Expenditure Survey (CEX) data set to estimate the life-cycle profiles of the consumption of higher education. Changes in the education consumption profile that are consistent with an intertemporal substitution effect would necessarily imply a steepening of the skill acquisition profile; the young and old respectively increase and decrease spending on the acquisition of skills. The estimation technique employs the Heckman (1979) model of self-selection. By estimating education life-cycle profiles, and their subsequent changes over time, we document a significant steepening of the skill acquisition profile over the years 1982-2002.

The organization of the paper is as follows. Section 2 develops the OLG model of skill acquisition and of the skill premium. Section 3 quantifies the dynamics of the theoretical model. Section 4 documents the empirical methodology and data sources. Section 5 quantifies the dynamics of the empirical model. Finally, Section 6 concludes.

THE THEORETICAL MODEL OF HUMAN CAPITAL

The theoretical analysis employs an overlapping generations (OLG) model of production and skill acquisition by drawing from Ben-Porath (1967), Heckman (1976), Auerbach and Kotlikoff (1987), Heckman et al. (1998), Fowler and Young (2004), and Guvenen and Kuruscu

(2010). The OLG model allows for the replication of heterogeneity in households with respect to their age and higher education type.

Within the model, there are two types of agents that make economic decisions: households and firms. In contrast to the previous literature, access to the production and skill acquisition sector is assumed to be limited: this further distinguishes two subgroups of skilled and unskilled households. The unskilled do not to have access to capital, either human or physical, because of credit constraints; the credit constraints do not permit the acquisition of skills and thus allow us to label the credit constrained as the unskilled. As a result, skill-biased technological change may enter the model in both the skill acquisition sector and the production sector. Technological change in the production sector alters the relative productivity of good production. Technological change in the skill sector alters the relative productivity of skill attainment. Skilled biased technological change occurring through the demand for labor via the production of goods is labeled extensive SBTC and through the supply of labor via skill acquisition is denoted intensive SBTC.

At any given time the household sector comprises several generations that are overlapping. For analysis purposes, adults are defined as those individuals of college age - 18 years of age and older. Each period, one generation dies and another takes its place. Agents from generation t live for I periods, retire after $I_R \leq I$ periods, and then die. Therefore, at any point in time there is a set of agents indexed by $i \in \mathbf{I} = \{0,1,2,\ldots,I-1\}$. For simplicity, no bequests or inheritances are considered in this model. Within each age cohort, individual tastes and initial capital stocks are assumed to be identical. Thus, the use of a representative agent for each generation enables one to describe the aggregate behavior of a generation by the behavior of a single member

Skilled Households

Skilled agents in the model make lifetime decisions about consumption, saving, and leisure over their lives. Let $u(c_{t+i}^t, \ell_{t+i}^t)$ be the flow of utility from consumption, c, and leisure, ℓ, at time $t+i$ of an agent born at time t. Let lifetime expected utility of an agent born at time t be represented by

$$E_t\left\{\sum_{i=0}^{I-1}\beta^i \Psi_i u(c_{t+i}^t, \ell_{t+i}^t)\right\}, \tag{1}$$

where β is a time preference discount factor such that $0<\beta<1$ and $\Psi_i = \prod_{j=0}^{i}\psi_j$ denotes the unconditional probability of surviving up to age i with each ψ_j representing the conditional probability of surviving from age $j-1$ to j. Assume that $u(\cdot)$ is real valued, **differentiable,** strictly increasing, and strictly concave. The time endowment is normalized such that

$$1 = n^t_{1,t+i} + n^t_{2,t+i} + \ell^t_{t+i}, \tag{2}$$

where n_1 is time devoted to labor, n_2 is time devoted to human capital accumulation or skill acquisition (time spent studying). Each individual is born with an initial level of human capital or innate ability and chooses whether or not to add to the endowment, $h^t_{t+i} > 0$.

The budget constraints of a typical consumer born at time t at any time $t+i$, satisfying $I \geq i \geq 0$, are given in equation (3):

$$c^t_{t+i} + k^t_{t+i+1} \leq (1 + r_{t+i} - \delta_k)k^t_{t+i} + (1-\tau)w_{t+i}h^t_{t+i}n^t_{1,t+i} + ss^t_{t+i}, \tag{3}$$

where k represents physical capital accumulation, r is the return to physical capital, δ_K denotes the depreciation rate associated with physical capital, τ is a labor tax to fund social security benefits ss to the old, and wh is the real effective wage rate of skilled workers. Since there are no bequests and inheritances, agents invest in physical capital by consuming less in their working years than they earn in wages. Accordingly, the initial level of physical capital, k^t_t, is set equal to zero. Additionally, the old consume all goods and saving in their final period of life implying that $k^t_{t+I} = 0$.

Human capital accumulation is constrained by the following:

$$h^t_{t+i+1} \leq q^t_{h,t+i}h^t_{t+i} + q^t_{n,t+i}n^t_{2,t+i} + (1-\delta_h)h^t_{t+i}, \tag{4}$$

where δ_h denotes the depreciation rate associated with human capital. The q functions represent the marginal products for the factor inputs to human capital production. They are taken as given by each agent and defined as:

$$q^t_{h,t+i} \equiv \theta_1 \exp(a_{t+i})(h^t_{t+i})^{\theta_1 - 1}(n^t_{2,t+i})^{\theta_2}$$
$$q^t_{n,t+i} \equiv \theta_2 \exp(a_{t+i})(h^t_{t+i})^{\theta_1}(n^t_{2,t+i})^{\theta_2 - 1},$$

where θ_1 represents the *private return on the existing stock* of human capital, θ_2 measures the *private return to study hours*, h denotes existing human capital used in the production of future human capital, or the *ability to earn*, and a is an *ability to learn* parameter and represents an exogenous shift in total efficiency of human capital formation for all $i \in \mathbf{I}$ (For simplicity, the input of physical capital into the production of human capital is ignored. Although this assumption seems restrictive, one can argue that it may not be a serious problem since human capital production is likely to be relatively labor-intensive (Heckman et al., 1998; and Fowler and Young, 2004)). Because the marginal products with respect to existing human capital and skill acquisition hours of the right-hand side of equation (4) will define the returns to human capital production, we note that θ_1, θ_2, a, and h all affect the returns to human capital production. The total product is defined as the sum of the marginal products and is given by the function:

$$q(a_{t+i}, h^t_{t+i}, n^t_{2,t+i}) = (\theta_1 + \theta_2)\exp(a_{t+i})(h^t_{t+i})^{\theta_1}(n^t_{2,t+i})^{\theta_2}.$$

Unskilled Households

For the agent who is unskilled, all earned wages are consumed and no saving takes place; the agent is assumed credit constrained and thus cannot invest in human or physical capital. The general model of equations (1) – (4) is modified by:

$$\max_{\{\tilde{c}^t_{t+i}, \tilde{n}^t_{1,t+i}\}_{i=0}^{I-1}} E_t\left\{\sum_{i=0}^{I-1} \beta^i \Psi_i u(\tilde{c}^t_{t+i}, \tilde{\ell}^t_{t+i})\right\},$$

subject to:

$$\tilde{c}^t_{t+i} \le (1-\tau)\tilde{w}_t \tilde{h}^t_{t+i}\tilde{n}^t_{1,t+i} + su^t_{t+i}, \qquad (5)$$

and $\tilde{h}^t_{t+i+1} = (1-\delta_h)\tilde{h}^t_{t+i}$ where $\tilde{w}\cdot\tilde{h}$ is the real effective labor wage rate for unskilled workers. Also, τ is a social security tax rate used to fund payments su to the old households. Again, the individual has no ability to accumulate human capital beyond their initial endowment given the credit constraints; thus, unskilled human capital merely depreciates over time.

The Firm

The representative firm is assumed to be infinitely lived, behaves competitively, and maximizes the current value of the firm by renting physical capital from the old and hiring labor hours -- human capital -- from the skilled and unskilled young. Physical capital is assumed homogeneous, while labor differs in its productive ability. The firm utilizes capital and labor, both skilled and unskilled, subject to a constant elasticity of substitution (CES) production technology. More specifically, the aggregate output from a firm is produced according to:

$$Y_t \equiv F(K_t, N_t, \tilde{N}_t) = \left[\alpha K_t^{\sigma_2} + (1-\alpha)(\lambda N_t^{\sigma_1} + (1-\lambda)\tilde{N}_t^{\sigma_1})^{\frac{\sigma_2}{\sigma_1}}\right]^{\frac{1}{\sigma_2}}, \qquad (6)$$

where $K_t = \sum_{i=0}^{I-1} k_t^{t-i}$ represents aggregate physical capital, $N_t = \sum_{i=0}^{I-1} h_t^{t-i} n_{1,t}^{t-i}$ is aggregate skilled labor, and $\widetilde{N}_t = \sum_{i=0}^{I-1} \widetilde{h}_t^{t-i} \widetilde{n}_{1,t}^{t-i}$ is aggregate unskilled labor. The parameter α is the income share parameter of physical capital in total income. The parameter λ represents the income share of skilled labor in total labor income. The parameters σ_1 and σ_2 govern the elasticity of substitution between physical capital, skilled labor and unskilled labor. Specifically, $1/(1-\sigma_1)$ is the elasticity of substitution between skilled and unskilled labor, $1/(1-\sigma_2)$ represents the elasticity of substitution between physical capital and labor - skilled and unskilled.

Profits of the firm, that are to be maximized, are:

$$\pi_t = F(K_t, N_t, \widetilde{N}_t) - r_t K_t - w_t N_t - \widetilde{w}_t \widetilde{N}_t.$$

Competitive behavior by the firms ensures that factors are paid their marginal productivity. The marginal productivity conditions are given by:

$$F_1(K_t, N_t, \widetilde{N}_t) = r_t, \quad F_2(K_t, N_t, \widetilde{N}_t) = w_t, \quad F_3(K_t, N_t, \widetilde{N}_t) = \widetilde{w}_t,$$

where $F_1(\cdot) = \partial F(K_t, N_t, \widetilde{N}_t) / \partial K_t$, for example.

Characterization of the Stationary Equilibrium

Optimal behavior by the households ensures that the following Euler equations, in addition to the budget constraints, hold for each agent in each time period. Every skilled agent will have three Euler equations: (i) investment in physical capital; (ii) amount of skilled work in production; and (iii) investment in human capital - the amount of skill acquisition. The Euler equations are derived by comparing the marginal costs and marginal benefits associated with each type of consumption and saving activity.

First, the Euler equation for investment in physical capital is derived by considering the trade-off between consumption and saving. Suppose the household from generation $t-i$ invests in a unit of time t physical capital. The marginal cost is the lost time t unit of consumption; in utility this is defined as the marginal utility of a unit of consumption**:**

$$u_{1,t}^{t-i} = \frac{\partial u(c_t^{t-i}, \ell_{1,t}^{t-i})}{\partial c_t^{t-i}}.$$

In terms of marginal benefit, the agent receives the discounted gross return on capital $(1+r_{t+1}-\delta_k)$; discounted by $\beta\psi_{\tau+1}$ and the marginal utility of one more unit of consumption:

$$u_{1,t+1}^{t-i}=\frac{\partial u(c_{t+1}^{t-i},\ell_{1,t+1}^{t-i})}{\partial c_{t+1}^{t-i}}.$$

Equating marginal benefits and costs gives the Euler equation in (9):

$$u_{1,t}^{t-i}=E_t\beta\psi_{\tau+1}\left\{u_{1,t+1}^{t-i}(1+r_{t+1}-\delta_k)\right\}. \tag{9}$$

Second, the Euler equation for a skilled worker is derived by considering the trade-off between work and leisure. Suppose that the agent works one extra hour at time t. Then the marginal cost is the time t lost leisure; in utility this is defined as the marginal disutility of a unit of labor:

$$u_{2,t}^{t-i}=\frac{\partial u(c_t^{t-i},1-n_{1,t}^{t-i}-n_{2,t}^{t-i})}{\partial n_{1,t}^{t-i}}.$$

In terms of marginal benefit, the agent receives an extra hour of effective wages times the marginal utility associated with an extra unit of consumption, $w_t h_t^{t-i}u_{1,t}^{t-i}$. Equating the marginal benefits to the marginal costs gives another Euler equation (10):

$$-u_{2,t}^{t-i}=u_{1,t}^{t-i}(1-\tau)w_t h_t^{t-i}. \tag{10}$$

Third, the Euler equation for investment in human capital is derived by considering the trade-off between obtaining an additional unit of human capital and leisure. Suppose that the agent invests in one unit of time t human capital. The marginal cost is the out-of-pocket and opportunity cost associated with purchasing one more unit of human capital and the time t lost leisure; in utility this is defined as the marginal utility of a unit of human capital, $-u_{3,t}^{t-i}/q_{n,t}^{t-i}$. In terms of marginal benefit, the agent receives the discounted gross return on human capital from work $w_t q_{n,t}^{t-i}n_{1,t}^{t-i}$ discounted by $\beta\psi_{\tau+1}$ and the marginal utility of one more unit of human capital. Additionally, given the investment in human capital, it is now easier for the household to obtain future human capital - implying *learning begets learning* or that skills acquired early facilitate later learning by increasing the marginal product of n_2. The benefit of learning begets learning is the marginal product of the human capital production function, $q_{h,t}^{t-i}$. Equating the marginal benefits and costs gives (11):

$$\frac{-u_{3,t}^{t-i}}{q_{n,t}^{t-i}} = E_t \beta \psi_{t+1} \left\{ u_{1,t+1}^{t-i}(1-\tau) w_{t+1} n_{1,t+1}^{t-i} + \left(\frac{-u_{3,t+1}^{t-i}}{q_{n,t+1}^{t-i}} [q_{h,t+1}^{t-i} + 1 - \delta_h] \right) \right\} \tag{11}$$

By the same logic, one could derive the Euler equation for the unskilled worker. Since that set of workers cannot invest in either human or physical capital, there will be only one Euler equation and it is found by considering the trade-off between work and leisure:

$$-\tilde{u}_{2,t}^{t-i} = \tilde{u}_{1,t}^{t-i}(1-\tau)\tilde{w}_t \tilde{h}_t^{t-i} \tag{12}$$

Extensive versus Intensive SBTC

The parameter λ is skilled labor's share in total labor. Alternatively, we can reinterpret λ as skilled labor's share times a technological parameter that determines the productivity of the skilled. The ratio $\lambda/(1-\lambda)$ is skilled labor's relative technological progress that occurs in the production of final goods. Since firms pay labor their marginal products, the relative wage of skilled to unskilled is directly determined by $\lambda/(1-\lambda)$. Therefore, an increase in λ is a SBTC. We denote this type of technological change as *extensive SBTC.*

An interesting feature that results from the model's skill acquisition sector and limited participation assumption is that biased technological improvements (in favor of skilled labor) can enter in another important way: the skill acquisition sector. If the labor's productivity in the acquisition of skills increases, then the demand for skills is affected causing the skill premium to change. Technological change occurring through the supply of labor via skill acquisition is denoted *intensive SBTC*. Intensive SBTC can occur from changes in the set of parameters $\{h_t^t, \theta_1, \theta_2, a_t\}$.

An example of the extensive type of technological change may be the introduction of computers; the productivity of skilled-workers, who most likely use the technology, increases relative to the unskilled (Johnson 1997). Intensive skill-biased technological change arises in the skill acquisition sector and occurs when the marginal product of skilled workers increases without necessarily decreasing the marginal product of unskilled workers. An example of this type of technological change may be the introduction of the Internet at campus libraries. The actual acquisition and, potentially, the retention of skills become more efficient.

Calibration

Calibration of the model requires the length of the life-cycle, a functional form for utility, and a variety of parameters to be set. The parameters form four groups: preferences, production, skill acquisition, and policy. Table 1 below provides a listing of the initial model parameters, descriptions, and values.

First, the length of the life-cycle, I, must be determined. In the OLG literature, agents typically make economic decisions over a 63-year period with retirement beginning at age 66. For this analysis, economic life starts at age 18, which implies that the terminal age is 80. To keep computation of the equilibria manageable, however, the life-cycle is condensed. Because few people graduate from college in less than 5 years, each period in the model chosen represents a 5-year time span. As such, the length of the life-cycle becomes $I = 12$ periods. Each agent dies at age 77 or at the end of period 12. For the skilled, retirement is assumed to begin at age 63, or at the end of period 9. Retirement represents the three periods where skilled labor hours are exogenously set to zero, $n_{1,t}^{t-10} = n_{1,t}^{t-11} = n_{1,t}^{t-12} = 0$. As a result of the exogenously set retirement age, skill acquisition hours stop after period eight since workers would not have enough time to be in the labor force to make skill acquisition worthwhile; thus, $n_{2,t}^{t-9} = n_{2,t}^{t-10} = n_{2,t}^{t-11} = n_{2,t}^{t-12} = 0$. These assumptions are also made for the unskilled; the unskilled are required to retire at the end of period 9.

Table 1: Baseline Model Parameters, Descriptions, and Values	
Parameter	**Description**
Preferences	
$\mu_1 = 1$	Arrow-Pratt measure of risk aversion
$\mu_2 = 2 = 1$	Determines the intertemporal labor supply elasticity
$\varphi = 1.225$	Weight parameter on leisure
$\beta = 0.8626$	Discount factor for time preferences
Production	
$\sigma_1 = 0.3333$	Determines demand elasticity of substitution between skilled and unskilled labor
$\sigma_2 = -0.05$	Determines demand elasticity of substitution between physical capital and labor
$\alpha = 0.34$	Share of physical capital to total labor
$\lambda = 0.51$	Share of skilled labor to total labor
$\delta_K = 0.266$	Depreciation rate of physical capital, 6% per year
= 0	Initial level of physical capital
Skill Acquisition	
$\theta_1 = 0.52$	Private return on existing human capital stock
$\theta_2 = 0.52$	Private return on study hours
= 13.62	Initial level of human capital of skilled
= 9.53	Initial level human capital of unskilled
= 0	Ability to learn
$\delta_h = 0.00005$	Depreciation rate of human capital

Table 1: Baseline Model Parameters, Descriptions, and Values	
Parameter	**Description**
Policy	
$\tau = 0.124$	Social Security tax rate

Preferences utilizing the conventional power utility specification are chosen:

$$u(c, n_1, n_2) = \frac{c^{1-\mu_1}}{1-\mu_1} + \varphi \frac{(1 - n_1 - n_2)^{1-\mu_2}}{1-\mu_2}.$$

The separable form of utility is chosen for two main reasons: (i) it permits one to separate the intertemporal elasticities of consumption and leisure; and (ii) it is commonly used in the dynamic macroeconomic literature (*e.g.*, Heathcote, Storesletten, Violante, 2004). The parameter μ_1 represents the Arrow-Pratt coefficient of relative risk aversion. The parameter's value is restricted to the limiting case where $\mu_1 = 1$ so that preferences will be consistent with balanced growth. As μ_1 approaches 1, the consumption portion of the utility function collapses to the log of consumption. The parameter μ_2 determines the intertemporal labor supply elasticity; setting $\mu_2 = 2$ falls within the range of existing estimates found in the micro and macro literature (Browning et al. 1999). Following Heathcote et al. (2004), the parameter φ denotes the weight parameter on leisure and is set such that the average fraction of time devoted to work is roughly 0.33; this results in a value of $\varphi = 1.225$. A value is needed to discount preferences over time; $\beta = 1/(1.03)^5 = 0.8626$ is chosen to be compatible with a yearly psychological rate of three percent. The survival probabilities are estimated by converting the annual mortality probabilities from the U.S. Life Tables of the National Center for Health Statistics (1992) to the $I = 12$ life-cycle. The values for survival probabilities are presented in Table 2.

Table 2:Calibrations for Survival Probabilities			
$\Psi_0 = 1.00000$	$\Psi_1 = 0.99819$	$\Psi_2 = 0.99731$	$\Psi_3 = 0.99717$
$\Psi_4 = 0.99306$	$\Psi_5 = 0.98510$	$\Psi_6 = 0.97070$	$\Psi_7 = 0.95365$
$\Psi_8 = 0.92483$	$\Psi_9 = 0.87436$	$\Psi_{10} = 0.81549$	$\Psi_{11} = 0.73835$
$\Psi_{12} = 0.63981$			

As indicated in equation (6), production has five main parameters to calibrate, σ_1, σ_2, δ_k, α, and λ. The parameter σ_1 represents the demand elasticity of substitution between skilled and unskilled labor. This value is set at $\sigma_1 = 0.3333$ giving an elasticity of 1.5, consistent with estimates found in the literature (*e.g.*, Browning et al., 1999; Autor, Katz, and Kearney, 2008). Krusell, Ohanian, Rios-Rull, and Violante (2000) estimate the parameter governing the demand elasticity of substitution between capital and labor at $\sigma_2 = -0.05$, resulting in an elasticity of substitution close to 1 that is not too different than the Cobb-Douglas specification between capital and labor ($\sigma_2 = 0$) found by Heckman, et al. (1998). As a consequence, α is roughly capital's share of output which Heckman et al. (1998) report at $\alpha = 0.34$. Next, the value for depreciation of physical capital is needed; $\delta_k = 1-(1-0.06)^5$ which implies a six percent annual depreciation rate, an average of the estimates most commonly found in the dynamic macroeconomic literature. The remaining parameter of the production function λ is set to match the wage premium for the beginning of the 1980's decade of approximately 1.30 (Card and DiNardo, 2002) which gives a share of skilled labor in total labor of $\lambda = 0.51$.

A final group of parameters is needed for skill acquisition. As stated previously, the parameter θ_1 represents the private return on the existing stock of human capital while the parameter θ_2 measures the private returns to study hours. There is a wide range of estimates found in the literature (*e.g.*, Ben-Porath, 1967; Heckman, 1976; Rosen, 1976; Browning et al., 1999). The two parameters are restricted by $0 \le \theta_1 < 1$ and $0 \le \theta_2 \le 1$ so as to guarantee that the human capital production function is concave in the control variables. Because we conduct comparative statics on these parameters, we utilize the lower end of the parameter estimates listed in Browning et al. (1999): $\theta_1 = \theta_2 = 0.52$. The initial levels of skilled and unskilled human capital must be set. The skill levels are set according to those identified by Heckman et al. (1998). Initial skilled human capital is set to $h_t^t = 13.62$ and unskilled human capital is set to $\widetilde{h}_t^t = 9.53$. Estimates for a and δ_h are needed to complete the calibration of skill acquisition. The ability to learn parameter is initially set to $\overline{a} = 0$. The level of human capital depreciation is initially set very close to zero, $\delta_h = 0.00005$ to allow for some loss in skill if human capital is not developed.

The current U.S. social security payroll tax is 12.4% implying $\tau = 0.124$. Though the program is pay-as-you-go, benefits are tied to contributions so as to guarantee a specific replacement rate of return. We take this to imply that the social security contributions of the skilled are used to fund the retired skilled work force; they are equally split between the three oldest generations of skilled retirees. Likewise, the contributions of the unskilled are used to fund the retirement of the unskilled workers; they are equally split between the three oldest groups of unskilled retirees.

MODELING RESULTS

Using the initial calibrations identified in Table 1, the baseline model is solved. Because the baseline results will be used as comparison for the forthcoming experiments, it is important to assess the model's performance. First, Table 3 shows that the model is able to replicate,

$$\tilde{w}_{i,t} = \tilde{w}_t \tilde{h}_{i,t}$$

roughly, aggregate labor hours. Though skilled workers do not work as many hours as unskilled workers (their human capital is more valuable and brings a higher wage rate), the average time spent in goods production is (31.33 + 34.75) / 2 = 33.04%. Consumption is rather unequal; the implied Gini coefficient for skilled to unskilled consumption is 26%. In the data, the U.S. consumption Gini is in the range of 25-29% (Blundell 2006). Given that the skilled investment in human capital is about 3.28% of total consumption (0.0417 / (0.0417+1.2283) = 0.0328), human capital non-trivially increases with age to 15.054 from the initial starting point - the acquisition of skills is an important margin of choice for the skilled. Finally, the average skill premium of 1.308 is consistent with that reported by Card and DiNardo (2002). Recall that skill-specific wages are given by: $w_{i,t} = w_t h_{i,t}$ and $\tilde{w}_{i,t} = \tilde{w}_t \tilde{h}_{i,t}$. The wage gap, or the logged skill premium, is defined as: $log(w_{i,t}/\tilde{w}_{i,t}$

Table 3: Selected Steady State Allocations – Baseline	
Measure	Mean
Skilled Labor Hours	0.3133
Unskilled Labor Hours	0.3475
Skilled Consumption of Goods	1.2283
Unskilled Consumption of Goods	0.7199
Skill Acquisition Expenditures	0.0417
Human Capital	15.054
Skill Premium	1.3088

Figure 2 illustrates the steady-state profiles of the baseline model. Figure 2(a) shows that consumption exhibits the typical hump shape consistently found in the life-cycle literature. The implication is that households do not perfectly smooth consumption by age. This is a direct result of the assumption of no income insurance markets. Skill acquisition expenditures, Figure 2(b), appear to be consistent with economic logic and with those found throughout the literature as well. For example, as one ages there is less time to recoup the benefits of additional years of schooling. As such, it makes sense that spending on higher education services (*i.e.*, skill acquisition expenditures) should fall with age. Given that the young are relatively poor in human capital, it is not surprising to see human capital, Figure 2(c), rise with age as well as the logged skill premium, panel (d). The wage gap corresponds nicely to Figure 1that is taken from Card and DiNardo (2002).

The next step is to evaluate the effect of changes in skill-biased technology; the following several paragraphs accomplish this task. The first experiment adjusts the baseline model by increasing λ from 0.51 to 0.561; roughly a 10% increase. Figure 3(a) plots the effects of this extensive SBTC on the wage premium. As expected, the relative marginal product of skilled workers increases for all ages. As a result, the wage gap increases uniformly across age. The impact on the average wage gap is about 28%, increasing from 0.308 to 0.596. Although the increase in λ is relatively small, the impact on the wage premium is large but consistently within the range of skill premiums in the literature (Card & DiNardo, 2002; Krueger, 2003). Figure 4(a) plots the effect of increasing λ by 10% on skill acquisition expenditures. We see for the young, skill acquisition expenditures rise; this is a substitution effect. Apparently, the higher relative wages from having skills induces the young to substitute into the acquisition of skills.

Figure 2: Steady State Profiles for the Baseline Model

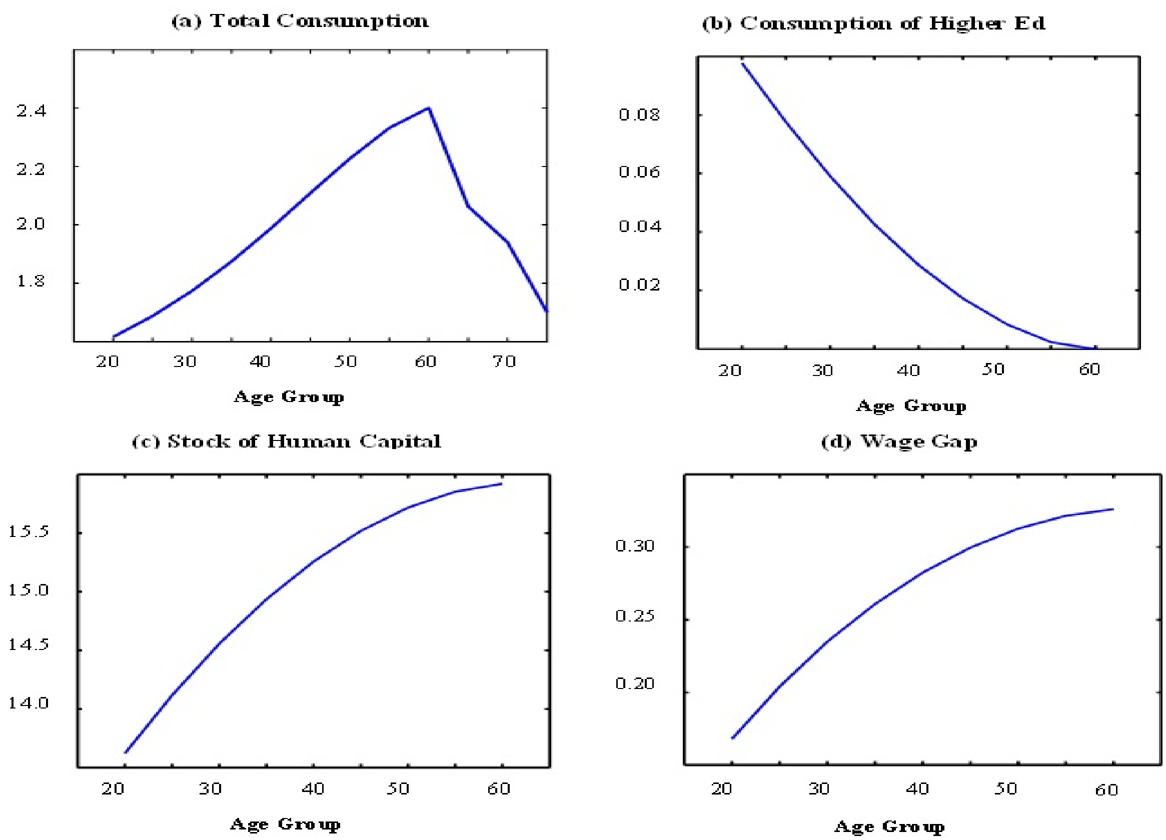


Figure 3(b) plots the effect on the wage gap of a 10% increase in the initial stock of skilled human capital (the ability to earn). The higher level of human capital increases the wage gap evenly across all age groups. However, the average increase in the wage premium is about 3% implying that the extra supply of human capital somewhat diminishes the skilled-to-unskilled wage. Presumably, the combination of increased supply of skilled labor and increased productivity of the unskilled (since they are complements) causes $\log(w_{i,t}/\tilde{w}_{i,t})$ to fall. Figure 4(b) shows the effect on human capital expenditures; there is little to no change in expenditures on higher education. This total effect is due two competing intermediate effects cancelling. In the first case, the extra initial human capital increases the wage return of an additional human capital unit and, as a result, the household demands more human capital. Alternatively, the marginal product of the actual return to skill production falls since $\partial q_h / \partial h < 0$. As a result, both effects cancel thus leaving consumption of higher education unchanged.

Now consider the effects of a 10% increase to the private return on the existing stock of human capital θ_1. Figure 3(c) plots the effects of this type of intensive SBTC; we see that the wage gap starts below and then rises above the existing profile. The increase in the private rate of return on existing human capital increases the acquisition of human capital; this is confirmed in Figure 4(c). The increase in skilled human capital has three competing effects. First, the increase in human capital increases the wage for the unskilled, $\tilde{w} \cdot \tilde{h}$, as they are relative complements to the skilled. Second, because the skilled wage rate, w, is a decreasing function of skilled human capital, the wage for the skilled falls. Alternatively, for a given skilled wage rate, the effective skilled wage rate, $w \cdot h$, increases. In total, the young skilled - who are relatively human capital poor - see their relative wage fall since they have not accumulated enough human capital to offset the negative effects on their relative wage rate.

Figure 3(d) plots the effects of a 10% increase to the private return on study hours θ_2. The wage gap starts above and falls below the existing profile. Because study hours are more effective, the household can shift more time into leisure activities; this is an *income* effect. The shift into leisure activities is evident in Figure 4(d) where investment in human capital falls for all age groups. As a result, the skilled enjoy the increase in study hour productivity when they are young. Those with relatively more skills (middle to older aged workers) see a lower skill premium since they economized on their skill acquisition activities when they were young.

Figure 3(e) plots the effects on the wage gap of a 10% increase to the ability to learn a. Just like the increase in the private return on the existing stock of human capital in Figure 3(c), the wage gap starts below and rises above the existing profile. Again, the increase in the productivity of human capital acquisition has three competing effects. The resulting effect is that the young see their relative wage fall since they have not accumulated enough human capital to offset the negative effects on their relative wage rate.

Figure 3: The Effects of Different Types of SBTC on the Wage Premium

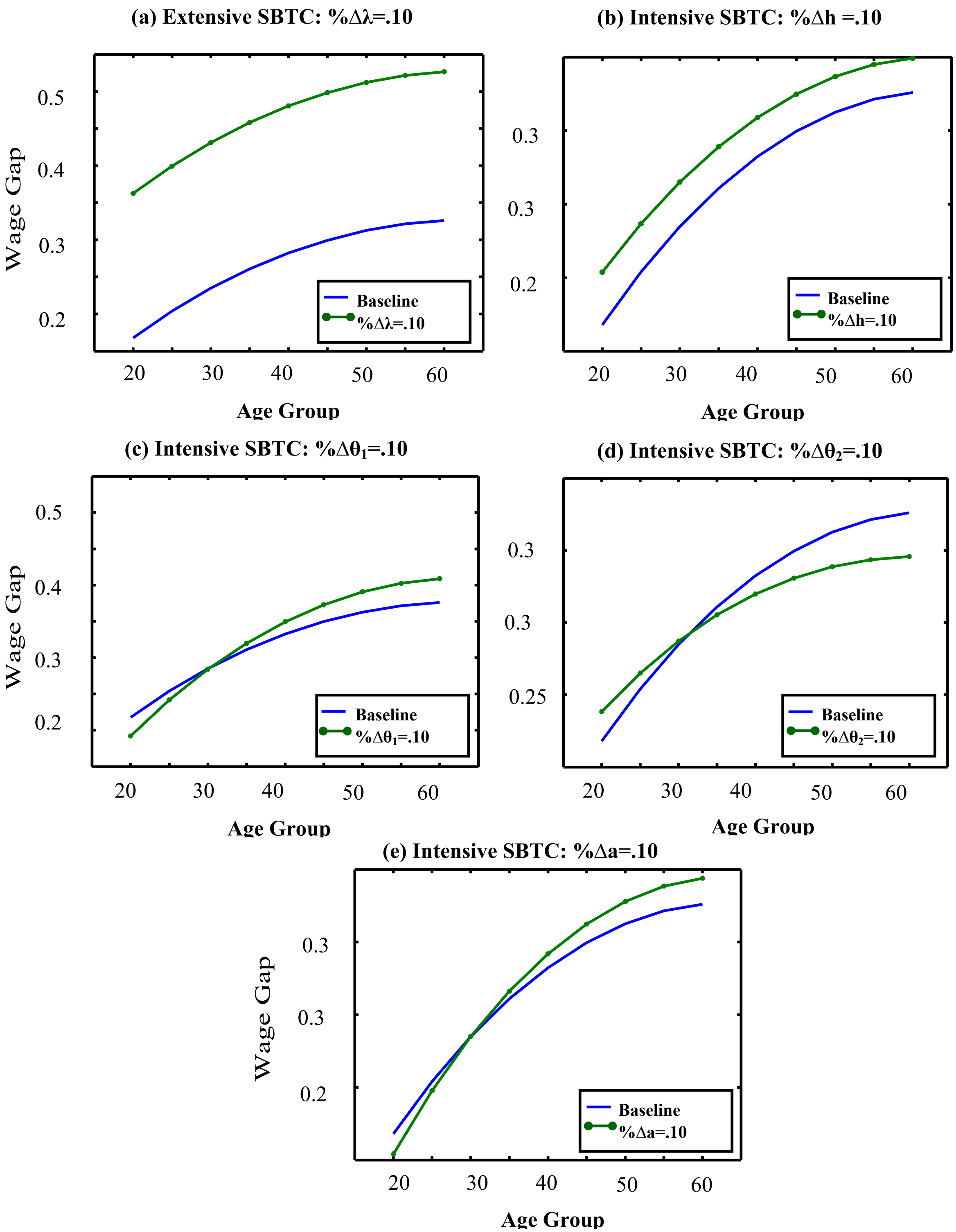


Figure 4: The Effects of Different Types of SBTC on Skill Acquisition

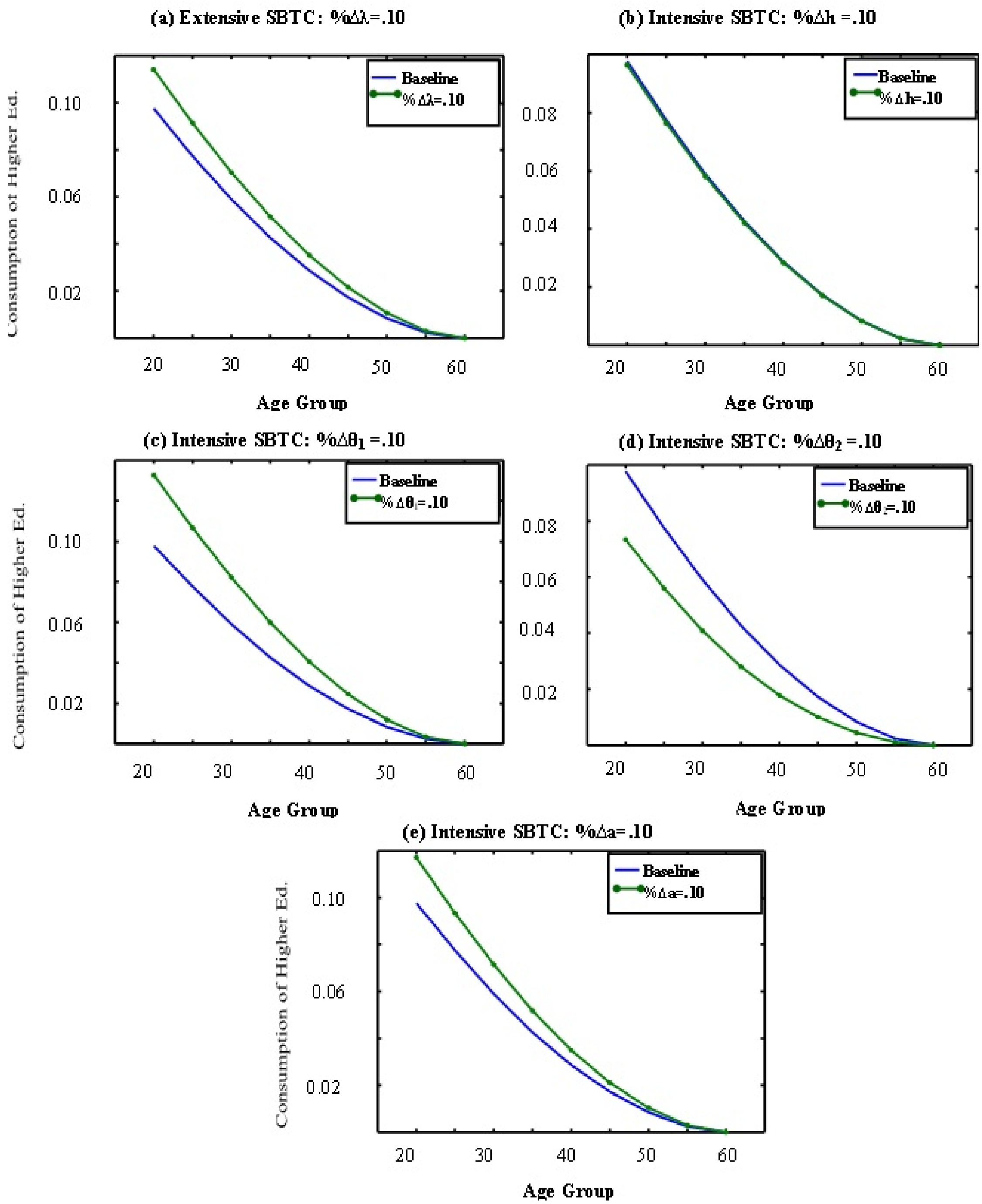
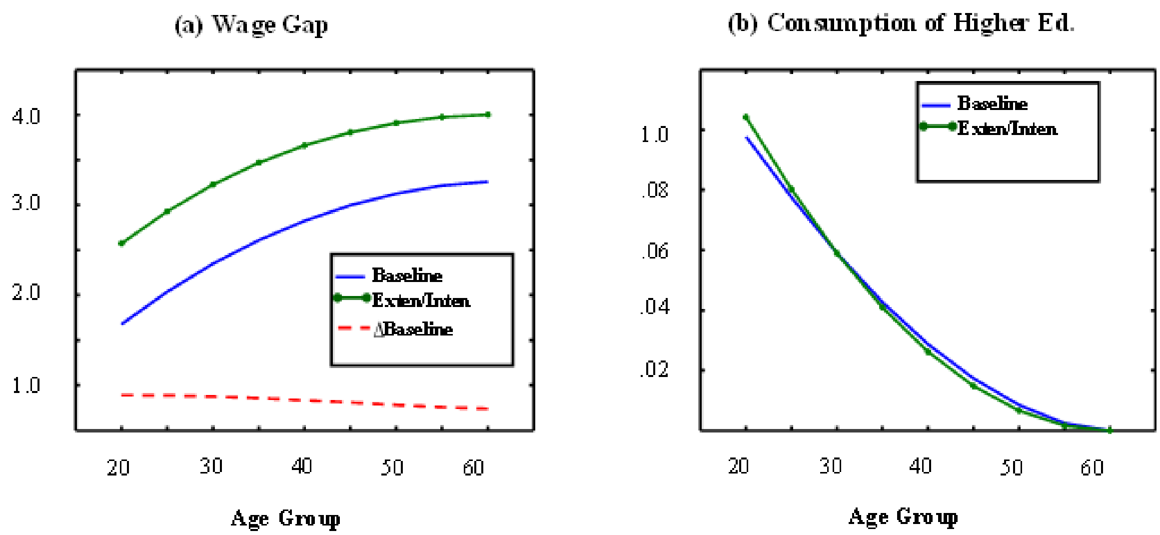


Figure 5: The Effects of Combined Types of SBTC on the Wage Premium & Skill Acquisition



Now consider Figure 5 that plots the effects of a combination of different types of SBTC. More specifically, we increase λ by 5% and increase θ_2 and a by 10%. Figure 5(a) shows that the wage gap profile shifts up at an unequal rate. More specifically, the increase in relative wages is larger for the young than the old. Figure 5(b) shows that the unequal shift in the wage gap is attributed to the fact that each household intertemporally substitutes their consumption of higher education more towards their younger years. The fact that the rate of return to human capital is higher causes the young the increase hours of study time. Alternatively, the old substitute away from study hours and presumably into consumption and leisure.

Graphically, it is apparent that the extensive SBTC parameter has the greatest impact on the skill premium and its associated wage gap. But, in terms of the empirical facts of the wage gap, extensive and intensive SBTC alone do not provide an answer to Card and DiNardo's (2002) critique of the SBTC hypothesis found in Figure 1; namely that the wage gap changes very little in older age groups. Instead, a combination of *both* extensive and intensive SBTC is needed to account for the flattening of the wage gap profile.

THE EMPIRICAL MODEL OF HUMAN CAPITAL ACQUISITION

The theoretical results show that household spending on higher education services shifts when SBTC occurs. Though a variety of macroeconomic studies have estimated life-cycle consumption profiles (Gourinchas and Parker 2002; and Fernandez-Villarverde and Krueger

2002), none have specifically focused on higher education expenditures and, if they exist, shifts across the life-cycle. Thus, our study builds upon the work of Gourinchas and Parker (2002) and Fernandez-Villarverde and Krueger (2002) - who estimate reduced form demands for consumption excluding higher education services - and extends their framework to the consumption of higher education.

The Data

To develop and estimate the higher education consumption profiles and subsequent changes over time, a variety of data sources are utilized. First, and foremost, U.S. Bureau of Labor Statistics' (BLS) Consumer Expenditure Survey (CES) is utilized to gather spending and demographic data on households. The CES has the best available data on household consumption. Approximately 5,500 households are interviewed quarterly across the United States. Each household remains in the survey for four consecutive quarters after which they are rotated out and replaced by a new household - also called a rotating panel. The data used cover the time period of 1982:1-2002:4; a time frame consistent with Card and DiNardo (2002). Next, the BLS average U.S. regional unemployment rates are used to proxy business cycle effects. Finally, the BLS's regional Consumer Price Index - All Urban Consumers 1982-1984 base year - is used to deflate all dollar denominated data.

We make several modifications to the data. First, we drop the households that do not complete all four quarterly interviews. This reduces the sample to about 78,431 households. Second, the CES asks each member of the household if they are enrolled in college and an acceptable missing response is reported if the family member is not qualified for college. For example, a missing response is reported for a two year old as well as a 70 year old who has not completed high school. Households who do not have at least one qualified member for each quarter are dropped from the sample leaving 67,726 households.

A plot of real higher education expenditures by age of the head of household would not necessarily give the skill acquisition profile of an individual - an empirical profile would presumably be upward sloping for certain age groups. There are two main reasons why spending on higher education may be upward sloping. First, spending by households most likely includes spending on other family members who would be of college age further into the head's life-cycle. Second, part-time student enrollments have a clear humped shaped pattern with a distinct peak; the peak occurs in the late twenties.

Therefore, for identification of the individual and full-time skill acquisition profile, we jointly pursue two identification strategies. In the first, we identify the members of the family who are in college. Though the CES only gives family expenditures on higher education (aggregated), the *incol* variable allows us to model the aggregation of the individual to the family level. Specifically, because the family members enrolled are identified, we are able to compute the average age of family members enrolled (*age1*) so that it may be related to the average real spending, relative to those enrolled, on higher education (*hied1*). Real spending on higher education is defined as tuition for college plus school books, supplies and equipment for college all deflated by the price index. In the second part of the strategy, we identify those individuals who are part-time students (*part1*) from the *incol* variable. Then, the *part1* variable is interacted with the age of the enrolled member, *age1,* so as to compute the average age, relative to those enrolled, of part time students (*age1part1*). The next section more formally describes the estimation model.

Figure 6 illustrates the average real higher education expenditures of enrolled students, *hied1*, by the average age of enrolled students *age1* for the time periods of 1982:1 to 2002:4. The data used for Figure 6 were split into 11 age cohorts, meaned by decade, by spenders (those households who spend on higher education), and by full-time students. The data anecdotally verify that real spending has consistently increased over the periods 1982:1-1992:2 to 1992:3-2002:4 for most, but not all, age groups. In fact, the old have appeared to decrease their spending.

Figure 6: Mean Household Higher Education Expenditures

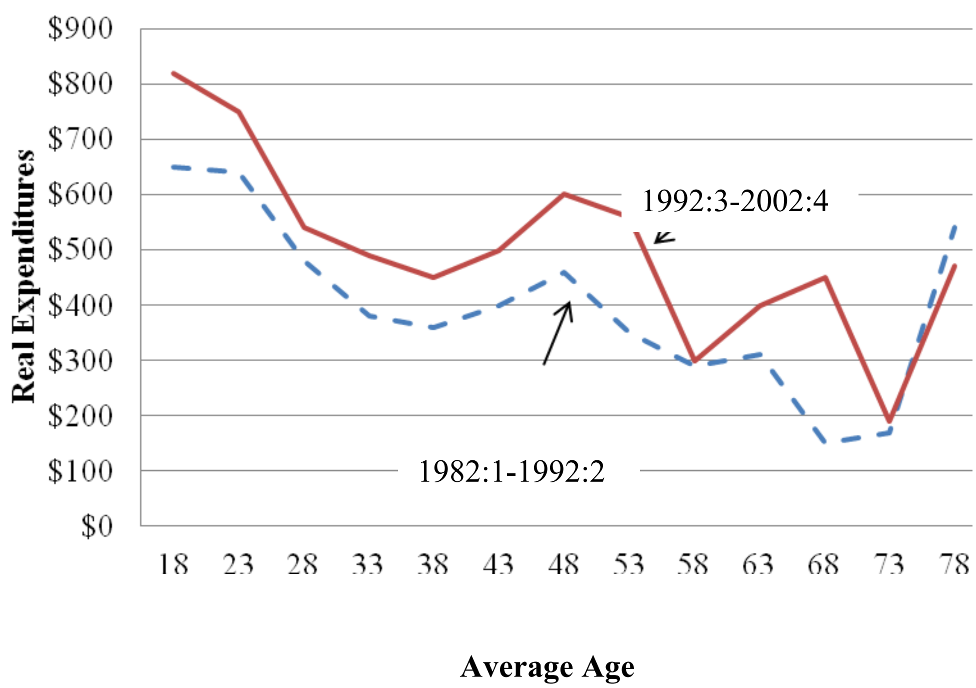


Table 4 lists the other variables that are extracted from the data sets for the purpose of identification of the skill acquisition profile. Most variable descriptions are self-explanatory but some may need further explanation. The variable *childeq0* represents a scale of the number of children age 18 and under in each household. Employing a methodology similar to Fernandez-Villaverde and Krueger (2002) and Browning and Ejrnæ s' (2002), a household equivalence scale, *childeq0*, is estimated for family j of size $famsize_j$ as follows:

$$childeq0_{j,t} = \sum_{i=1}^{famsize_j} \left(\mu_0 + \mu_1 \left(\frac{age_i}{18} \right) + \mu_2 \left(\frac{age_i}{18} \right)^2 + \mu_3 \left(\frac{age_i}{18} \right)^3 \right) (1 - d_i)$$

where age_i is equal to the maximum of the i'th family member's age or 18, $\{\mu_0, \mu_1, \mu_2, \mu_3\}$ is the set of child response parameters used to approximate the age effects of children, and d_i is a zero-one dummy representing an adult when age_i is greater than 18. Note that if the individual age is greater than 18 years old, then $d_i = 1$. The restriction $\mu_3 = 1 - \mu_0 - \mu_1 - \mu_2$ is imposed so that the function is continuous. Employing estimates from Browning and Ejrnæ s (2002), the child response parameters have the following values: $\mu_0 = -0.091$, $\mu_1 = 2.469$, and $\mu_2 = -5.73$.

Table 4:Descriptive and Summary Statistics of Data

Variable	Description	Mean: All HHS	Mean: Spenders
Dependent Variables:			
hied0	0/1: higher education participation	0.051	1.000
hied1	Real average household spending on higher education	29.393	572.157
Family Variables:			
age0	Age of head of household	48.309	42.124
age02	Squared age of head of household	2592.70	1923.42
mwst0	0/1: live in urban Mid-West	0.249	0.244
sth0	0/1: live in urban South	0.274	0.253
west0	0/1: live in urban West	0.221	0.272
rural0	0/1: rural residence	0.097	0.072
blk0	0/1: black head of household	0.097	0.073
othrc0	0/1: other than Caucasian or black race head of household	0.037	0.061
fem0	0/1: female head of household	0.353	0.309
mar0	0/1: married head of household	0.634	0.695
nohs0	0/1: no high school diploma for head of household	0.092	0.048
hs0	0/1: only high school diploma for head of household	0.351	0.174
childeq0	Number of equivalent children in household	0.280	0.290
colage0	Number of college-age people in household, excl. head	0.998	1.498
dyr0	0/1: indicator of time: 1992:3-2002:4	0.557	0.497
age0dyr0	Interaction: age of head of household and time	27.358	20.870
age02dyr0	Interaction: squared age of head of household and time	1489.02	948.635

Table 4:Descriptive and Summary Statistics of Data			
Variable	Description	Mean: All HHS	Mean: Spenders
Member Variables:			
age1	Average age of household members enrolled in college	1.459	28.391
age12	Average squared age of household members enrolled in college	46.875	912.450
age13	Average cubed age of household members enrolled in college	1714.38	33371.62
part1	Fraction of members enrolled in part-time college	0.020	0.393
age1part1	Interaction: age of member and enrolled in part-time college	0.691	13.450
age12part1	Interaction: squared age of member and enrolled in part-time college	26.074	507.552
age1dyr0	Interaction: age of enrolled member and time	27.358	20.870
age12dyr0	Interaction: squared age of enrolled member and time	24.027	467.711
age13dyr0	Interaction: cubed age of enrolled member and time	891.723	17358.00
Regional B.C.Variables			
uer2	Average regional unemployment rate	0.060	0.061
Weight Variable:			
enroll3	Average number of members enrolled in college	0.062	1.209
Households: 67,726. Total observations: 270,904. Spending on higher education observations: 13,917.			

METHODOLOGY

In order to generate higher education consumption profiles, this empirical analysis centers on a hierarchical application to the sample selection model of Heckman (1976). By utilizing a sample selection model (Heckit), two types of parameters are estimated. For the first type, a probit model - using all households - estimates the probability of household higher education participation. For the second type of parameters, a linear model is utilized to find the marginal effects of demographic and descriptive variables on the consumption of higher education. Consumption profiles are then generated from the linear model results.

More specifically, the j'th family's choice to participate is given by the following discrete choice model:

$$y_{j,t} = 1[\mathbf{w}_{j,t}\boldsymbol{\theta}_1 + \mathbf{z}_{j,t}\boldsymbol{\theta}_2 + \varepsilon_{j,t} > 0] \tag{13}$$

where $y_{j,t}$ is one if the household spends on college (*hied0*), $\mathbf{w}_{j,t}$ includes the age of the head of household (*age0*), no high school diploma for the head (*nohs0*), to name just a few, and the $\mathbf{z}$ is a vector of exogenous variables used to proxy business cycle effects that includes a regional unemployment rate (*uer2*).

Let $c^i_{j,t}$ be defined as real higher education consumption by individual i from family j at time t. Then, for an individual i who is enrolled in college and spending on college, we specify an equation that relates consumption of higher education to age by:

$$\begin{aligned} c^i_{j,t} = \beta^0_{j,t} + \beta^1_{j,t} age^i_{j,t} + \beta^2_{j,t}(age^i_{j,t})^2 + \beta^3_{j,t}(age^i_{j,t})^3 + \\ \beta^4_{j,t} part^i_{j,t} + \beta^5_{j,t} part^i_{j,t} age^i_{j,t} + \beta^6_{j,t} part^i_{j,t}(age^i_{j,t})^2 + u^i_{j,t}, \end{aligned}$$

where $age^i_{j,t}$ is the time t age of individual i (less 18) from family j who is enrolled in college, $part^i_{j,t}$ is a discrete variable equal to 1 if the individual has indicated enrollment is part-time, and $u^i_{j,t}$ is an unobserved transitory shock that is independently, identically (across families), and normally distributed: $u^i_{j,t} \sim N(0, \sigma^2_u)$. In matrix form, we write the above equation as:

$$c^i_{j,t} = \mathbf{x}^i_{j,t} \boldsymbol{\beta}_{j,t} + u^i_{j,t}. \tag{14}$$

Additionally, following a typical hierarchical approach, the parameters in $\boldsymbol{\beta}_{j,t}$ are related to family characteristics by the following relationship:

$$\boldsymbol{\beta}_{j,t} = \mathbf{w}_{j,t} \boldsymbol{\gamma} + \varepsilon_{j,t}$$

where $\varepsilon_{j,t} \sim N(0, \sigma^2_{j,\varepsilon})$ and γ are fixed coefficients to be estimated.

Unfortunately, the CEX does not give $c^i_{j,t}$. Instead, in any time period, the CEX provides total household spending on higher education. Given that the *incol* variable gives the total number of members of family j enrolled in college ($n_{j,t}$), we divide equation (14) by $n_{j,t}$ to yield:

$$c^i_{j,t} / n_{j,t} = \mathbf{x}^i_{j,t} / n_{j,t} \boldsymbol{\beta}_{j,t} + u^i_{j,t} / n_{j,t}.$$

Or, alternatively,

$$\bar{c}_{j,t} = \mathbf{x}_{j,t}\boldsymbol{\beta}_{j,t} + \bar{u}_{j,t} \tag{15}$$

where the bars indicate that the variable has been meaned across those enrolled in college. Equations (13) and (15) form the base likelihood model for our regressions. The number of members enrolled in college is used to weight the regression since the variance of the error is a function of $n_{j,t}$. Also, the standard errors are robust and clustered on the household.

Notice that we include the business cycle variable in equation (13) but not in (15). Although the state of the business-cycle is important in the initial participation stage, one can argue that once the decision to participate in higher education is made the state of the economy is no longer an important determinate of spending. While many people have the option of purchasing as few as one class per semester, significant enrollment costs in most U.S. universities place a floor on the dollar cost of attending. Additionally, due to time and course load constraints, students can take no more than a maximum of 18 to 24 credit hours per semester, thus placing a ceiling on the number of credit hours and cost of attendance. Given the existence of both a tuition floor and ceiling, the impact of business-cycle variables at the second stage - how much to actually spend - becomes less important.

Our selection of the family variables in $\boldsymbol{\beta}_{j,t}$ is determined by the restrictions placed on $\boldsymbol{\gamma}$. Most of the family variables are assumed to interact with the constant (a level shift) making most of the columns, except for the first, of $\boldsymbol{\gamma}$ zero. However, it is often the case that the head of the household is also the higher education spender. In this case, the coefficients on *age1* and *age0* are not able to be identified. To sharpen the differences between *age0* and the member variable *age1*, we interact *age0* with *age1* (denoted *age0age1*). Next, the fraction of households that spend on higher education and have a head without a high school education is small. To increase the variation in *nohs0*, it is added to *hs0* (denoted *nohs0*+*hs0*) to form a new dummy for households headed by an individual with an education at or below the high school level. Finally, all ages- for both the head of household and enrolled students - are normalized to zero on age 18.

EMPIRICAL RESULTS

Table 5 presents the results of the probit model. The age variables and the interaction terms that include age are, overall, not that significant. The most notable estimation results for the probit are the education status of the head; the variables *nohs0* and *hs0* are each negative and significant at any reasonable critical level implying that an increase in these variables leads to an decrease in the probability of spending for the family on higher education. Also notable is the age composition of the family. For example, when the number of children, *childeq0*, increases in the household, the probability of spending on higher education falls presumably due to the need to substitute toward other goods and services such as food and clothing. Finally, as the number of people in the household who are of college age rises, the probability of spending on higher education rises, the coefficient on *colage0* is positive and significant at any reasonable critical level.

Table 5: Heckit Model Part 1 – Probit Selection				
Probability that hied0 = 1				
hied0	Coefficient	Robust Std. Error	z	Pr>|z|
age0	.0026269	.0029885	0.88	0.379
age02	-.0003163	.0000494	-6.40	0.000
mwst0	.0463135	.0205362	2.26	0.024
sth0	.0025115	.0202449	0.12	0.901
west0	.075089	.0208541	3.60	0.000
rural0	-.0266413	.0278553	-0.96	0.339
blk0	-.1320247	.0245546	-5.38	0.000
othrc0	.0353989	.031871	1.11	0.267
fem0	.0185132	.0151573	1.22	0.222
mar0	-.1622509	.0164435	-9.87	0.000
nohs0	-.6474605	.0309952	-20.89	0.000
hs0	-.5214397	.0159076	-32.78	0.000
childeq0	-.1861652	.0170776	-10.90	0.000
colage0	.3945015	.0077119	51.16	0.000
dyr0	.0139871	.0525902	0.27	0.790
age0dyr0	-.0058436	.0039145	-1.49	0.135
age02dyr0	.0000491	.0000639	0.77	0.442
uer2	2.060779	.4586827	4.49	0.000
constant	-1.620917	.0530227	-30.57	0.000
Number of Observations: 270,904				

Table 6 presents the results for the second part of the Heckit Model. Unlike before, the age variables and the interaction terms that include age are mostly significant at the .05-level. For the most part, higher education consumption is downward sloping (*age1*'s coefficient is -26.415) with some slight curvature; the higher order coefficients for age are marginally significant. Other results indicate, for example, that relative to those in the northeast survey participants in the midwest, south, west, and rural areas spent less on higher education. The race variable, *blk0*, is negative and significant at the .01-level but other races show no significant difference from whites. Because the estimation is in reduced form, however, the causality of variables like region and race are difficult to ascertain. It may be the case that race and region are tracking income. In any event, the majority of the estimates in Table 6 appear consistent with economic intuition.

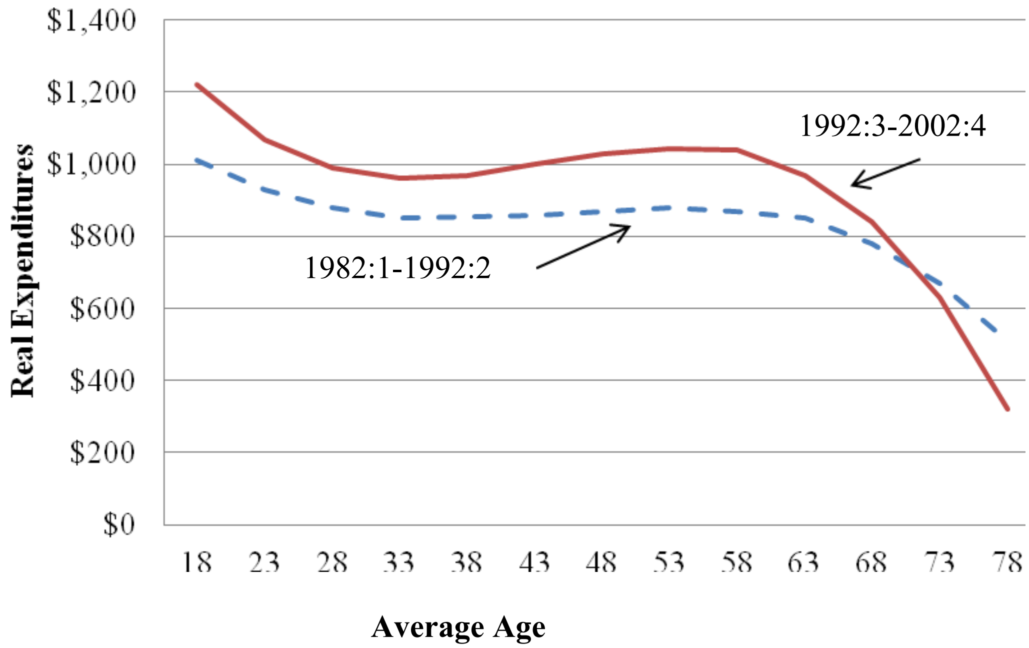
Table 6: Heckit Model Part 2: Weighted Linear Regression				
Real Spending on Higher Education				
hied1	Coefficient	Robust Std. Error	z	Pr>|z|
age1	-26.41472	7.064849	-3.74	0.000
age12	.2640707	.3870469	0.68	0.495
age13	-.0126318	.0046371	-2.72	0.006
dyr0	220.2577	55.03836	4.00	0.000
age1dyr0	-17.98413	10.45942	-1.72	0.086
age12dyr0	1.13283	.5766594	1.96	0.049
age13dyr0	-.0104936	.0067866	-1.55	0.122
part1	-305.049	37.76138	-8.08	0.000
age1part1	-2.610083	5.009091	-0.52	0.602
age12part1	.144462	.1275978	1.13	0.258
mwst0	-219.8566	39.73325	-5.53	0.000
sth0	-352.662	37.13394	-9.50	0.000
west0	-410.1195	37.26241	-11.01	0.000
rural0	-378.9035	42.97729	-8.82	0.000
blk0	-74.79774	30.3838	-2.46	0.014
othrc0	82.12133	43.32208	1.90	0.058
fem0	8.232381	24.90061	0.33	0.741
mar0	201.3869	25.96113	7.76	0.000
childeq0	-46.70799	22.55757	-2.07	0.038
colage0	-62.86587	13.20729	-4.76	0.000
nohs0+hs0	-94.70125	25.60374	-3.70	0.000
age0age1	.7845043	.1558	5.04	0.000
age0dyr0age1	-.3076398	.1822183	-1.69	0.091
constant	1057.05	81.2169	13.02	0.000
Mills:				
ρ	-.0518312	.030853		
σ	948.7052	49.98462		
λ	-49.17255	29.43049		
Goodness of fit:				
Null:	H_0: $\beta = 0$			
Wald χ^2_{26} :	524.19			
Pr > χ^2_{26} :	0.0000			
Number of Observations: 13,917				

We see in Table 6 that the majority of the individual time coefficients are significant (*age13dyr1* is not significant). The test of the constants, *dyr0,* presented in Table 7 shows, that for the youngest consumers, real consumption increases by 220.26 real dollars in the 1990's. The joint test on the slopes rejects the null hypothesis that slopes, with respect to age, are the same across time periods; the test results in a $\chi^2_{(6)} = 16.16$ with a probability value equal to 0.0129. The joint test on the constants and slopes further confirms that structural change in real higher education consumption has occurred between the 1980s and the 1990s; the test results in a $\chi^2_{(8)} = 95.66$ with a probability value equal to zero.

Table 7: Tests of Coefficients	
Test 1: Constants	
H_0 :	dyr0 = 0
χ^2_2 :	16.10
Pr> χ^2_2 :	0.0003
Test 2: Slopes	
H_0 :	age0dyr0 = age02dyr0 = age1dyr0 = age12dyr0 = age13dyr0 = age0dyr0age1 = 0
χ^2_6 :	16.16
Pr> χ^2_6 :	0.0129
Test 3: Joint	
H_0 :	dyr0 = age1dyr0 = age12dyr0 = age13dyr0 = age0dyr0age1 = 0
χ^2_8 :	95.66
Pr> χ^2_8 :	0.0000

Parameter estimates from Table 6 and age are used to create the household higher education consumption profiles. The typical household that generates the profile is assumed to be: a single, white, male who lives in the northeast, has some college education, does not have any children, and is the head of his household. Figure 7 depicts the results. The empirical profile appears to be consistent with the theoretical life-cycle profiles. In addition, the life-cycle profile displays structural change. Each have statistically changed between the 1980s and the 1990s - the young consume more higher education services while the old consume less in the 1990s. In terms of our theory, the position in the life-cycle appears to determine the relative importance of the income and substitution effects that arise from the increasing college skill premium**.**

Figure 7: Estimated Skill Acquisition Profile



CONCLUSION

Theoretically, the following conclusions can be drawn from the quantitative experiments presented. First, although pure substitution effects resulting from extensive SBTC are consistent with the widening skill premium over time, they do not explain why the skill premium has leveled off for the older age groups. When intensive SBTC parameters are investigated separately, they can lead to income effects - specifically changes in θ_2. A combination of extensive and intensive SBTC parameters is able to provide a flatter wage gap via a change in skill acquisition expenditures. This final quantitative result provides an explanation for one of the problems that Card and DiNardo (2002) cite regarding SBTC, namely, by showing that SBTC can lead to a flatter wage gap profile via an intertemporal substitution of skill acquisition.

Empirically, the major finding is that the higher education life-cycle consumption profiles have statistically changed between the 1980s and the 1990s implying that the position in the life-cycle appears to be an important determinate to how households respond from, presumably, an increasing skill premium. The steeper higher education consumption profile is important because it is exactly what the theory predicted from both an extensive and an intensive SBTC; a substitution effect for the young accompanied by an income effect for the old.

Several interesting conclusions flow from our analysis. First, the innovations generated by technological advancements in the goods production sector have been also incorporated in the human capital sector. Put another way, the large investments made by higher education institutions (by both administrations and faculty) on things like information technology over the last three decades have been effective. Second, though the probability of spending on higher education did not statistically change over the two periods, the changes in the spending on higher education imply changing college classroom demographics. There should be relatively more younger students.

Though the theory of SBTC is both theoretically and empirically plausible, our analysis has one caveat. We are unable to rule out other theories on the rising skill premium. However, this study can serve as a roadmap for future research in that we have shown how higher education consumption should shift over the life-cycle. That is, alternative future theories must simultaneously explain the steeping of the skill acquisition as well as Card and DiNardo's (2002) flatter wage gap profile.

REFERENCES

Auerbach, Alan J. and Laurence J. Kotlikoff. 1987. *Dynamic fiscal policy.* Cambridge: Cambridge University Press.

Autor, David H., Lawrence F. Katz, and Melissa S. Kearney. 2008. Trends in U.S. Wage Inequality: Revising the Revisionists. *The Review of Economics and Statistics 90(2): 300-323.*

Autor, David H., Lawrence F. Katz, and Alan B. Krueger. 1998. Computing Inequality: Have Computers Changed the Labor Market? *The Quarterly Journal of Economics* 113 (November): 1169-1213.

Autor, David H.and Lawrence F. Katz. 1999. Changes in the Wage Structure and Earnings Inequality. In *Handbook of Labor Economics. Ed.* O. Ashenfelter and D. Card. *Vol. 3A,* 1464-1555. Amsterdam: Elsevier.

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

Bertaut, Carol C. and Martha Starr-McCluer. 2002. Household portfolios in the United States. In *Household Portfolios.* Ed. L. Guiso, M. Haliassos, and T. Jappelli. 181-218. Cambridge: MIT Press.

Bound, John and George Johnson. 1992. Changes in the Structure of Wages in the 1980's: An Evaluation of Alternative Explanations. *The American Economic Review* 82 (June): 371-392.

Browning, Martin, Lars Peter Hansen, and James J. Heckman. 1999. Micro Data and General Equilibrium Models. In *Handbook of Macroeconomics. E*d. John B. Taylor and Michael Woodford. *Vol. 1A,* 544-633. Amsterdam: North Holland.

Browning, Martin, and Mette Ejrnæs. 2002. Consumption and Children. Working Paper, Centre for Applied Microeconometrics, Institute of Economics, University of Copenhagen.

Card, David and John E. DiNardo. 2002. Skill-Biased Technological Change and Rising Wage Inequality: some Puzzles and Problems. *Journal of Labor Economics* 20 (October): 733-783.

Ferná ndez-Villaverde, Jesú s. and Dirk Krueger. 2002. Consumption over the Life-cycle: Some Facts from Consumer Expenditure Survey Data, Working Paper No. w9382, National Bureau of Economic Research, Inc., New York, New York.

Fowler, Stuart J. and Eric R. Young. 2004. The Acquisition of Skills Over the Life-Cycle. Working Paper, Department of Economics and Finance, Middle Tennessee State University, Murfreesboro, Tennessee.

Gourinchas, Pierre-Olivier and Jonathan A. Parker. 2002. Consumption Over the Life Cycle. *Econometrica* 70 (January): 47--89.

Guvenen, Fatih and Burhanettin Kuruscu. 2010. A Quantitative Analysis of the Evolution of the U.S. Wage Distribution: 1970-2000, In *NBER Macroeconomics Annual 2009*. Ed. Daron Acemoglu, Kenneth Rogoff, and Michael Woodford. Vol. 24, 227-276. Chicago: Chicago University Press.

Haliassos, Michael and Carol C. Bertaut. 1995. Why do so Few Hold Stocks? *The Economic Journal* 105, (Sep.): 1110-1129.

Heathcote, Jonathan, Kjetil Storesletten, and Giovanni L. Violante. 2004. The Macroeconomic Implications of Rising Wage Inequality in the United States. Working Paper No. gueconwpa~03-0319, Department of Economics, Georgetown University, Washington, D.C.

Heckman, James J. 1976. A Life-Cycle Model of Earnings, Learning, and Consumption. *Journal of Political Economy* 84 (August): S11-S44.

Heckman, James J. 1979. Sample Selection Bias as a Specification Error. *Econometrica* 47 (January): 153-162.

Heckman, James J. Lance Lochner, and Christopher Taber. 1998. Explaining Rising Wage Inequality: Explorations with a Dynamic General Equilibrium Model of Labor Earnings with Heterogeneous Agents. *Review of Economic Dynamics* 1 (January): 1-58.

Johnson, George E. 1997. Changes in Earnings Inequality: The Role of Demand Shifts. *Journal of Economic Perspectives* 11 (spring): 41-54.

Judd, Kenneth L. 1998. *Numerical Methods in Economics.* Cambridge: The MIT Press.

Katz, Lawrence F. and Kevin M. Murphy. 1992. Changes in Relative Wages, 1963-1987: Supply and Demand Factors. *The Quarterly Journal of Economics* 107 (February): 35-78.

Krusell, Per, Lee E. Ohanian, José -Victor Rios-Rull, and Giovanni L. Violante. 2000. Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis. *Econometrica* 68 (September): 1029-1054.

Mankiw, N. Gregory and Stephen P. Zeldes. 1991. The consumption of stockholders and nonstockholders. *Journal of Financial Economics* 29 (March): 97-112.

Rios-Rull, José –Victor. 1999. Computation of Equilibria in Heterogenous Agent Models. In *Computational Methods for the Study of Dynamic Economies: An Introduction.* Ed. Ramon Marimon and Andrew Scott. 238-264. Oxford: Oxford University Press.

Rosen, Sherwin. 1976. A Theory of Life Earnings. *Journal of Political Economy* 84 (August): S45-S57.