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ABSTRACT

This paper formulates and estimates an open-economy overlapping generation general-equilibrium model of endogenous heterogeneous human capital in the form of schooling and on-the-job training. Physical capital accumulation is also analyzed. We use the model to explain rising wage inequality in the past two decades due to skill-biased technical change and to estimate investment responses. We compare an open economy version with a closed economy version.

Using our empirically grounded general equilibrium model that explains rising wage inequality, we evaluate two policies often suggested as solutions to the problem of rising wage inequality: (a) tuition subsidies to promote skill formation and (b) tax policies. We establish that conventional partial equilibrium policy evaluation methods widely used in labor economics and public finance give substantially misleading estimates of the impact of national tax and tuition policies on skill formation. Conventional microeconomic methods for estimating the schooling response to tuition overestimate the response by an order of magnitude. Simulations of our model also reveal that move to a flat consumption tax raises capital accumulation and the real wages of all skill groups and barely affects overall measures of income inequality.

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In his 1977 Walras-Bowley lecture presented at the Summer Meetings of the North American Econometric Society in Boulder, Colorado, T.N. Srinivasan presented a magisterial survey of the state of the art in social cost-benefit analysis and project evaluation. He stressed the value of general-equilibrium models in analyzing policies and making specific policy recommendations, and at the same time recognized their limitations.

This paper builds on Srinivasan's lecture and considers four of the many topics he discussed: (1) the importance of accounting for general-equilibrium effects of large scale programs; (2) the importance of accounting for dynamics; (3) the importance of understanding the causes of a problem in evaluating proposed solutions for it and (4) the importance of accounting for the impact of a program on the personal distribution of income and welfare. Since we consider policy evaluation in a developed economy, many of T.N.'s other concerns about the importance of understanding market failure and institutional failure - two topics central to development economics — are less central to this paper and are not discussed here.

The emphasis in this paper is on understanding the sources of rising wage inequality in the U.S. economy and evaluating proposals that have been made to combat it. Wage inequality has increased substantially in the American economy since the early 1980^s. Workers with low skills have experienced large declines in their earnings, both absolutely and relative to more skilled workers. Only recently have economists begun to develop models that explain the rise in wage inequality, focusing on explaining the college - high school wage differential. The primary causes for the recent increase in overall wage inequality are still being debated. Despite the lack of a consensus on the cause, there is no shortage of proposed cures. Numerous tax and tuition policies have been proposed to stimulate investment in high-skilled labor to alleviate rising wage inequality by making some of the unskilled into skilled workers who benefit from the rising skill differential, while at the same time making remaining unskilled workers more scarce. These proposals have not been evaluated within the context of articulated economic models that explain the problems that the policies are designed to solve. Moreover, most of the estimates of the rising "return" to education are based on the coefficient of schooling in a series of cross-sectional Mincer earnings functions. During a period of transition driven by skill-biased technical change, estimated "rates of return" are poor guides to the true rates of return that will be experienced by any cohort, and are a poor guide to policy.

Our previous work (Heckman, Lochner and Taber, 1998 a,b,c) addresses these issues. We develop an empirically based heterogeneous-agent dynamic general-equilibrium model of labor earnings for the U.S. economy. We study both the sources of rising earnings inequality and the effects of various policy proposals aimed at increasing skill formation.

We demonstrate the danger in using estimated cross-sectional "rates of return" estimated in a period of transition to guide educational policy. Our previous work assumes that the U.S. economy is closed. One major goal of this paper is to relax that assumption and evaluate tax and tuition policies in an open-economy environment. Many predictions of an open-economy version of our model are similar to those derived from a closed-economy version but there are some important differences. When we compare the open-economy model to the closed-economy model, the closed-economy version produces more plausible predictions about the time paths of economic aggregates in the U.S. economy and the effects of policy. A major conclusion of this paper is that for the class of general-equilibrium models we consider, a closed-economy model provides a more accurate characterization of the U.S. economy.

This paper also emphasizes more forcefully than our previous papers have done the crucial distinction between cross- sectional "rates of return" to schooling and the "rates of return" that are experienced by cohorts of persons living through a transition. We demonstrate that the coefficient on schooling in the Mincer equation is only weakly connected to the true rate of return that should guide human capital investment decisions.

We also emphasize the value of accounting for heterogeneity in ability and heterogeneity in the economic history experienced by different cohorts of persons in evaluating policies and discussing the problems created by rising wage inequality. Distributional considerations affect the likelihood that different policies will be favored. Any assessment of policies should recognize this point.

We demonstrate the value of a general-equilibrium approach to the evaluation of human capital policies instituted at the national level. Partial-equilibrium - "treatment effect" - approaches are very misleading. This is true both in open-economy and closed-economy versions of our model.

Heckman, Lochner and Taber (1998a) meet Srinivasan's desideratum that policy analysis be based on a model that explains the problem that the policy is designed to solve by producing a model that can explain the changing distribution of wages in the U.S. economy over the last thirty years. We show that accounting for the distinction between skill prices and measured wages is important for analyzing the changing wage structure, because the two often move in different directions. This is also true in the open-economy version of our model reported here. The general patterns are the same in both models. However, there are several features of these model such as the timing of the transitions and patterns across cohorts that are different in the open - and closed-economy versions. The closed-economy version of the model seems to be able to do a somewhat better job at explaining the changing wage structure and hence is a better framework within which to conduct policy analysis. For both open-and closed-economy versions of our model, the partial-equilibrium effects of tax and tuition policies are substantial. However, the general-equilibrium effects are very small. We find that while the effects of tax reform on capital accumulation are drastically affected by the open-economy assumption, the simulated effects of tax reform on human capital are very similar in the open-economy and closed-economy cases.

The structure of this paper is as follows. In Section I, we first present an intuitive introduction to our model and the policy problems considered here. In Section II, we present a more formal discussion of the model. In Section III, we consider methods for determining the parameters of the model to convert it from a theoretical exercise into a framework for quantitative economic policy evaluation. In Section IV, we demonstrate how well the open-economy version of our model explains rising wage inequality over the past 30 years. We compare the predictions of the open-economy version with the closed-economy version of our model. In Section V, we analyze how overall welfare, and the welfare of different ability and schooling groups, is affected during the transition to a new high-skill economy. In Section VI we present a formal analysis of what a Mincer "rate of return" measures. We compare cross section and cohort "rates of return" to reveal how misleading the Mincer rate of return is as a guide to formulating and evaluating educational policy, especially in a period of change in the technology. In Section VII we use our model to present a general-equilibrium evaluation of tuition policy and compare it with conventional partial-equilibrium treatment effect estimates of the sort routinely generated by labor economists. In Section VIII, we compare general-equilibrium and partial-equilibrium approaches to the evaluation of tax reforms designed to stimulate human capital production. In Section IX, we summarize the evidence that supports the closed-economy version of our model. Section X summarizes and concludes the paper.

I. A general-equilibrium Model With Heterogeneous Agents and the Policy Problems We Analyze

Our dynamic general-equilibrium model of human capital and physical capital accumulation has several sources of heterogeneity among its agents: (1) Persons differ in initial ability levels and this ability affects both earnings levels and personal investment decisions. (2) Skills are heterogeneous. Different schooling levels correspond to different skills. The post-school skills acquired at one schooling level are not perfect substitutes for the post-school skills acquired at another schooling level; however, skills are perfect substitutes across age groups within a given schooling level. (3) The model uses an overlapping-generations framework to produce heterogeneity among different cohorts as a result of rational investment behavior. In a period of transition, different skill price paths facing different entry cohorts produce important differences in the levels and rates of growth of earnings across cohorts due to differential human capital investment. All three sources of heterogeneity are important in explaining rising wage inequality over time and over cohorts.

Our model considers human capital choices at both the extensive margin (schooling) and the intensive margin (on-the-job training). Schooling enables people to learn on the job and also directly produces market skills. Our model extends the Roy (1951) model of self-selection and earnings to allow for investment and embeds it in a dynamic general-equilibrium model in which the prices of heterogenous skills are endogenously determined. It extends the widely-used framework of Ben-Porath (1967) by permitting different technologies to govern the production of skill in schools and the production of skill on the job, by recognizing that schooling affects both productivity on the job as well as the ability to learn on the job, and by allowing for multiple skill types. Our model extends the schooling models of Willis and Rosen (1979) and Keane and Wolpin (1997) by making post-schooling on-the-job training endogenous. It also extends those models and the analysis of Siow (1984) by embedding both schooling and job training in a general-equilibrium framework.

We relax the efficiency units assumption for the aggregation of labor services that is widely used in macroeconomics (see, e.g. Kydland, 1995). This assumption is not consistent with rising wage inequality across skill groups except in the unlikely case when quantities of skill embodied in each group change over time in a fashion that exactly mimics movements in relative wages. Our model introduces human capital accumulation into the overlapping generations framework of Auerbach and Kotlikoff (1987) extending the model of Davies and Whalley (1991).[1] We consider multiple skill types, rational expectations, heterogeneity in human capital endowments and production, and distinguish between schooling and on-the-job training as separate means for producing skills. We then use our model to examine the effectiveness of various tax and tuition policies that have been proposed to reduce wage inequality in the U.S. economy.

A commonly-used approach for assessing the sources of rising wage inequality begins with an equation postulated as a time-differenced demand relationship which connects the changes in the relative wages of skilled (W_{St}) and unskilled (W_{Ut}) workers at time t to the respective quantities of the two factors, Q_{St} and Q_{Ut}:

$$\text{(I-1)} \qquad \Delta \log \left[\frac{W_{St}}{W_{Ut}}\right] = \alpha - \frac{1}{\sigma}\Delta \log \left[\frac{Q_{St}}{Q_{Ut}}\right].$$

In this equation, α is the trend rate of relative wage growth arising from skill-biased technical change and σ is the elasticity of substitution between the two types of labor. Katz and Murphy (1992) estimate this equation for the U.S. economy using the measures of skilled and unskilled labor defined in their paper for the period 1963-1987. They report $\sigma = 1.41$ with a standard error of .150, although they also suggest that a range of estimates with σ as low as .5 are also consistent with the data.[2] They estimate α to be .033 (standard error

[1] Fullerton and Rogers (1993) also estimate a general equilibrium model using micro data, but do not incorporate human capital investment.

[2] Johnson (1970) reports an estimate of $\sigma = 1.50$ for the elasticity of substitution between college and

.007).

Using Katz and Murphy's definition of skill groups, it is necessary to transform approximately 5.4 million people to college equivalents to reverse the decade-long (1979-87) erosion of real wages for individuals not attending college. Even using their lower range estimate of $\sigma = .5$, two million persons need to be shifted from the unskilled to the skilled category to offset the decade-long trend against unskilled labor. Maintaining the skill gap against the secular bias operating against unskilled labor requires that the percentage of persons acquiring post-secondary skills in each year rise by 55% (22% in the lower bound case).[3]

It is tempting to use the demand function (I-1), in conjunction with micro estimates of the supply response of skills to tuition or other subsidies, to evaluate government policies. Conventional microeconomic approaches to policy evaluation assume that skill prices remain constant at their pre-subsidy levels when calculating supply responses. They ignore the feedback of induced price changes (created by the increase in the supply of skill) on the supply decisions of agents. Only when these feedback responses are incorporated into supply decisions can equation (I-1) be used as a valid basis for policy evaluation. Informed policy evaluations allow for skill prices to adjust and for agents to anticipate this adjustment and respond appropriately. Such evaluations reveal that the response to a policy evaluated in a microeconomic setting, which holds prices constant, may be a poor guide to the actual response when prices adjust with changes in quantities. Thus, the effect of any policy characterized by parameter ψ, $\partial\left[\frac{Q_{S_t}}{Q_{U_t}}\right]/\partial\psi$, is not the same when skill prices are held fixed as it is when skill prices are allowed to vary in response to the policy-induced change.

A more convincing evaluation of any policy designed to promote skill formation and alleviate wage inequality requires a model that explains the rising wage inequality in the U.S. labor market. As stressed by Srinivasan, it is potentially dangerous to "solve" problems whose origins are not well understood. These concerns motivate us to develop a dynamic general-equilibrium model of labor earnings that is consistent with evidence from the U.S. labor market (Heckman, Lochner and Taber, 1998a). We now present that model.

II. A Dynamic general-equilibrium Model of Earnings, Schooling and On-the-Job Training

Our model extends Ben-Porath's model (1967) of skill formation in several ways. (1) In contrast to his model, we distinguish between schooling capital and job training cap-

high school labor.

[3]These calculations are presented in Heckman (1996).

ital at a given schooling level. In our model, schooling human capital is an input to the production of human capital acquired on the job and is also directly productive in the market. However, the tight link between schooling and on-the-job training investments, which is characteristic of Ben-Porath's model, is broken. (2) Skills produced by different schooling levels command different prices, and wage inequality among persons is generated by differences in skill levels, differences in investment, and in the prices of different skills. In Ben-Porath's model, wage inequality can only be generated by differences in skill levels and investment behavior, because all skill commands the same price. In our model, persons with different levels of schooling invest in different skills through on-the-job training in the post-schooling period. In the aggregate, skills associated with different schooling groups are not perfect substitutes.[4] Within schooling groups, however, persons with different amounts of skill are perfect substitutes.[5] Unlike the Ben-Porath framework, our model of heterogeneous skills captures comparative advantage which is an important feature of modern labor markets.[6] (3) In addition to the post-school investment stressed by Ben-Porath, persons in our model choose among schooling levels with associated post-school investment functions. (4) We build in heterogeneity within schooling levels. Among persons of the same schooling level, there is heterogeneity both in initial stocks of human capital and in the ability to produce job-specific human capital. (5) We embed our model of individual human capital production into a general-equilibrium setting so that the relationship between the capital market and the markets for human capital of different skill levels is explicitly developed. We extend the open-economy general-equilibrium sectoral-choice model of Heckman and Sedlacek (1985) to allow for investment in sector-specific human capital.

A. The Microeconomic Model

We first review the optimal consumption, on-the-job investment, and schooling choices for a given individual of type θ who takes skill prices as given. We then aggregate the model to a general-equilibrium setting. Until Section VIII, we simplify the tax code and assume that income taxes are proportional. Individuals live for $\bar{a}$ years and retire after $a_R \leq \bar{a}$ years. Retirement is mandatory. In the first portion of the life cycle, a prospective student decides whether or not to remain in school. Once he leaves school, he cannot

[4] This specification is consistent with evidence that the large increase in the supply of educated labor consequent from the baby boom depressed the returns to education. (See Freeman, 1976, Autor, Katz and Krueger, 1997, and Katz and Murphy, 1992.)

[5] This specification accords with the empirical evidence summarized in Hamermesh (1993, p. 123) that persons of different ages but with the same education levels are highly substitutable for each other.

[6] See the empirical evidence summarized in Sattinger (1993).

return. Individuals choose the schooling option that gives them the highest level of lifetime utility.

Define K_{at} as the stock of physical capital held at time t by a person age a; H_{at}^S is the stock of human capital at time t of type S at age a. The optimal life cycle problem can be solved in two stages. First, condition on schooling and solve for the optimal path of consumption (C_{at}) and post-school investment (I_{at}^S) for each type of schooling level. Individuals then select among schooling levels to maximize lifetime welfare. Given S, an individual age a at time t has the value function

$$\text{(II-1)} \qquad V_{at}(H_{at}^S, K_{at}, S) = \max_{C_{at}, I_{at}^S} U(C_{at}) + \delta V_{a+1,t+1}(H_{a+1,t+1}^S, K_{a+1,t+1}, S),$$

where U is strictly concave and increasing and δ is a time preference discount factor. This function is maximized subject to the budget constraint

$$\text{(II-2)} \qquad K_{a+1,t+1} \leq K_{a,t}(1 + (1-\tau)r_t) + (1-\tau)R_t^S H_{at}^S(1 - I_{at}^S) - C_{at},$$

where τ is the proportional tax rate on capital and labor earnings, R_t^S is the rental rate on human capital of type S, and r_t is the net return on physical capital at time t. In this paper, we abstract from labor supply. Estimates of intertemporal substitution in labor supply estimated on annual data are small, so ignoring labor supply decisions will not greatly affect our analysis.[7]

In the empirical analysis in this paper, we use the conventional power utility specification of preferences

$$\text{(II-3)} \qquad U(C_{at}) = \frac{C_{at}^{\gamma} - 1}{\gamma}.$$

On-the-job human capital for a person of schooling level S accumulates through the human capital production function

$$\text{(II-4)} \qquad H_{a+1,t+1}^S = A^S(\theta)(I_{at}^S)^{\alpha_S}(H_{at}^S)^{\beta_S} + (1-\sigma^S)H_{at}^S,$$

where the conditions $0 < \alpha_S < 1$ and $0 \leq \beta_S \leq 1$ guarantee that the problem is concave in the control variable, and σ^S is the rate of depreciation of job-S specific human capital. This functional form is widely used in both the empirical literature and the literature on human capital accumulation.[8]

For simplicity, we ignore the input of goods into the production of human capital on the job. We explicitly allow for tuition costs of college, which we denote by D_{at}^S. The same good that is used to produce physical capital and final output is used to produce schooling human capital.[9] After completion of schooling, time is allocated to two activities: on-the-

[7] See Browning *et al* (1998) or the survey in Heckman (1993).

[8] Uzawa (1965) assumes $\beta_S = 1$. Ben Porath (1967), Lucas (1988) and Ortigueira and Santos (1994) assume that $\alpha_S = \beta_S$. Rosen (1976) assumes $\alpha_S = 1/2$ and $\beta_S = 1$.

[9] More general specifications which allow the price of schooling inputs to track the price of skilled labor produce almost identical results.

job investment, I^S_{at}, and work, $(1 - I^S_{at})$, both of which must be non-negative. The agent solves a lifecycle optimization problem given initial stocks of human and physical capital, $H^S(\theta)$ and K_0, as well as his ability to produce human capital on the job, $A^S(\theta)$.

$H^S(\theta)$ and $A^S(\theta)$ represent ability to "earn" and ability to "learn," respectively, measured *after* completing school. They embody the contribution of schooling to subsequent learning and earning in the schooling-level S-specific skills as well as any initial endowments. Notably absent from our model are short-run credit constraints that are often featured in the literature on schooling and human capital accumulation. Our model is consistent with the evidence presented in Cameron and Heckman (1997, 1998) that long-run family factors correlated with income (the θ operating through $A^S(\theta)$ and $H^S(\theta)$) affect schooling, but that short-term credit constraints are not empirically important. Such long-run factors can account for the empirically well-known correlation between schooling attainment and parental income. The mechanism generating the income-schooling relationship is through family-acquired human capital and not credit-rationing. The α and β are also permitted to be S-specific, which emphasizes that schooling affects the process of learning on the job in a variety of different ways.

Assuming interior solutions conditional on the choice of schooling, we obtain the following first order conditions for consumption and investment:

(II-5) $$U_{C_{at}} = \delta \frac{\partial V_{a+1,t+1}}{\partial K_{a+1,t+1}}$$

(II-6) $$\frac{\partial V_{a+1,t+1}}{\partial K_{a+1,t+1}} = \frac{\partial V_{a+1,t+1}}{\partial H_{a+1,t+1}} \left[\frac{A\alpha_S (I^S_{a,t})^{\alpha_S - 1} (H^S_{a,t})^{\beta_S}}{R^S_t H^S_{a,t}(1-\tau)} \right];$$

and envelope conditions for physical and human capital:

(II-7) $$\frac{\partial V_{a,t}}{\partial K_{a,t}} = \delta \frac{\partial V_{a+1,t+1}}{\partial K_{a+1,t+1}} (1 + r_t(1-\tau))$$

(II-8) $$\frac{\partial V_{a,t}}{\partial H^S_{a,t}} = \delta \frac{\partial V_{a+1,t+1}}{\partial K_{a+1,t+1}} R^S_t (1 - I^S_{a,t})(1-\tau)$$

$$+ \delta \frac{\partial V_{a+1,t+1}}{\partial H^S_{a+1,t+1}} (A\beta_S (I^S_{a,t})^{\alpha_S} (H^S_{a,t})^{\beta_S - 1} + (1 - \sigma^S)).$$

At the end of working life, the final term, which is the contribution of human capital to earnings, has zero marginal value. We assume mandatory retirement at age a_R, leaving ages $\bar{a} - a_R$ as the retirement period during which there are no labor earnings.

At the beginning of life, agents choose the value of S that maximizes lifetime utility:

(II-9) $$\hat{S} = \operatorname*{Argmax}_S \left[V^S(\theta) - D^S - \varepsilon^S \right]$$

where $V^S(\theta)$ is the value of schooling at level S, D^S is the discounted direct cost of schooling and ε^S represents nonpecuniary benefits expressed in present value terms. Discounting of V^S and D^S is back to the beginning of life to account for different ages of completing school. Tuition costs are permitted to change over time so that different cohorts face different environments for schooling costs. Given optimal investment in physical capital, schooling, investment in job-specific human capital, and consumption, we calculate the path of savings. For a given return on capital and rental rates on human capital, the solution to the S-specific optimization problem is unique, given concavity of the production function of (II-4) in terms of I_{at}^S, $(0 < \alpha_S < 1)$, the restriction that human capital be self-productive, but not too strongly $(0 \leq \beta_S \leq 1)$, that investment is in the unit interval $(0 \leq I_{at}^S \leq 1)$, and concavity of U in terms of C $(\gamma < 1)$.

The choice of S is unique almost surely if ε^S is a continuous random variable, as we assume in our empirical analysis. The dynamic problem is of split-endpoint form. We know the initial condition for human and physical capital, and optimality implies that investment is zero at the end of life. In this paper, we numerically solve this problem using the method of "shooting" (see Lipton, Poterba, Sacks and Summers, 1982). For any terminal value of H^S and K, we solve backward to the initial period and obtain the implied initial conditions. We iterate until the simulated initial condition equals the pre-specified value.

B. Aggregating The Model

The prices of skills and capital are the derivatives of an aggregate production function. In order to compute rental prices for capital and the different types of human capital, it is necessary to construct aggregates of each of the skills. Given the solution to the individual's problem for each value of θ and each path of prices, we use the distribution of θ, $G(\theta)$, to construct aggregates of human and physical capital. We embed our human capital model into an overlapping generations framework in which the population at any given time is composed of $\bar{a}$ overlapping-generations, each with an identical ex-ante distribution of heterogeneity, $G(\theta)$.

Human capital of type S is a perfect substitute for any other human capital of the same schooling type, whatever the age or experience level of the agent, but it is not perfectly substitutable with human capital from other schooling levels. In our model, cohorts differ from each other only because they face different price paths and policy environments within their lifetimes. We assume perfect foresight (as used in Auerbach and Kotlikoff, 1987) and not myopic expectations. Let c index cohorts, and denote the date at which cohort c is born by t_c. Their first period of life is $t_c + 1$. Let P_{t_c} be the vector of paths for rental prices of physical and human capital confronting cohort c over its lifetime from time $t_c + 1$

to $t_c + \bar{a}$. The rental rate on physical capital at time t is r_t. The rental rate on human capital of type S is R_t^S. The choices made by individuals depend on the prices they face, P_{t_c}; their type, θ, and hence their endowment; and their nonpecuniary costs of schooling, ε^S. Let $H_{at}^S(\theta, P_{t_c})$ and $K_{at}^S(\theta, P_{t_c})$ be the amount of human and physical capital possessed, respectively, and let $I_{at}^S(\theta, P_{t_c})$ be the time devoted to investment by an individual with schooling level S, at age a, of type θ, in cohort c.

By definition, the age at time t of a person born at time t_c is $a = t - t_c$. Let $N^S(\theta, t_c)$ be the number of persons of type θ, in cohort c, of schooling level S. In this notation, the aggregate stock of employed human capital of type S at time t is cumulated over the non-retired cohorts in the economy at time t :

$$\bar{H}_t^S = \sum_{t_c = t - a_R}^{t-1} \int H_{t-t_c,t}^S(\theta, P_{t_c})(1 - I_{t-t_c,t}^S(\theta, P_{t_c}))N^S(\theta, t_c)dG(\theta)$$

where $a = t - t_c$,and $S = 1, ..., \bar{S}$, where $\bar{S}$ is the maximum number of years of schooling. The aggregate *potential* stock of human capital of type S is obtained by setting $I_a^S(\theta, P_{t_c}) = 0$ in the preceding expression:

$$\bar{H}_t^S(\text{potential}) = \sum_{t_c = t - a_R}^{t-1} \int H_{t-t_c,t}^S(\theta, P_{t_c})N^S(\theta, t_c)dG(\theta).$$

The aggregate capital stock is the capital held by persons of all ages:

$$\bar{K}_t = \sum_{t_c = t - \bar{a}}^{t-1} \sum_{s=1}^{\bar{S}} \int K_{t-t_c,t}^S(\theta, P_{t_c})N^S(\theta, P_{t_c})dG(\theta).$$

C. Equilibrium Conditions Under Perfect Foresight

To close the model, it is necessary to specify the aggregate production function $F(\bar{H}_t^1, ..., \bar{H}_t^S, \bar{K}_t)$ which is assumed to exhibit constant returns to scale. The equilibrium conditions require that marginal products equal pre-tax prices $R_t^S = F_{\bar{H}_t^S}(\bar{H}_t^1, ..., \bar{H}_t^{\bar{S}}, \bar{K}_t, t)$, $S = 1, ..., \bar{S}$ and $r_t = F_{\bar{K}_t}(\bar{H}_t^1, ..., \bar{H}_t^{\bar{S}}, \bar{K}_t, t)$. In the two-skill economy estimated below, we specialize the production function to

(II-10) $\quad F(\bar{H}_t^1, \bar{H}_t^2, \bar{K}_t)$

$$= a_3 \left(a_2 \left(a_1 (\bar{H}_t^1)^{\rho_1} + (1 - a_1)(\bar{H}_t^2)^{\rho_1} \right)^{\rho_2/\rho_1} + (1 - a_2)\bar{K}_t^{\rho_2} \right)^{1/\rho_2}.$$

When $\rho_1 = \rho_2 = 0$, the technology is Cobb-Douglas.[10] When $\rho_2 = 0$, we obtain a model consistent with the constancy of capital's share irrespective of the value of ρ_1.

D. Linking The Earnings Function To Prices and Market Aggregates

The earnings at time t for a person of type θ and age a from cohort c and schooling level S are

(II-11) $$W^S_{a,t}(c,\theta) = R^S_t H^S_{a,t}(\theta, P_{t_c})(1 - I^S_{a,t}(\theta, P_{t_c})).$$

They are determined by aggregate rental rates (R^S_t), individual endowments, $H^S_{at}(\theta, P_{t_c})$, and individual investment decisions, $I^S_a(\theta, P_{t_c})$. The last two components depend on agent expectations of future prices. Different cohorts facing different price paths will invest differently and have different human capital stocks. An essential idea in this paper, an idea absent from currently used specifications of earnings equations in labor economics, is that *utilized* skills, and not potential skills, determine earnings. The utilization rate is an object of choice linked to personal investment decisions and is affected both by individual endowments, interest rates, and aggregate skill prices. As the quantity of aggregate skill is changed, so are aggregate skill prices. This affects investment decisions, measured wages, and savings decisions.

III. Determining the Parameters of The Model

This section reviews our choice of parameters for the model. In estimating skill-specific human capital production functions, we account for individual heterogeneity in technology and endowments. In Heckman, Lochner, and Taber (1998a), we present a new test of the consistency of the estimates of model parameters used to generate the general-equilibrium simulations. We require that the econometric procedure used to produce the micro-based parameters employed in our model (including the implicit assumptions made about the economic environment in implementing any particular econometric procedure) recover the parameters estimated from synthetic micro data sets generated by the model used to simulate the economy. We further require that our assumptions about agent expectations produce the behavior observed in our sample period.

The ideal data set for our purposes would combine micro data on firms, data on the earnings of workers, their life-cycle consumption, and their wealth holdings, and macro data on prices and aggregates. With such data, we could estimate all the parameters of our model and the distribution of wages, wealth, and earnings. Using micro data joined

[10] Auerbach and Kotlikoff (1987) assume efficiency units so different labor skills are perfect substitutes ($\rho_1 = 1$). In addition, they assume a Cobb-Douglas aggregate technology relating human capital and physical capital ($\rho_2 = 0$).

with aggregate prices, we could estimate the parameters of the micro model. Using the estimated micro functions, we can construct aggregates of human capital that can be used to determine the output technology. The estimated aggregates should match measured empirical aggregates and, when inserted in aggregate technology, should also reproduce the market prices used in estimation. This self-consistency property is an important aspect of a general-equilibrium model.

Two obstacles prevent us from implementing this approach. (1) We lack information on individual consumption linked to labor earnings. (2) The data on market wages do *not* reveal skill prices, as is evident from the distinction between R_t^S and $W_{a,t}^S(c, \theta)$ in equation (II-11). Since prices cannot be directly equated with wages, it would seem impossible to estimate aggregate stocks of human capital to use in determining aggregate technology.

To circumvent the first limitation, we follow practices widely used in the literature on empirical general-equilibrium models by choosing discount and intertemporal substitution parameters in consumption that are consistent with those reported in the empirical literature and that enable us to reproduce key features of the macro data – like the capital-output ratio. In Heckman, Lochner and Taber (1998a), we explore the sensitivity of our simulations to alternative choices of these parameters.

To circumvent the second problem, we develop a new method for using wages to infer prices and to estimate skill-specific human capital aggregates. Since calibration methods and sensitivity analysis are widely used in applied general-equilibrium analysis, we turn to our more original empirical contribution.

A. Simple Methods For Estimating Skill Prices and Aggregate Production Technology With Heterogeneous Skills

We first present a method for identifying the aggregate technology and estimating skill-specific human capital stocks by combining micro and macro data. It exploits the insight that at older ages, changes in wages are due solely to changes in skill prices and to depreciation. Suppose that for two consecutive ages, a and $a+1$, $I_{a,t}^S = I_{a+1,t+1}^S = 0$. More ages of zero investment only help to identify skill prices, so we present a worst-case analysis. At late ages in the life cycle, $I_{a,t}^S \cong 0$ is an implication of optimality. This condition enables us to identify rental rates up to scale. Note that from the definitions (dropping the θ and c subscripts for simplicity) and from the identifying assumption at ages a and $a+1$, for older cohorts it follows that

$$W_{a+1,t+1}^S \equiv R_{t+1}^S H_{a+1,t+1}^S = R_{t+1}^S H_{a,t}^S (1 - \sigma^S)$$

where σ^S is the rate of depreciation for skill S. It is assumed that deflated real wages are used. Then, it follows that

$$\frac{W^S_{a+1,t+1}}{W^S_{a,t}} = \frac{R^S_{t+1}(1-\sigma^S)}{R^S_t}.$$

Normalize $R_0 = 1$. In the absence of measurement error in wage ratios, we can identify $R^S_0, ..., R^S_T$ from a time series of cross sections of individuals ages a and $a+1$ up to scale $(1-\sigma^S)^t$, where t is the time period; *i.e.* we can identify R^S_0, $R^S_1(1-\sigma^S), ..., R^S_T(1-\sigma^S)^T$. If the ratios have mean zero measurement error, we can estimate the ratios of skill prices without bias. With these rental rates in hand, we can recover utilized human capital stocks up to scale.

Denote WB^S_t as the total wage bill in the economy at time t for schooling level S. This is available from the aggregate information in a time series of cross sections on wages. Then, it is possible to estimate the aggregate utilized human capital stock of type S up to scale from the equation

$$\frac{WB^S_t}{(1-\sigma^S)^t R^S_t} = \frac{\sum_{a=1}^{A} H^S_{a,t}(1-I^S_{a,t})}{(1-\sigma^S)^t} = \frac{\bar{H}^S_t}{(1-\sigma^S)^t}$$

so that we can generate human capital stocks at time t up to scale $(1-\sigma^S)^t$. If there is no depreciation ($\sigma^S = 0$), then we can identify the entire time series of skill prices and stocks with only the initial normalization $R^S_0 = 1$. Since this assumption cannot be rejected by the data (Browning, et. al, 1998) and it greatly simplifies the analysis, we proceed under this assumption and show how to recover the aggregate technology.[11]

B. Identifying the Aggregate Technology

From aggregate production technology (II-10), and the assumption of market clearing in competitive markets, we obtain the first order conditions that generate skill prices. To simplify the derivation, we first define

$$Q_t = \left[a_1 \left(\bar{H}^1_t\right)^{\rho_1} + (1-a_1)\left(\bar{H}^2_t\right)^{\rho_1}\right]^{1/\rho_1},$$

so the aggregate technology can be written in terms of this composite:

$$F\left(\bar{H}^1_t, \bar{H}^2_t, \bar{K}_t\right) = \left[(1-a_2)Q^{\rho_2}_t + a_2 \bar{K}^{\rho_2}\right]^{1/\rho_2}.$$

[11] See Heckman, Lochner, and Taber (1998a) for the more general case where $\sigma^S \neq 0$.

Let $C_t = \left[(1-a_2)Q_t^{\rho_2} + a_2\bar{K}_t^{\rho_2}\right]^{(1-\rho_2)/\rho_2}$. Then in this notation

$r_t = C_t a_2 \bar{K}_t^{\rho_2 - 1}$

$R_t^1 = C_t(1-a_2)a_1 Q_t^{\rho_2-1}(\bar{H}_t^1)^{\rho_1-1}$

$R_t^2 = C_t(1-a_2)(1-a_1)Q_t^{\rho_2-1}(\bar{H}_t^2)^{\rho_1-1}$.

The log ratio of the last two optimality conditions is

$$\text{(III-1)} \qquad \log\left(\frac{R_t^2}{R_t^1}\right) = \log\left(\frac{1-a_{1t}}{a_{1t}}\right) + (\rho_1 - 1)\log\left(\frac{\bar{H}_t^2}{\bar{H}_t^1}\right)$$

where we now permit the a_1 to depend on time. We allow for linear trends in $\log[(1-a_{1t})/a_{1t}]$ so $\log[(1-a_{1t})/a_{1t}] = \log[(1-a_{10})/a_{10}] + \varphi_1 t$ where $t=0$ is the baseline period.

Ordinary least squares applied to

$$\text{(III-2)} \qquad \log\left(\frac{R_t^2}{R_t^1}\right) = \alpha + \beta\log\left(\frac{\bar{H}_t^2}{\bar{H}_t^1}\right) + \varphi_1 t + \varepsilon_t$$

consistently estimates $\alpha = \log\left(\frac{1-a_{10}}{a_{10}}\right)$, $\beta = \rho_1 - 1$, and φ_1 if the measured shifters are exogenous to ε_t.

To recover the other parameters, observe that from CES algebra the price of the bundle Q_t is

$$R_t^Q = \left((R_t^1)^{\frac{\rho_1}{\rho_1 - 1}}(a_1)^{\frac{1}{1-\rho_1}} + (R_t^2)^{\frac{\rho_1}{\rho_1-1}}(1-a_1)^{\frac{1}{1-\rho_1}}\right)^{\frac{\rho_1 - 1}{\rho_1}}.$$

Then, we may write the log ratio of the first order conditions for Q_t and $\bar{K}_t$ as

$$\text{(III-3)} \qquad \log\left(\frac{R_t^Q}{r_t}\right) = \log\left(\frac{a_2}{1-a_2}\right) + (\rho_2 - 1)\log\left(\frac{Q_t}{\bar{K}_t}\right).$$

Substituting for a_2, we may write the estimating equation for (II-3) as

$$\text{(III-4)} \qquad \log\left(\frac{R_t^Q}{r_t}\right) = \log\left(\frac{a_{20}}{1-a_{20}}\right) + (\rho_2 - 1)\log\left(\frac{Q_t}{\bar{K}_t}\right) + \varphi_2 t + \nu_t.$$

Instruments are required for estimation of equations (III-2) and (III-4) if there are demand shocks.[12] A test of $\rho_2 = \rho_1 = 0$ is a test of the Cobb-Douglas specification for aggregate technology using the constructed skill prices and aggregates obtained from the first stage estimation procedure.

[12]Observe that in forming R_t^Q and Q_t and using them in subsequent estimation, one should correct for parameter estimation error in subsequent steps in order to produce correct standard errors.

C. Estimating Human Capital Production Functions

We estimate human capital production parameters using NLSY data on white male earnings for the period 1979-1993. We follow the literature (Heckman, 1975, 1976) and assume that interest rates and the after-tax rental rates on human capital are fixed at constant but empirically concordant values. This ignores the price variation induced by technological change. A remarkable finding of our previous research (Heckman, Lochner, and Taber, 1998a, Appendix B) is that this misspecification of the economic environment has only slight consequences for the estimation of the curvature parameters of the human capital technology, at least within the range of skill price variation generated by our model of the U.S. economy. Misspecification in shared parameters is compensated for by calibration.

We take the real after-tax interest rate r as given and fix it at .05, which is in the range of estimates reported by Poterba (1997) for our sample period. We treat R_t^S as a constant (normalized to 1) for all skill services, following a tradition in the literature. We set $\sigma^S = 0$, an estimate consistent with what is reported in the literature (See Browning, et.al, 1998). This estimate is also consistent with the lack of any peak in life cycle wage-age profiles (Meghir and Whitehouse, 1996). We use a tax rate of 15% which is consistent with the effective rate over our sample period reported by Pechman (1987). For each ability-schooling (θ, S) type, the relevant parameters are $(\alpha^S, \beta^S, A^S(\theta), H^S(\theta))$. We assume that, conditional on measured ability, there is no dependence on unobservables across the schooling and wage equations.

Solving the human capital model backward is easier computationally than simultaneously solving it forward and backward. (We know the terminal value for $\frac{\partial V_{a_R+1}}{\partial H^S_{a_R+1}}$ and the initial value for $H_0^S(\theta)$.) Rather than parameterizing the model in terms of initial human capital, we parameterize it in terms of terminal human capital, denoted $H^S_{a_R}(\theta)$. Since there is a one-to-one relationship between initial human capital and terminal human capital, this parameterization is innocuous.

For any particular set of parameters $(\alpha^S, \beta^S, A^S(\theta), H^S_{a_R}(\theta))$, we can simulate the model and form log wage profiles as functions of these parameters. For each ability type (θ), we estimate the model by nonlinear least squares, minimizing over individuals (denoted i):

$$\sum_i \sum_a (W^*_{i,a} - W_a(\alpha^S, \beta^S, A^S_\theta(\theta), H^S_{a_R}(\theta)))^2,$$

and constraining $0 < \alpha_S < 1$, $0 \leq \beta_S \leq 1$ and $A^S(j) > 0$ for two schooling groups. $S = 2$ if a person has completed one year of college; $S = 1$ otherwise. Estimates from this model are presented in the top panel of Table 1. Level $\theta = 1$ is the lowest quartile of AFQT ability while $\theta = 4$ is the highest quartile. The estimates of α^S and β^S are quite similar for the two schooling groups. The value of the productivity parameters $A^S(\theta)$ usually increase with AFQT, suggesting that more able people are more efficient in producing human capital. The terminal levels of human capital are higher for college-educated individuals than for persons attending high school.

In Heckman, Lochner and Taber (1998a), we present a sensitivity analysis of our estimates of the model to misspecification of heterogeneity and the economic environment. Except for the case where we estimate the model under one interest rate and simulate the model under another, the model is surprisingly robust to misspecifications of the economic environment.

In the top panel of Table 2, we present the initial levels of human capital for each schooling type by solving the model backward given the terminal condition estimates reported in Table 1. For all four ability types, the job market entry level of human capital increases with college. Except for one case, the initial level of human capital increases with AFQT across schooling groups. The one anomaly in the table is that the initial level of human capital is larger for the high school group of ability type 3 than for the high school group of ability type 4. (This is consistent, however, with the earnings profiles of young men in the NLSY displayed in Figures 1A and 1B.) The present value of earnings increases with ability for most groups.

The estimates of the human capital production function reported in Tables 1 and 2 are consistent with the Ben-Porath model ($\alpha^S = \beta^S$) that was widely used in the early literature on estimating human capital technology. The point estimates are remarkably similar to those reported by Heckman (1976) for his income maximizing models ($\alpha^S = \beta^S = .812$) for males and are consistent with the range of estimates reported by Brown (1976) for his sample of young males.[13] The estimated models fit the earnings data rather well for different schooling and ability levels. See Figures 1A and 1B.

Using our model and the assumption of no depreciation in skills, we can estimate the contribution of schooling and on-the-job training to lifetime human capital. Using an accounting framework that equates marginal and average rates of return, Mincer (1962) estimates that half of all human capital formation is on the job. Using our optimizing framework which distinguishes between marginal and average rates of return, we find that the contribution of OJT to the total human capital stock is much less - on the order of 23% - over all ability groups.

[13] Our estimates for women are quite similar to those for males (Heckman, Lochner and Taber, 1997). For them "β^S" and "α^S" are high and we cannot reject the Ben Porath model as a description of their human capital production function, or that women and men have the same human capital production function. Lochner (1998) reports similar estimates for a much more extensive analysis of the human capital production function with controls for heterogeneity.

D. Estimating the Probability of Attending College

Let D_i be the college tuition faced by individual i. The difference in utility between going to college and not going to college for individual i who is of ability type θ can be written as

$$V_i^*(\theta) = (1-\tau)[V_i^2(\theta) - V_i^1(\theta)] - D_i + \varepsilon_i(\theta)$$

where τ is the tax rate, and $\varepsilon_i(\theta) \sim N(\mu_\theta, \sigma_\varepsilon^2)$. We estimate μ_θ and σ_ε^2 by probit analysis using a two-step procedure. First, we run a probit regression of college attendance on tuition and dummy variables for each schooling-ability group for each of the seven birth cohorts in the NLSY. (The dummies estimate the difference in the after-tax valuation of schooling for each group.) The tuition variable is measured in units of thousands of dollars. We cannot reject the null hypothesis of no change in the value of attending school over the time period 1975-1982 when our sample makes its schooling decisions. We report results (in the bottom panel of Table 1) for the case when the value of attending school is constrained to be the same across time.

The third column in the bottom panel of Table 1 presents average derivatives. The interpretation of the average derivative is that an increase in tuition of $1000 decreases the probability of attending college by about .07 on average. This estimate is on the high end of the range of estimates reported in the literature (see *e.g.* Cameron and Heckman, 1997, or Kane, 1994). In the second stage, we transform the parameters D_i presented in Table 1 into the structural parameters of our model. We use the relationships $\lambda = \frac{1}{\sigma_\varepsilon}$, and $\alpha(\theta) = \frac{(1-\tau)[V^2(\theta) - V^1(\theta)] + \mu(\theta)}{\sigma_\varepsilon}$ and the estimates reported in Table 1 to form $[V^2(\theta) - V^1(\theta)](1-\tau)$. Then, we obtain

$$\mu(\theta) = \alpha(\theta)\sigma_\varepsilon - (1-\tau)[V^2(\theta) - V^1(\theta)]$$

as the mean nonpecuniary return to college for a person of ability level θ. The estimates are reported in the bottom panel of Table 2. The only surprise in this table is the negative mean psychic cost of attending college for persons of the highest ability.

E. Estimating the Technology and Aggregate Stocks of Human Capital By Skill

Using the CPS data for the period 1963-1993, we employ the methodology presented in subsections A and B to estimate skill prices and human capital aggregates. The data sources for the macro aggregates are presented in Appendix A. From the constructed aggregates, we estimate aggregate technology (II-10) and test for various specifications of the aggregate technology. To correct for endogeneity of inputs, we use the standard instrumental variables often used in macroeconomics - military expenditures and cohort size. OLS and IV estimates of the technology are reported in Table 3 for all possible combinations of the instruments.

The estimated elasticity of substitution between capital and the labor aggregate Q is $\sigma_2 = \frac{1}{1-\rho_2}$ and is not statistically significantly different from one. (See the fourth and fifth columns of Table 3.) Our estimates justify excluding capital (or the interest rate) from equation (I-1). Our model produces rising wage inequality without assuming a special complementary relationship between capital and skilled human capital - the centerpiece of the Krussell, Ohanian, Rios-Rull and Violante (1996) analysis of wage inequality and other discussions of rising wage inequality. Our estimates are consistent with the near-constancy of the capital share in the U.S. economy but the declining share of unskilled labor. (See Figure 2.) The estimated elasticity of substitution between high-skill and low-skill labor (1.441) is remarkably close to the point estimates reported by Katz and Murphy (1.41) and Johnson (1.50). The instrumental variable estimators do not change this estimate very much. Assuming no depreciation in human capital, we estimate the skill-bias parameter $\varphi_1 = .036$, very close to the corresponding estimate of .033 reported by Katz and Murphy.

F. Calibrating the Model

Given our estimates of the human capital production function, we choose an initial steady state which is consistent with the assumptions used to obtain those estimates in the NLSY data. Given a tax rate τ (= .15) that is suggested by Pechman (1987) as an accurate approximation to the true rate over our sample period once itemizations, deductions and income-contingent benefits are factored in, we calibrate the aggregate production parameters to yield a steady state after-tax interest rate of .05 and pre-tax rental rates on human capital of 2. These values are consistent with those used in estimation of the human capital production parameters. Since human capital is measured in terms of hourly wages, earnings from our simulations are annual income measured in thousands of dollars if agents work 2000 hours per year. The calibration yields shares that are consistent with the NLSY white male sample we use.

It is necessary to make some assumptions about time preference and the intertemporal elasticity of substitution for consumption in order to determine savings rates and aggregate capital. Given the levels of human capital investment implied by the estimates of our model and levels of initial assets for each individual, we obtain consumption and savings under the assumption that $\delta = 0.96$ and $\gamma = 0.1$. In order to determine initial levels of assets, we partially redistribute physical capital from retiring workers (cohort a_R) to the cohort just entering the labor market so that the capital-output ratio in the economy is 4.[14] This calibration procedure yields an initial steady state which emulates the NLSY data and central features of the macro economy. In Appendix C of Heckman *et al* (1998a), we test the sensitivity of our simulations to the choice of these parameter values, and find quantitatively similar results across a variety of specifications.

IV. A Dynamic general-equilibrium Model of Rising Wage Inequality in the U.S. Economy

In our previous papers, we use our estimated technology and human capital accumulation equations and determine whether or not we can explain the central features of rising wage inequality in the U.S. labor market over the period of the late 70^s to the early 90^s using a model of skill-biased technical change. The novel feature of our model, in contrast to the model of Bound and Johnson (1992), Katz and Murphy (1992) and Krussell *et al.* (1996) is that we allow for endogenous skill formation. Ours is a model of a gradual shift in the skill bias of technology to a higher permanent level.

Since we use a human capital production function fitted on young white males from the NLSY, our empirical model may not capture all features of the U.S. labor market. Since our estimates of the human capital production function for females are virtually identical to those of males, we do not think that this is a major source for concern.[15] Of potentially greater concern is our use of earnings data fit on the early years of the life cycle for a recent cohort of workers. Since most human capital investment takes place early in the life cycle, we capture the main portion of such investment. One final concern is the possibility of cohort effects in terms of endowments, ability, and human capital investment functions which we ignore in this paper although our model produces an endogenous cohort effect in a period of transition to a new level of technology.

We consider a permanent shift in technology toward skilled labor using the estimated trend parameter $\varphi_1 = .036$ reported in Table 3 as our base case. We start from an initial steady state and suppose that the technology reported in Table 3 begins to manifest a skill bias in the mid 70^s. Greenwood and Yorukoglu (1997) claim that 1974 is a watershed year for modern technology. Following their suggestion about the timing of the onset of technical change, $\log[a_1/(1-a_1)]$ is assumed to decline linearly at 3.6% per year (as estimated above) starting in the mid-70^s and continuing for 30 years. Shifts of longer and shorter duration

[14] For each year, transfer X is taken from all workers at retirement age a_R, and the total amount is equally distributed to all individuals (irrespective of ability) of age 1 in that period. For the simulations reported in this paper, $X \approx \$30,000$.

[15] See the estimates in Heckman, Lochner and Taber (1998a).

produce qualitatively similar simulation results within the time period we analyze. (See Heckman, Lochner and Taber (1998a), Appendix C.)

In this paper, we explore wage dynamics in an economy with open capital markets. We hold the after tax interest rate constant at .05 for all time periods, so that changes in the supply of skill and "local" savings rates do not affect the price of capital. Capital is assumed to flow in and out of the economy to maintain the constant world interest rate. However, the labor market in this economy is closed, so that the prices of skills are determined nationally by the derivative of the aggregate production technology given the national supply of skill.[16] Factor price equalization theorems do not apply since we have one good and three factors.

To compute the general-equilibrium of our model and the implied transition paths, we use the methodology of Auerbach and Kotlikoff (1987, p. 213). Starting from an initial steady state calibrated using the parameters of preferences and technology specified or estimated in Section III, we examine the transitional dynamics to the new steady state, imposing the requirement that convergence occurs in 200 periods or less.[17] Agents make their schooling and skill investment decisions under full rational expectations about future price paths, but they are surprised by a change in technology.

In the period immediately after the introduction of technological change, the price of skilled human capital increases while that of unskilled human capital decreases. (See Figure 3.) This results because short-term demand curves for skills shift more quickly than short-term supply curves which take time to shift because the stock of college graduates is slow to grow. This produces a rising college - high school wage differential (see Figure 4). The "rate of return" in a Mincer regression increases 40-60% over the 10-15 year period after the technology shock begins. (See Figure 5.)[18]

While not shown in the 30-year graphs we present,[19] the skill price paths eventually converge again (though not completely) as aggregate technology and demand for skills stops shifting, while short-term supply curves for skill continue to shift outward until skill supplies settle into their new steady state values. Consider the price path for college skill. The price rises initially as the demand for skill rises quickly, while the number of college graduates rises more slowly. Therefore, short-term demand curves shift out quickly, while supply curves move slowly. Once technology stops changing, demand curves for skill

[16]National prices and quantities refer to the economy of interest – the U.S. – while world prices and quantities are determined outside the model.

[17]Our models always converge in less than 200 periods so increasing the number of periods would not affect the transition path.

[18]The "rate of return" is the coefficient of schooling in a regression of log earnings on schooling, experience, and experience squared.

[19]Graphs of the full transition are available on request from the authors.

remain fixed, while supply curves continue to shift right as more college graduates enter the market. This causes the college skill price to fall until it reaches its new steady state level inducing what looks like a cobweb in a model with perfect foresight and privately optimal skill supplies. The "oversupply" of human capital in the process of adjustment is privately optimal because long-lived agents harvest both the returns when skill is scarce and when it is in glut and make a sufficient return in the period of scarcity to offset the period of glut see Figure 6 graphs the trend in the aggregate stock of potential and utilized skills produced from our model. Investment in human capital creates the wedge between the two measures of human capital stock.

An important feature of our description of the economy of the late 70^s and early 80^s is that the movement in wage differentials differs from the movement in price differentials, especially for younger workers. (See Figure 7 where wage differentials at different ages are compared to price differentials.) This phenomenon is a consequence of the economics embodied in equation (II-11). In response to the rise in skill prices in the years following the onset of technological change, high-skilled people who have left college invest *more* on-the-job (forseeing the upward trend in the price of their skill) and then curtail their investment as opportunity costs of investment rise relative to the payoff. These effects are especially large for younger workers who are more active investors. Cohorts of young skilled workers entering the market after the onset of technical change invest substantially less than earlier cohorts. (See Figure 8.) The story is quite different for low-skill workers. For these workers, the price of skill initially declines and then rises, so new cohorts of young workers invest slightly less in the early years of the transition. Late cohorts invest more as the price of low-skill human capital turns upward (Figure 9). As the price of their skill begins to converge to its new steady-state level, still later cohorts reduce their investment.

This differential response in investment by skill groups over time explains the evidence for the 1980^s presented in Katz and Murphy (1992, Table I) that the measured skill differential by education increases more for young persons than it does for older persons.[20] Additionally, Figure 7 shows the wage differential declining for young workers but rising for older workers during the first periods of the transition. In the first phase of the transition, differential investment by skill groups *narrows* the college-high school wage gap for young workers. For older workers, however, the rise in the skill premium is enough to offset changes in investment, so the wage gap rises for them. On average, the wage gap between skilled and unskilled labor increases over the first six years of the transition as skill prices diverge and the investment differential narrows. As investment by low-skill workers continues to rise, the college-high school wage gap begins to decline for about 15 years, at

[20]This assumes that the onset of the technology shift is in the mid-70^s as claimed by Greenwood and Yorukoglu (1997).

which time it starts to rise again. Both changes in investment behavior and skill prices are responsible for observed patterns in the skill differential.

These results differ from the closed economy version of our model, where only two trends in the wage gap are present after the onset of skill-biased technical change: a short decline arising from increased investment by college workers which more than offsets the rise in their skill price and then a sustained rise (as the investment differential narrows and skill prices diverge). This difference between the models occurs because in the closed-economy version, interest rates rise and disproportionately choke off the rise in investment for high school workers. The closed-economy version of the model is more consistent with the evidence reported by Bartel and Sicherman (1998). They find that over the period of the mid-80s, when wage inequality was increasing substantially, investment in company training increased for less-educated workers, both absolutely and compared to that of more-educated workers in industries where technological progress was rapid. While the open-economy version presented here yields this result for a short stretch of the early period of the transition, it does not characterize later periods wheras the closed-economy model does.

The model produces a large jump in college enrollments with the onset of technical change. This is an artifact of our perfect foresight assumption. A model in which information about skill bias disseminates more slowly would be more concordant with the data.[21]

While both investment in on the job and schooling increase during early years of the transition, the amount of human capital per worker declines for each skill type in the long run. In the closed-economy version, there is a phase where more people attend college, but both college and high school workers invest less on the job. Thus, movements in skill investment at the extensive margin may differ from those made at the intensive margin.

It is interesting to examine the self-correcting properties of this equilibrium. In response to the new technology regime, the standard deviation of log wages initially rises 75-100% but then converges to its original steady state value. The model also explains rising wage inequality at different percentiles of the wage distribution. However, this phenomenon is transient. (See Figure 10.) Wage inequality initially rises quickly for college graduates, but it then declines to approximately its initial steady state value. The story is quite different for high school graduates. For this group, inequality is stable for almost 30 years, at which point within-group inequality begins to rise steeply. On this point, our model is at odds with the stylized facts about wage inequality.[22]

[21] An alternative way to generate a more gradual response in educational enrollment is to endogenize tuition, recognizing that college is skilled-labor intensive so that as skill prices increase, the cost of schooling rises.

[22] Our model is consistent with the more recent evidence. Krueger (personal communication, 1997)

The models of Krussell, *et al.* (1996) and Greenwood and Yorukoglu (1997) abstract from heterogeneity within skill groups and cohorts and cannot explain the within-skill-class rise in inequality. Their models cannot explain the flattening of wage-experience profiles for high-skill groups or the steepening of wage-experience profiles for low-skill groups. The analyses of Caselli (1997) and Violante (1996) cannot explain this phenomenon either. For Caselli, individuals work only one period, so his model offers no prediction about experience-wage profiles. Violante's model predicts that when a new technology arrives, the returns to skills learned on previous technologies fall, leading to a *decline* in the slope of wage - experience profiles for low-skill workers. This prediction is grossly at odds with the data. However, both Caselli's and Violante's models explain the rise in wage inequality within narrowly-defined skill cells. For Violante, this is a consequence of the matching of workers to vintages, accelerated technical change, and induced labor turnover. For Caselli, this is due to increased sorting of high-skill labor with capital, where skill is endogenously determined.

Accounting for the Baby Boom

As a test of our model, we ask how well we match the past 35 years of U.S. wage history using the aggregate technology and human capital accumulation equations estimated in this paper. We consider an economy in which an episode of skilled-biased technical change ($\varphi_1 = .036$) begins in 1960 and continues for 30-40 years. To this, we add the demography of the Baby Boom in which cohort sizes increased by approximately 32%. We assume that Baby Boom cohorts begin to enter the economy in the mid-60^s and continue for a period of 15 years.

Figure 11 presents the simulated college-high school wage differential. It captures the essential features of recent U.S. wage history. The differential increases in the 60^s, decreases in the 70^s and rises again the 80^s and 90^s. The simulated model predicts that college enrollment rates jump up in the 60^s and decline in the 70^s and 80^s. Predicted real wages of high school graduates fall in the 60^s and 70^s but rise in the 80^s and 90^s. The real wages of college graduates rise, fall, and then rise in the period of the 60^s, 70^s, and 80^s respectively. The college-high school wage differential at age 30 rises over the period 1963-74, decreases until the mid-80^s and then rises again. (See Figure 12.) However, the closed-economy version of our model tracks the Baby Boom more closely. Overall, the standard deviation of log wages rises throughout most of the 30-year period.

suggests that rising wage inequality within narrowly-defined skill groups is no longer increasing for all skill groups. When we alter the model to account for migration of low ability workers into the economy, we can produce widening wage inequality within all skill groups. However the required increase in migration is implausibly large.

Table 4 summarizes the properties of our model in a format comparable to Table I of Katz and Murphy (1992). The college-high school wage differential rises in the 60^s, falls in the 70^s and rises in the 80^s in a fashion that mirrors the evidence reported by Katz and Murphy (Table I). Income inequality measured by the standard deviation in log wages increases over all decades, although the largest change is in the 70^s. These basic trends are consistent with those of our closed-economy version of the model.

With the same basic ingredients of human capital investment and aggregate technology, we explain 35 years of U.S. wage history, assuming that skill-biased technology starts around 1960 and continues for 30-40 years and the Baby Boom cohorts enter the work and schooling economy in the mid 60^s. The expansion in college enrollment in the 60^s can be explained by basic economic forces and not as a consequence of generous tuition policies. In fact, as we show in section VI, tuition policies are likely to have small effects on enrollment and wage inequality once skill prices are allowed to adjust and rational agents respond to these adjustments in making their schooling decisions.

V. Comparisons Between Cohorts and Cross Sections in Utility Levels and in Mincer "Rates of Return"

One benefit of an overlapping-generations model is that it enables us to compare cross sections with cohort paths, which are economically more interpretable for conducting welfare analysis and for making policy recommendations about human capital investment decisions for new cohorts entering the labor market. We use our model to perform systematic generational accounting in the fashion pioneered by Auerbach and Kotlikoff (1987). Figures 13A-D show how overall lifetime utility, lifetime utility by ability, and lifetime utility by ability and schooling type change over cohorts.

The widely-used Benthamite measure of aggregate lifetime utility (obtained by summing over the utilities of all persons in the economy at a point in time) rises for cohorts entering the labor market less than 30 years prior to the onset of technological change and jumps up even more for cohorts entering the labor market immediately after the shock. (See Figure 13A.) The date of onset of the technology change is at the time cohort zero enters the labor market. Later cohorts gain even more than those entering immediately after the shock.

Disaggregating by ability groups (Figure 13B), higher ability workers gain from the new economy both in the long run and in the short run. High-ability persons who enter the economy before the technology shock do somewhat better than their predecessors. Low-ability persons entering the economy before the technology shock do slightly worse. Low-ability cohorts born before the onset of the technology change are hurt for substantial periods of time after the shock occurs. In the long run, however, cohorts of workers of all ability levels are better off.

Figures 13C and D report results disaggregated by ability and education. For cohorts born after the shock, the utility path for high school-educated workers declines but recovers until it reaches a new higher level. (See Figure 13C.) Cohorts entering the market before the shock have lower utility than the predecessor and successor cohorts. In the new steady state, cohort utility levels are higher. For college-educated persons, the story is different and is not entirely the mirror image of the case for high school graduates. (See Figure 13D.) High-skill persons educated before the advent of technology change capture a large rent due to the unanticipated rise in skill prices. Successor cohorts do not fare as well, though they are still better off than if the economy had remained in the initial steady state. Their lower mean utility can be attributed to the strong distaste for college of the new college entrants. They now attend college, because the decline in their earnings in the unskilled sector is even greater than the tuition and psychic costs of attending college.[23]

In the closed-economy version of our model, both high school and college graduates entering the labor market within 10-15 years after the onset of technological change fare worse than their predecessors and successors. In the open- economy version of our model, all cohorts fare much better throughout the transition, and those born after the transition begins fare better than their predecessors. That is because in the open-economy version of our model capital inflows keep the interest rate from rising and choking off investment in skills. The lower interest rate particularly favors high school graduates born early in the transition since they want to borrow and invest heavily as they see the price of their skill rising after a few years into the transition.

Evidence reported by MaCurdy and Mroz (1995) and Beaudry and Green (1997) that cohorts entering the labor market immediately after the start of technological change do worse than predecessor cohorts is consistent with our closed-economy version but is at odds with the open-capital market version presented here. This is another strike against the open-economy version. Figure 14 shows the lifetime earnings of various cohorts of college and high school graduates. Each successive cohort of college graduates earns more than its predecessor until almost thirty years after the change in technology began. High school cohorts born near the beginning of the transition fare the worst in terms of lifetime earnings.

The important role of nonpecuniary costs in explaining college attendance accounts, in part, for the gap between the after-tax opportunity cost of capital (5%) and the conventional cross-section Mincer "return" which ranges from 7.5%-18% (see Figure 5). Nonpecuniary components are 15% of the total cost to college attendance for the most able. Also, observe

[23]The discontinuity in the utility paths for college graduates arises from the discontinuity in college attendance induced by the onset of technology change and by the greater psychic and tuition costs of attending school by the marginal college entrants.

the gap between the cohort "rate of return" (Figure 15) and the cross-section rate (Figure 5). During early years of the transition, the estimated cross-section "rate of return" is substantially lower than the "rate of return" experienced by any entry cohort. However, in later periods of the transition, the opposite is true. Cross-sectional "rates of return" are not appropriate guides to educational investments for entering cohorts, although they are often used that way. This points to an important weakness in the conventional method of evaluating tuition and other policies, in addition to the more familiar problems that (a) monetary rates of return are not true rates of return (because of psychic benefits) and (b) steady-state general-equilibrium adjustments resulting from policies are typically ignored and (c) taxes are required to raise revenue. During periods of transition to a new skill regime, cross-section rates of return to education present an inaccurate account of the "rate of return" any single cohort can earn. For example, the Mincer coefficient in year 15 is around 16% (Figure 5) while the Mincer return for the cohort entering in year 15 is 6.5% (see Figure 15). We discuss this discrepancy further in the next section.

Observe, finally, that within-cohort wage inequality, presented in Figure 14, often moves in the opposite direction from aggregate wage inequality. In years immediately after the technology shock, entry level cohorts experience declining aggregate wage inequality even though aggregate wage inequality is rising (compare Figures 10 and 14).

VI. Understanding Mincer Rates of Return

It is instructive to compare the rate of return in our model with that reported in the standard literature in labor economics - the coefficient of schooling in a log wage regression. The standard approach in labor economics is based on the following model which implicitly assumes that skill prices are stationary. Let $w(s,x)$ = wage income at experience x for schooling level s; $T(s)$ = last age of earnings; v is private tuition costs minus nonpecuniary returns, $(1-\tau) = 1$ minus the proportional tax rate; and r = before-tax interest rate.

Agents are assumed to maximize the present value of earnings. The criterion maximized at the individual level is

(VI-1) $$\int_0^{[T(s)-s]} (1-\tau)e^{-(1-\tau)r(x+s)}w(s,x)dx - \int_0^s ve^{-(1-\tau)rj}dj.$$

This expression embodies an institutional feature of the U.S. economy where income from all sources is taxed but one cannot write off costs of tuition. However, we assume that agents can write off interest on their loans. This is consistent with the institutional feature that persons can deduct mortgage interest, that 70% of American families own their own homes and that mortgage loans can be used to finance college education.

The first order conditions for maximizing present value are

(VI-2) $$(1-\tau)[T'(s)-1]e^{-rT(s)(1-\tau)}w(s,T(s)-s)-(1-\tau)r\int_0^{T(s)-s}(1-\tau)e^{-(1-\tau)r(x+s)}w(s,x)dx$$

$$+\int_0^{T(s)-s}(1-\tau)e^{-(1-\tau)r(x+s)}\frac{\partial w(s,x)}{\partial s}dx - ve^{-(1-\tau)rs} = 0.$$

Rearranging, we obtain

(VI-3) $$(1-\tau)[T'(s)-1]e^{-(1-\tau)r[T(s)-s]}w(s,T(s)-s)-(1-\tau)^2r\int_0^{T(s)-s}e^{-(1-\tau)rx}w(s,x)dx$$

$$+\int_0^{T(s)-s}(1-\tau)e^{-(1-\tau)rx}\frac{\partial w(s,x)}{\partial s}dx = v.$$

Thus

(VI-4) $$\frac{[T'(s)-1]e^{-(1-\tau)r[T(s)-s]}w(s,T(s)-s)}{\int_0^{T(s)-s}e^{-(1-\tau)rx}w(s,x)dx}$$

$$+\left[\int_0^{T(s)-s}e^{-(1-\tau)rx}\left[\frac{1}{w(s,x)}\frac{\partial w(s,x)}{\partial s}\right]w(s,x)dx \Big/ \int_0^{T(s)-s}e^{-(1-\tau)rx}w(s,x)dx\right]$$

$$-\frac{v}{(1-\tau)\int_0^{T(s)-s}e^{-(1-\tau)rx}w(s,x)dx} = (1-\tau)r.$$

The special case assumed in the Mincer model writes $v = 0$, $T'(s) = 1$. (No private tuition costs and no loss of work life from schooling). This simplifies the first order condition to

(VI-5) $$(1-\tau)r\int_0^{T(s)-s}e^{-(1-\tau)rx}w(s,x)dx = \int_0^{T(s)-s}e^{-(1-\tau)r(x)}\frac{\partial w(s,x)}{\partial s}dx.$$

Mincer further assumes multiplicative separability:

(VI-6) $w(s,x) = \mu(s)\varphi(x)$

so in logs,

$$\log w(s,x) = \log\mu(s) + \log\varphi(x).$$

Thus

$$(1-\tau)r\mu(s)\int_0^{T(s)-s}e^{-(1-\tau)rx}\varphi(x)dx = \mu'(s)\int_0^{T(s)-s}e^{-(1-\tau)rx}\varphi(x)dx$$

and

(IV-7) $$(1-\tau)r = \frac{\mu'(s)}{\mu(s)}.$$

Then the coefficient on schooling in a Mincer equation estimates the rate of return to schooling which is the same as the after tax interest.

In the general case, we obtain

$$\underbrace{\frac{[T'(s)-1]e^{-(1-\tau)r[T(s)-s]}w(s,T(s)-s)}{\int\limits_0^{T(s)-s} e^{-(1-\tau)rx}w(s,x)dx}}_{\text{(Term 1)}} + \underbrace{\frac{\int\limits_0^{T(s)-s} e^{-(1-\tau)rx}\left[\frac{\partial \ln w(s,x)}{\partial s}\right]w(s,x)dx}{\int\limits_0^{T(s)-s} e^{-(1-\tau)rx}w(s,x)dx}}_{\text{(Term 2)}} - \underbrace{\frac{v}{(1-\tau)\int\limits_0^{T(s)-s} e^{-(1-\tau)rx}w(s,x)dx}}_{\text{(Term 3)}}$$

$$= \quad (1-\tau)r.$$

Term 1 is the earnings-life effect - the value of the change in the present value of earnings due to the change in working-life due to schooling as a fraction of the present value of schooling measured at age s. Term 2 is the weighted (by discounted income over the lifetime) effect of schooling on earnings by age. Term 3 is the cost of tuition expressed as a fraction of lifetime income measured at age s.

Observe that if there is uncertainty about future earnings, then we may replace $w(s,x)$ and $\frac{\partial \ln w(s,x)}{\partial s}$ by their expected values. In the special case of the Mincer model, if the shocks to earnings equations are multiplicatively-separable, the basic relationship (VI-7) is unaffected. Thus if $w(s,x) = \mu(s)\varphi(x)\varepsilon(s,x)$, the Mincer model is not affected at any age as long as $\varepsilon(s,x) \neq 0$.

The evidence presented in this paper and Heckman, Lochner and Taber (1998) argues strongly against assumption (VI-6). Log wage profiles are not parallel in work experience across schooling groups. (See also the evidence in Heckman and Todd, 1997). In addition, private tuition costs ($v\theta$) are not zero and are not offset by work in school for most college students. In addition, we estimate substantial psychic costs/benefits of schooling (see the estimates reported in Table 2). The assumption of equal-working lives for people of different schooling levels is at odds with the data presented by Mincer. These factors account for the disparity between the after-tax interest rate of .05 (= (1-τ)r) and the steady-state Mincer coefficient obtained from regressing simulated steady-state log earnings on schooling, experience and experience squared. (This is the intercept in Figure 5 and is .092). Finally, the least squares estimate does not control for variation in the ability of persons attending college so that classical ability bias may raise the return.[24]

More serious, however, is the implicit steady-state assumption built into the Mincer model. In a period of changing demand for different skill groups, cross-sectional and cohort Mincer coefficients disagree, as is evident from comparing Figures 5 and 15, and as discussed in Section V. High-skilled individuals who acquire their schooling before the onset of technological change earn a rent just as low-skilled individuals who entered the work force before the onset of technical change suffer a capital loss. Cross-section earnings functions capture these rents which are the returns that fresh entrants into the labor force will enjoy. Moreover, persons who become skilled just after the onset of technical change earn super-normal returns that will not be experienced by subsequent cohorts as supplies adjust. Accordingly, widely-used cross-sectional "rates of return" to schooling are a poor guide to policy. Fifteen years after the onset of technological change, cross section Mincer rates of return are over 16% while cohort rates are under 7%. The cross-section rate of return is wildly optimistic and should not be used as a guide to educational policy.

VII. General-equilibrium Treatment Effects: A Study of Tuition Policy

This section of the paper uses our model to consider the effects of changes in tuition on schooling and earnings, accounting for general-equilibrium effects on skill prices. The typical evaluation estimates the response of college enrollment to tuition variation using geographically dispersed cross-sections of individuals facing different tuition rates. These estimates are then used to determine how subsidies to tuition will raise enrollment. The impact of tuition policies on earnings is evaluated using a schooling-earnings relationship fit on pre-intervention data and does not account for the enrollment effects of the taxes raised to finance the tuition subsidy. Kane (1994) exemplifies this approach.

The danger in this widely-used practice is that what is true for policies affecting a small number of individuals need not be true for policies that affect the economy at large. A national tuition-reduction policy that stimulates substantial college enrollment will likely compress skill prices, as advocates of the policy claim. However, agents who account for these changes will not enroll in school at the levels calculated from conventional procedures which ignore the impact of the induced enrollment on earnings. As a result, standard policy evaluation practices are likely to be misleading about the effects of tuition policy on schooling attainment and wage inequality. The empirical question is how misleading? We show that these practices lead to estimates of enrollment responses that are more than

[24]The evidence on the importance of ability bias is mixed. See, *e.g.* Griliches (1979) and Card (1996). The evidence reported in Cawley *et.al* 1998 demonstrates that fundamental identification problems plague studies of the effect of ability on earnings.

ten times larger than the long-run general-equilibrium effects. We also improve on current practice in the treatment effects literature by considering both the gross benefits of the program and the tax costs of financing the treatment as borne by different groups.

Evaluating the general-equilibrium effects of a national tuition policy requires more information than the tuition-enrollment parameter that is the centerpiece of partial-equilibrium policy analysis. Most policy proposals extrapolate well outside the range of known experience and ignore the effects of induced changes in skill quantities on skill prices. We apply our open capital market general-equilibrium framework to evaluate tuition policies that attempt to increase college enrollment.

Conventional Models of Treatment Effects

The standard framework for microeconometric program evaluation is partial-equilibrium in character (see Heckman and Robb, 1985). For a given individual i, $Y_{0,i}$ is defined to be the outcome the individual receives if he participates in the program, and $Y_{1,i}$ is the outcome he receives if he does not participate. The treatment effect for person i is $\Delta_i = Y_{1,i} - Y_{0,i}$. When interventions have general-equilibrium consequences, these effects depend on who else is treated and the market interaction between the treated and the untreated.

To see the problems that arise in the standard framework, consider instituting a national tuition policy. In this case, $Y_{0,i}$ is person i's wage if he does not attend college, and $Y_{1,i}$ is his wage if he does attend. The "parameter" Δ_i then represents the impact of college, and it can be used to estimate the impact of tuition policies on wages. It is a constant, or policy-invariant, parameter only if wages $(Y_{0,i}, Y_{1,i})$ are invariant to the number of college and high school graduates in the economy.

In a general-equilibrium setting, an increase in tuition increases the number of individuals who attend college, which in turn decreases the relative wages of college attendees, $Y_{1,i}/Y_{0,i}$. In this case, the program not only impacts the wages of individuals who are induced to move by the program, but it also has an impact on the wages of those who do not. For two reasons, then, the "treatment effect" framework is inadequate. First, the parameters of interest depend on who in the economy is "treated" and who is not. Second, these parameters do not measure the full impact of the program. For example, increasing tuition subsidies may increase the earnings of uneducated individuals who do not take advantage of the subsidy. To pay for the subsidy, the highly educated would be taxed and this may affect their investment behavior. In addition, additional educated workers enter the market as a result of the policy, depressing the earnings of other college graduates. Conventional methods ignore the effect of the policy on nonparticipants. In order to account for this effect, it is necessary to conduct a general-equilibrium analysis.

Exploring Increases in Tuition Subsidies in a General-Equilibrium Model

We first simulate the effects of a revenue-neutral $500 increase in tuition subsidy (financed by a proportional tax) on enrollment in college and wage inequality starting from our baseline economy. The partial-equilibrium increase in college attendance is 5.3 percent in the new steady state. This is in the range of effects reported by Kane (1994) and Cameron and Heckman (1998). This analysis holds skill prices, and therefore college and high school wage rates, fixed – a typical assumption in microeconomic "treatment effect" analyses of tuition policies.

When the policy is evaluated in a general-equilibrium setting, the estimated effect falls to 0.49 percent. Because the college-high school wage ratio falls as more individuals attend college, the returns to college are less than when the wage ratio is held fixed. Rational agents understand this effect of the tuition policy on skill prices and adjust their college-going behavior accordingly. Policy analysis of the type offered in the "treatment effect" literature ignores the responses of rational agents to the policies being evaluated. There is substantial attenuation of the effects of tuition policy on capital and the stocks of the different skills in our model. Simulating the effects of this policy under a number of additional alternative assumptions about the parameters of the economic model, including analysis of a case where tuition costs rise with enrollment, reproduces the basic result of substantial partial-equilibrium effects and much weaker general-equilibrium effects.

Our steady state results are long-run effects. When we simulate the model with rational expectations, the short-run enrollment effects are also very small, as agents anticipate the effects of the policy on skill prices and calculate that there is little gain from attending college at higher rates. If we simulate using myopic expectations, the short-run enrollment effects are much closer to the estimated partial-equilibrium effects. All of these results are qualitatively robust to the choice of different tax schedules. Progressive tax schedules choke off skill investment and lead to even lower enrollment responses in general equilibrium.

We next consider the impact of a policy change on discounted earnings and utility. We decompose the total effects into benefits and costs, including tax costs for each group. Table 5 compares outcomes in two steady states: (a) the benchmark steady state and (b) the steady state associated with the new tuition policy. Given that the estimated schooling response to a $500 subsidy is small, we instead use an extremely high $5000 subsidy for the purpose of exploring general-equilibrium effects. The rows High School - High School report the changes in a variety of outcome measures for those persons who would be in high school under the benchmark or new policy regime; the High School - College rows report the changes in the same measures for high school students in the benchmark who are induced to attend college only by the new policy; College - High School outcomes refer to those persons in college in the benchmark economy who only attend high school after the new policy is put in place; and so forth.

By the measure of the present value of earnings (column 3), some of those induced to change are worse off. Contrary to the monotonicity assumption built into the LATE parameter of Imbens and Angrist (1994), defined in this context as the effect of tuition change on the earnings of those induced to go to college, we find that the tuition policy produces a two-way flow. Some people who would have attended college in the benchmark regime no longer do so. The rest of society also is affected by the policy–again, contrary to the implicit assumption built into LATE that only those who change status are affected by the policy. People who would have gone to college without the policy and continue to do so after the policy are financially worse off for two reasons: (a) the price of their skill is depressed and (b) they must pay higher taxes to finance the policy. However, they now receive a tuition subsidy and for this reason, on net, they are better off both financially and in terms of utility. Those who would abstain from attending college in both steady states are also better off in the second steady state. They pay higher taxes, but their skill becomes more scarce and their wages rise. Those induced to attend college by the policy are better off in terms of utility but are not always better off in terms of income. For example, individuals from ability quartiles 2 and 3 have lower net incomes as a result of the tuition policy; however, their utility rises due to a strong taste for college education. While most groups gain about the same in terms of utility, there is substantial variation in the effects on lifetime earnings. Note that neither category of non-changers is a natural benchmark for a "difference in differences" estimator. The movement in their wages before and after the policy is due to the policy and cannot be attributed to a benchmark "trend" that is independent of the policy. The implicit assumptions that justify the widely-used difference in differences estimator do not apply here. The tax system, and the market make the "nontreated" affected by the policy. (See the discussion in Heckman, LaLonde and Smith, 1999). These conclusions are robust as to whether a closed-economy or open-economy model is used.

VIII. Tax Policy and Human Capital Formation

Missing from recent discussions of tax reform is any systematic analysis of the effects of various tax proposals on skill formation. (See the papers in the collection edited by Aaron and Gale, 1996. Davies and Whalley, 1991, and Dupor, *et. al*, 1997, are notable exceptions.) This gap in the literature in empirical public finance is due to the absence of any empirically based general-equilibrium models with both human capital formation and physical capital formation that are consistent with observations on modern labor markets. We use our model to study the impacts on skill formation of proposals to switch from progressive taxes to flat income and consumption taxes, focusing our attention on steady states.

Tax Effects on Human Capital Accumulation

In the absence of labor supply and direct pecuniary or nonpecuniary costs of human capital investment, there is no effect of a proportional wage tax on human capital accumulation. Both marginal returns and costs are scaled down in the same proportion. When untaxed costs or returns to college are added to the model (*i.e.* non-pecuniary costs/benefits), proportional taxation is no longer neutral. An increase in the tax rate decreases college attendance if the net financial benefit before taxes is positive $(V^2 - D^2 - V^1 > 0)$. Progressivity reinforces this effect. A progressive wage tax reduces the incentive to accumulate skills, since human capital promotes earnings growth and moves persons to higher tax brackets. As a result, marginal returns on future earnings are reduced more than marginal costs of schooling.

Heckman (1976) notes that in a partial-equilibrium model, proportional taxation of interest income with full deductibility of all borrowing costs reduces the after-tax interest rate and, hence, promotes human capital accumulation. In a time-separable, representative agent general-equilibrium model, the after-tax interest rate is unaffected by the tax policy in steady state as agents shift to human capital from physical capital (see Trostel (1993)). In that framework, flat taxes with full deductibility have no effect on human capital investment. In a dynamic overlapping-generations model with heterogeneous agents, endogenous skill formation, and progressive rates, taxes have ambiguous effects on human capital and both their quantitative and qualitative effects can only be resolved by empirical research. We use our empirically grounded model to study alternative proposals for tax reform in this framework.

Analyzing Two Tax Reforms

Following Kotlikoff, Smetters and Walliser (1997), we assume that the U.S. income tax can be captured by a progressive tax on labor income and a flat tax on capital income. This assumption greatly simplifies the computations. Similar results are obtained from a more realistic tax schedule. We assume that each earner has 1.22 children and is single. For each additional dollar beyond \$9660, we assume that there is an increase in itemized deductions of 7.55 cents. Therefore, an individual with labor income Y has taxable income $(Y - 9660)(1 - .0755)$. Using the 1995 tax schedule, we compute the taxes paid by income and approximate this schedule by a second order polynomial. We assume a 0.15 flat tax rate on physical capital.

We consider two revenue-neutral tax reforms from this benchmark progressive schedule. The first reform (which we call "Flat Tax") is a revenue-neutral flattening of the tax on labor earnings holding the initial flat tax on capital income constant. The second reform ("Flat Consumption Tax") is a uniform flat tax on consumption. In both flat tax schemes, tuition is not treated as deductible. For each tax, we consider two models: (1) a partial-equilibrium model in which skill prices and interest rates are fixed and (2) an open-economy general-equilibrium model in which skill prices adjust while pretax interest rates remain constant.

Table 6 presents both partial-equilibrium and general-equilibrium simulation results measured relative to a benchmark economy with the KSW tax schedule. Table 7 presents a corresponding closed-economy version where the interest rate is not fixed in world capital markets. We first discuss the open-economy partial-equilibrium effects of a move to a "Flat Tax," which eliminates progressivity in wages and stimulates skill formation. College attendance rises dramatically as the higher earnings associated with college graduation are no longer taxed away at higher rates. The amount of post-school on-the-job training (OJT) also increases for each skill group (as measured by the stocks of human capital per worker of each skill). While the percentage increases in college enrollment are substantially larger among low ability individuals (reflecting in part their low initial enrollment rates), the amount of skill per worker acquired during the first 10 years of work increases more for the most able who benefit more from the flattening of the wage tax. The aggregate stock of high school and college human capital rises, while the stock of physical capital used in production declines. This reflects the fact that the flatter tax schedule favors human capital formation over the benchmark economy. The college-high school wage differential increases by roughly 2%, and the standard deviation of log wages increases by about 4%. The partial-equilibrium effects of reform on aggregate consumption and output are inconsequential.

The open-economy general-equilibrium effects of tax reform are noticeably different from the partial-equilibrium effects. The skill prices for both types of human capital now decline, although the price of college human capital drops much more. As a result the effects on college attendance are negative for low-ability workers, although the overall attendance rate still rises marginally. Since interest rates are the same in both the partial-equilibrium and general-equilibrium flat tax environment, the gains in human capital over the early part of the life-cycle are identical to those of the partial-equilibrium model. The on-the-job investment profiles will be identical in the closed-economy and the open-economy model as long as after-tax interest rates are identical. Flat taxes on labor earnings mark down costs and returns in the same proportions. The greater increases in human capital per worker in the general-equilibrium are, therefore, due solely to the fact that only the more able are drawn into college compared to the partial-equilibrium state. Aggregate stocks of college and high school human capital both rise in the general-equilibrium. Now that since fewer workers respond to the tax change by attending college, the aggregate stock of high school human capital rises rather than falls since each high school graduate responds to the flat tax by investing more. In general equilibrium, the physical capital stock still drops substantially, and the declines in output and consumption are much larger than in the partial-equilibrium model due to the large drop in skill prices. By these measures of welfare, the flat tax is worse than the progressive wage tax even though skill levels are higher per worker. In regard to wage inequality, our two measures show different effects. The standard deviation in log wages rises as it did in the partial-equilibrium case; however, the college - high school wage premium declines by about 2%.

The greatest differences in the general-equilibrium effects of reform from our previous closed-economy version of the model deal with physical capital. (See the simulation estimates in Table 7). In a closed-economy, interest rates rise in response to the policy change. This substantially reduces the decline in physical capital that occurs in the open-economy case. Furthermore, the closed-economy version shows little effect of the tax reform on aggregate consumption and output, while our open-economy version shows declines in excess of 5% for each which is largely due to the huge outflow of capital. The decline in the college-high school wage gap is less in the closed-economy version and the rise in wage inequality as measured by the standard deviation of log wages is less in the closed-economy model. College attendance becomes more stratified in the closed-economy version. Because of the rise in the after-tax interest rate, the increase in post-school human capital investment is smaller in the closed-economy version of the model than in the open-economy version.

Next, consider a revenue neutral move to a "flat consumption tax." This reform is more pro-capital and is less favorable to human capital than the flat income tax because it increases the tax on human capital to offset the cut in tax on physical capital. It raises output, the capital stock and consumption substantially, while it reduces the aggregate stock of college human capital. In general equilibrium, it also reduces the stock of high school human capital. The amount of human capital per worker declines for college graduates but is nearly constant for high school graduates once general-equilibrium effects are accounted for. Investments on the job decline by about 7-8% for all individuals due to the large increase in the after-tax interest rate.[25] The fraction attending college declines substantially for all ability types in partial-equilibrium. In general-equilibrium, the policy reduces the attendance of middle ability workers and raises attendance rates of individuals at the top

[25] This is the effect stressed by Heckman (1976).

and bottom of the ability distribution.[26] The reform raises wage inequality as measured by the college-high school wage premium, but lowers it as measured by the standard deviation of log wages. The general-equilibrium comparison shows more equality (by both measures) than the partial-equilibrium. Skill prices and mean wage rates rise substantially as capital flows into the economy, in contrast to the "Flat Tax" economy discussed above. Since capital is a direct complement with both forms of human capital, the increase in capital raises skill prices about equally for both skill groups.

The increase in the physical capital stock (124%) in general-equilibrium in the open-economy case raises output (42%) and consumption (34%). The scale of most responses seem inflated compared to the closed-economy case when the after-tax interest rate increases after the reform. For that version of our model, the simulated general-equilibrium responses look more credible. (See Table 7.) Capital stock increases by 19.5%, consumption by 3.6% and output by 5%. The increase in the college-high school wage differential is much less than is predicted in the open-economy case. The decrease in the fraction attending college is the same in both cases. However, in the closed-economy case, movement to a flat consumption tax promotes post-school investment whereas it substantially reduces post-school investment in the open-economy case.

When we introduce deductibility of tuition in both reforms, and preserve revenue neutrality, there is virtually no change in the effects skill formation (or anything else) in general-equilibrium for either the closed-economy or the open-economy. This is consistent with the simulations reported in the previous section, in which we show that general-equilibrium effects of tuition subsidies are small. The lessons from partial-equilibrium analyses are substantially misleading guides for analyzing the effects of tax and tuition policy on skill formation. The benefits from changing to proportional wage taxation are small and must be weighed against the costs. While our open-economy simulations show that it would increase skill formation, it would also reduce consumption, output, and wages. A change to a flat consumption tax has larger (and positive) effects on output, consumption, and real wages, but it also slightly raises the college - high school wage premium and reduces aggregate skill levels. However these effects are all much weaker in the closed-economy case. The effects of tax reform on physical capital accumulation seem implausibly large in the open-economy case.

IX. Comparing Open and closed-economy Versons of The Model

Comparing the open-economy model with the closed-economy model, the closed-economy version produces more plausible investment responses for both physical and human capital.

[26]The rise in college going at the bottom of the ability distribution is due to the greater tax on the earnings of the less able and the flattening of the tax schedule. They now pay greater taxes and going to college offsets their enhanced tax burden.

For example, the open-economy version predicts unbelievably large OJT responses during the period of transition to the new technology compared to the closed-economy version. The physical capital inflows implied by the open-economy version are also implausibly large. The investment responses to tax reform also seem implausibly large in the open-economy version compared to the closed-economy version. Investment is very sensitive to interest rates in our model. The movement in the interest rate induced by technical change or tax reform in the closed-economy version of our model chokes off these implausibly large investment responses.

Additional support for the closed-economy model comes from the pattern of skill investment by the less skilled during the transition. Bartel and Sicherman (1998) report that over the period of the mid 80^s, when wage inequality was increasing substantially, investment in company training increased for less educated workers, both absolutely and compared to that of more educated workers in industries where technological progress was rapid. The open-economy version of the model produces this phenomenon only for a brief stretch of time. The closed-economy version of the model produces this phenomenon for the longer periods of time observed in the Bartel-Sicherman study.

Assuming that skill-biased technical change commences in the early 1970^s, the path of the real interest rate produced by the closed-economy version of the model is in rough agreement with the data. See Figure 17 which reveals that in the early stages of the onset of technical change, the real interest rate is predicted to rise as indeed it did in the late 70^s and early 80^s in the U.S. economy. This is one more bit of evidence in support of the closed-economy version of our model.

X. Summary and Conclusions

This paper summarizes the overlapping-generations general-equilibrium model of heterogeneous skills developed in Heckman, Lochner and Taber (1998a) and applies it in an open-capital market environment in order to evaluate proposals designed to foster skill formation. The model has important self-correcting features. Through supply adjustments, substantial wage inequality induced by skill-biased technical change is all but eliminated in the long run. Skill-biased technical change hurts cohorts of unskilled and low-ability workers entering the market at the time of the onset of technical change. In the long run, all groups benefit. The major policy problem is intergenerational in character. Certain cohorts are badly hurt by the onset of technical change. Temporary policies that compensate the losers are appropriate — not long term skill subsidies of the sort proposed in recent policy discussions. In results not reported in this paper, tuition subsidies financed by taxes have only a slight effect on improving intergenerational equity.

This paper also defines and estimates general-equilibrium treatment effects. Focusing on the impact of tuition policy, we find that general-equilibrium impacts of tuition on college enrollment are an order of magnitude smaller than those reported in the literature on microeconometric treatment effects. The assumptions used to justify the LATE parameter in a microeconomic setting do not carry over to a general-equilibrium framework. Policy changes, in general, induce two-way flows and violate the monotonicity—or one-way flow—assumption of LATE. We extend the LATE concept to allow for the two-way flows induced by the policies. The effects of the tuition policy on both "treated" and "untreated" persons as a result of taxes and skill adjustments renders conventional differences in differences estimators invalid. We present a more comprehensive approach to program evaluation by considering both the tax and benefit consequences of the program being evaluated and placing the analysis in a market setting.

We have also examined the impact of two proposed tax reforms on skill formation and wage inequality. A shift to a flat consumption tax slightly discourages skill formation but increases the real wages of all skill groups and barely affects the two commonly used measures of wage inequality. The closed-economy version of our model produces more plausible responses. Widely used partial-equilibrium analyses are misleading and reveal the value of our general-equilibrium approach.

We have examined the commonly utilized Mincer "rate of return" to schooling and show that even in a stationary environment it does not reflect the true economic rate of return. In a period of transition induced by skill-biased technical change, the conventionally computed cross section Mincer coefficient captures rents that accrue to specific cohorts of workers that will not be captured by later generations. Cross-section Mincer rates of return to education do not measure cohort rates of return to new entrants and are a poor guide to policy.

In comparing the open-economy version of our model to the closed-economy version, the closed-economy version seems more plausible. The movement in the interest rate in the closed-economy version chokes off implausibly large investment responses that appear in the open-economy version. The movement in the real interest rate induced by skill biased technical change originating in the early 70^s that is predicted by the closed-economy version of our model is in rough agreement with the actual movement of the real interest rate observed in that period.

Table 1
Estimated Parameters
for Human Capital Production Function
and Schooling Decision
(Standard Errors in Parentheses)

Human Capital Production

$$H_{a+1}^{S} = A^{S}(\theta)\left(I_{a}^{S}\right)^{\alpha_s}\left(H_{a}^{S}\right)^{\beta_S} + (1-\sigma)H_{a}^{S}$$

$$S = 1,2$$

	High School (S=1)	College (S=2)
α	0.945(0.017)	0.939(0.026)
β	0.832(0.253)	0.871(0.343)
$A(1)$	0.081(0.045)	0.081(0.072)
$H_{aR}(1)$	9.530(0.309)	13.622(0.977)
$A(2)$	0.085(0.053)	0.082(0.074)
$H_{aR}(2)$	12.074(0.403)	14.759(0.931)
$A(3)$	0.087(0.056)	0.082(0.077)
$H_{aR}(2)$	13.525(0.477)	15.614(0.909)
$A(4)$	0.086(0.054)	0.084(0.083)
$H_{aR}(4)$	12.650(0.534)	18.429(1.095)

College Choice Equation

$$P\left(\delta^2 = 1\right) = \Lambda\left(-\lambda D^2 + \alpha(\theta)\right)$$

	Probit Parameters	Average Derivatives
λ	0.166(0.062)	-0.0655(0.025)
$\alpha(1)$	-1.058(0.097)	-
$\alpha(2)$	-0.423(0.087)	0.249(0.037)
$\alpha(3)$	0.282(0.089)	0.490(0.029)
$\alpha(4)$	1.272(0.101)	0.715(0.018)
Sample Size:		
Persons	869	1069
Person Years	7996	11626

(1) D^2 is the discounted tuition cost of attending college.
(2) $\alpha(\theta)$ is the nonparametric estimate of $(1-\tau)[V^2(\theta)-V^1(\theta)]$, the monetary value of the gross discounted returns to attending college.
(3) δ^2=1 if attend college; δ^2=0 otherwise. Λ is the unit normal cdf.

Table 2
Derived Parameters
for Human Capital Production Function
and Schooling Decision
Units are Thousands of Dollars

	Human Capital Production High School (S = 1)	College (S = 2)
$H^S(1)$	8.042(0.0.094)	11.117(0.424)
$H^S(2)$	10.0634(0.118)	12.271(0.325)
$H^S(3)$	11.1273(0.155)	12.960(0.272)
$H^S(4)$	10.361(0.234)	15.095(0.323)
Present Value Earnings 1	260.304(3.939)	289.618(12.539)
Present Value Earnings 2	325.966(5.075)	319.302(10.510)
Present Value Earnings 3	360.717(6.352)	337.260(9.510)
Present Value Earnings 4	335.977(8.453)	393.138(11.442)

	College Decision: Attend College if $(1-\tau)V^2(\theta)-D^2+\varepsilon_i \geq (1-\tau)V^1(\theta)$ $\varepsilon_\theta \sim N(\mu_\theta,\sigma_\varepsilon)$
σ_ε (Std. deviation of ε)	22.407(8.425)
Nonpecuniary costs by ability level	
μ_1 (Lowest Ability Quartile)	-53.0190(16.770)
μ_2 (Second Ability Quartile)	-2.8173(12.760)
μ_3 (Third Ability Quartile)	29.7712(11.540)
μ_4 (Highest Ability Quartile)	-28.6494(16.966)

(1) $V^i(\theta)$ is the monetary value of going to schooling level i for a person of AFQT quartile θ. i=1 for high school; i=2 for college. We assume $\tau_r=\tau_h=\tau$.
(2) ε_θ is the nonpecuniary benefit of attending college for a person of ability quartile θ.
(3) D^2 is the discounted tuition cost of attending college.

Table 3

Estimates of Aggregate Production Function
Estimated from Factor Demand Equations (II-2) and (II-4)
1965-1990
Allowing for Technical Progress Through a Linear Trend
(Standard Errors in Parentheses)

Instruments	ρ_1	Implied Elasticity of Substitution (σ_1)	Time Trend (φ_1)	ρ_2	Implied Elasticity of Substitution (σ_2)	Time Trend (φ_2
OLS (Base Model)	0.306	1.441	0.036	-0.034	0.967	-0.004
	(0.089)	(0.185)	(0.004)	(0.200)	(0.187)	(0.007)
Percent Working Pop. < 30 & Defense Percent of GNP	0.209	1.264	0.039	-0.036	0.965	-0.004
	(0.134)	(0.215)	(0.005)	(0.200)	(0.187)	(0.007)
Defense Percent of GNP	0.157	1.186	0.041	-0.171	0.854	-0.008
	(0.125)	(0.175)	(0.004)	(0.815)	(0.594)	(0.024)
Percent Working Pop. < 30	0.326	1.484	0.036	0.364	1.572	0.007
	(0.182)	(0.400)	(0.006)	(1.150)	(2.842)	(0.034)

Table 4

Simulated Changes in Wages and Wage Inequality from 1960-90
Includes the Estimated Trend in Technology
and Entrance of Baby Boom Cohorts from 1965-80
(Multiplied by 100)

Years	Coll. - HS Log Wage Diff.	Mean HS Log Wage		Mean Coll. Log Wage		Std. Deviation of Log Wages		
		Age 25	Age 50	Age 25	Age 50	HS	College	All
1960-70	7.22	-36.39	-8.43	1.8	0.13	3.16	2.54	4.88
1970-80	-4.38	6.17	-0.74	-14	-3.61	20.85	3.12	13.28
1980-90	7.9	7.83	1.66	17.98	-1.04	13.54	-11.48	7.84
1960-90	10.74	-22.39	-7.51	5.78	-4.51	37.55	-5.82	25.99

Table 5

Simulated Effects of $5000 Tuition Subsidy on Different Groups
Steady State Changes in Present Value of Lifetime Wealth
(Thousands of 1995 Dollars)

Group(Proportion)†	After-Tax Earnings Using Base Tax‡ (1)	After-Tax Earnings‡ (2)	After-Tax Earnings Net of Tuition‡ (3)	Utility‡ (4)
High School-High School (0.5210)	17.520	6.849	6.849	6.849
High School-College (0.023)	9.757	-0.372	14.669	8.263
College-High School (0.0003)	-37.874	-49.528	-45.408	7.287
College-College (0.447)	1.574	-10.233	8.412	8.412
Ability Quartile 1				
High School-High School (0.844)	14.696	5.673	5.673	5.673
High School-College (0.045)	30.587	21.043	36.179	8.001
College-High School (0.000)	0.000	0.000	0.000	0.000
College-College (0.111)	1.273	-8.271	10.353	10.353
Ability Quartile 2				
High School-High School (0.689)	18.571	7.269	7.269	7.269
High School-College (0.033)	-5.356	-15.874	-0.841	8.440
College-High School (0.000)	0.000	0.000	0.000	0.000
College-College (0.277)	1.308	-9.210	9.428	9.428
Ability Quartile 3				
High School-High School (0.446)	20.691	8.181	8.181	8.181
High School-College (0.014)	-22.046	-33.156	-18.409	8.694
College-High School (0.000)	0.000	0.000	0.000	0.000
College-College (0.541)	1.4010	-9.6910	8.946	8.946
Ability Quartile 4				
High School-High School (0.139)	19.286	7.633	7.633	7.633
High School-College (0.000)	0.000	0.000	0.000	0.000
College-High School (0.001)	-37.874	-49.528	-45.408	7.287
College-College (0.859)	1.802	-11.152	7.498	7.498

(†) The groups denote counterfactual groups. For example, the High School-High School group consists of individuals who would not attend college in either steady state, and the High School-College group would not attend college in the first steady state, but would in the second, etc.

(‡) Column (1) reports the after-tax present value of earnings in thousands of dollars discounted using the after-tax interest rate where the tax rate used for the second steady state is the base tax rate. Column (1) reports just the effect on earnings, column (2) adds the effect of taxes, column (3) adds the the effect of tuition subsidies and column (4) includes the nonpecuniary costs of college expressed in dollars.

Table 6

Open Economy Effects of Alternative Tax Proposals
General Equilibrium (Steady State) and Partial Equilibrium Effects§
Percentage Difference from Progressive Case†

	Flat Tax‡		Flat Cons. Tax‡	
	PE	GE	PE	GE
After Tax Interest Rate	0.00	0.00	17.65	17.65
Skill Price College HC	0.00	-5.60	0.00	22.87
Skill Price HS HC	0.00	-4.13	0.00	21.77
Stock of Physical Capital	-15.07	-16.21	86.50	124.42
Stock of College HC	22.41	4.49	-15.77	-5.16
Stock of HS HC	-9.94	2.19	1.88	-5.05
Stock of College HC per College Graduate	3.04	3.88	-4.08	-3.30
Stock of HS HC per HS Graduate	1.84	2.56	-5.23	0.16
Aggregate Output	-0.09	-5.14	15.76	42.11
Aggregate Consumption	-0.08	-5.81	7.60	34.40
Mean Wage College	3.39	-1.09	0.12	24.00
Mean Wage HS	2.44	-1.13	0.25	22.31
Standard Deviation Log Wage	4.09	3.45	-1.94	-1.22
College/HS Wage Premium at 10 Yrs Exp*	1.92	-1.90	3.10	7.19
Fraction attending college	18.79	0.59	-12.18	-1.92
Type 1: Fraction Attending College	50.29	-6.85	-42.57	11.47
Type 2: Fraction Attending College	28.50	-1.97	-15.60	-17.95
Type 3: Fraction Attending College	14.13	-1.82	-5.20	-21.56
Type 4: Fraction Attending College	15.27	3.47	-11.77	11.93
Type 1: College HC Gain First 10 Years**	5.81	5.81	-7.53	-7.53
Type 2: College HC Gain First 10 Years**	5.33	5.33	-6.84	-6.84
Type 3: College HC Gain First 10 Years**	5.60	5.60	-6.70	-6.70
Type 4: College HC Gain First 10 Years**	6.85	6.85	-6.41	-6.41
Type 1: HS HC Gain First 10 Years**	3.42	3.42	-7.79	-7.79
Type 2: HS HC Gain First 10 Years**	4.49	4.49	-7.60	-7.60
Type 3: HS HC Gain First 10 Years**	5.36	5.36	-7.62	-7.62
Type 4: HS HC Gain First 10 Years**	5.29	5.29	-7.95	-7.95

§ General equilibrium (GE) effects allow skill prices to change, while partial equilibrium (PE) effects hold prices constant.

† In the progressive case we allow for a progressive tax on labor earnings, but assume a flat tax on capital at 15% .

‡ In the flat tax regime we hold the tax on capital fixed to the same level as the progressive tax, but the tax on labor income is flat and is calculated to balance the budget in the new GE steady state. This yields a tax rate on labor income of 7.7% . In the consumption regime, we tax only consumption at a 10.0% rate, again balancing the budget in steady states.

* The college - high school wage premium measures the difference in log mean earnings between college graduates and high school graduates with ten years of experience.

** These rows present changes in the ratio of human capital at ten years of experience versus human capital upon entering the labor force.

Table 7
Closed Economy Effects of Alternative Tax Proposals
General Equilibrium (Steady State) and Partial Equilibrium Effects§
Percentage Difference from Progressive Case†

	Flat Tax‡		Flat Cons. Tax‡	
	PE	GE	PE	GE
After Tax Interest Rate	0.00	1.96	17.65	3.31
Skill Price College HC	0.00	-1.31	0.00	3.38
Skill Price HS HC	0.00	-0.01	0.00	4.65
Stock of Physical Capital	-15.07	-0.79	86.50	19.55
Stock of College HC	22.41	2.82	-15.77	1.85
Stock of HS HC	-9.94	0.90	1.88	0.08
Stock of College HC per College Graduate	3.04	2.55	-4.08	1.72
Stock of HS HC per HS Graduate	1.84	1.07	-5.23	0.16
Aggregate Output	-0.09	1.15	15.76	4.98
Aggregate Consumption	-0.08	0.16	7.60	3.66
Mean Wage College	3.39	2.60	0.12	6.96
Mean Wage HS	2.44	2.44	0.25	6.82
Standard Deviation Log Wage	4.09	1.56	-1.94	0.69
College/HS Wage Premium at 10 Yrs Exp*	1.92	-0.45	3.10	0.18
Fraction attending college	18.79	0.26	-12.18	-1.92
Type 1: Fraction Attending College	50.29	-1.25	-42.57	2.14
Type 2: Fraction Attending College	28.50	-5.89	-15.60	-7.88
Type 3: Fraction Attending College	14.13	-6.93	-5.20	-9.56
Type 4: Fraction Attending College	15.27	6.13	-11.77	7.50
Type 1: College HC Gain First 10 Years**	5.81	3.12	-7.53	1.51
Type 2: College HC Gain First 10 Years**	5.33	2.86	-6.84	1.38
Type 3: College HC Gain First 10 Years**	5.60	3.10	-6.70	1.61
Type 4: College HC Gain First 10 Years**	6.85	4.17	-6.41	2.56
Type 1: HS HC Gain First 10 Years**	3.42	1.06	-7.79	-0.34
Type 2: HS HC Gain First 10 Years**	4.49	1.97	-7.60	0.46
Type 3: HS HC Gain First 10 Years**	5.36	2.67	-7.62	1.06
Type 4: HS HC Gain First 10 Years**	5.29	2.55	-7.95	0.92

§ General equilibrium (GE) effects allow skill prices to change, while partial equilibrium (PE) effects hold prices constant.

† In the progressive case we allow for a progressive tax on labor earnings, but assume a flat tax on capital at 15%.

‡ In the flat tax regime we hold the tax on capital fixed to the same level as the progressive tax, but the tax on labor income is flat and is calculated to balance the budget in the new GE steady state. This yields a tax rate on labor income of 7.7% . In the consumption regime, we tax only consumption at a 10.0% rate, again balancing the budget in steady states.

* The college - high school wage premium measures the difference in log mean earnings between college graduates and high school graduates with ten years of experience.

** These rows present changes in the ratio of human capital at ten years of experience versus human capital upon entering the labor force.

Figure 1A: Predicted vs Actual Hourly Wages (in 1992 dollars) by AFQT Quartile (College Category)

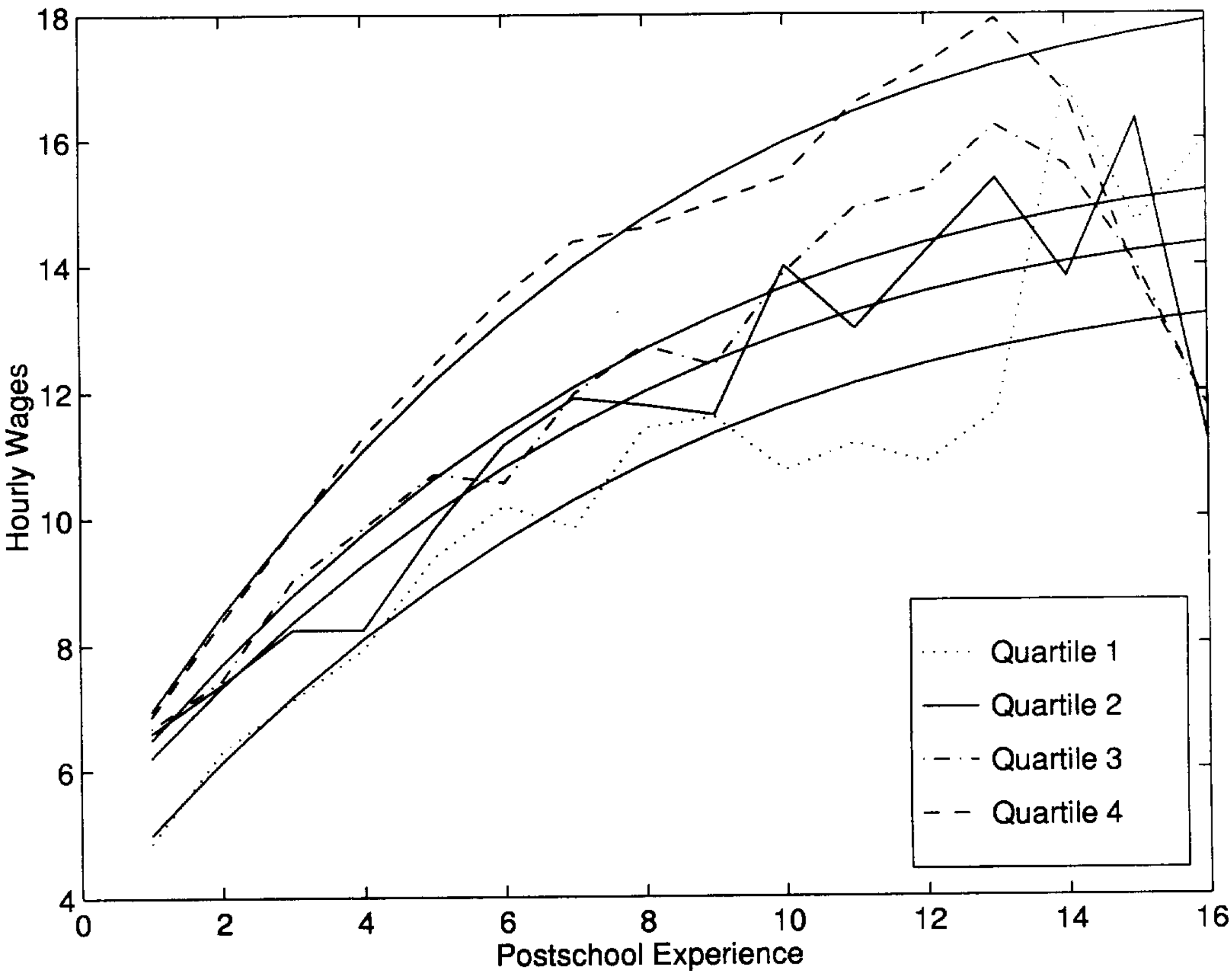


Figure 1B: Predicted vs Actual Hourly Wages (in 1992 dollars) by AFQT Quartile (High School Category)

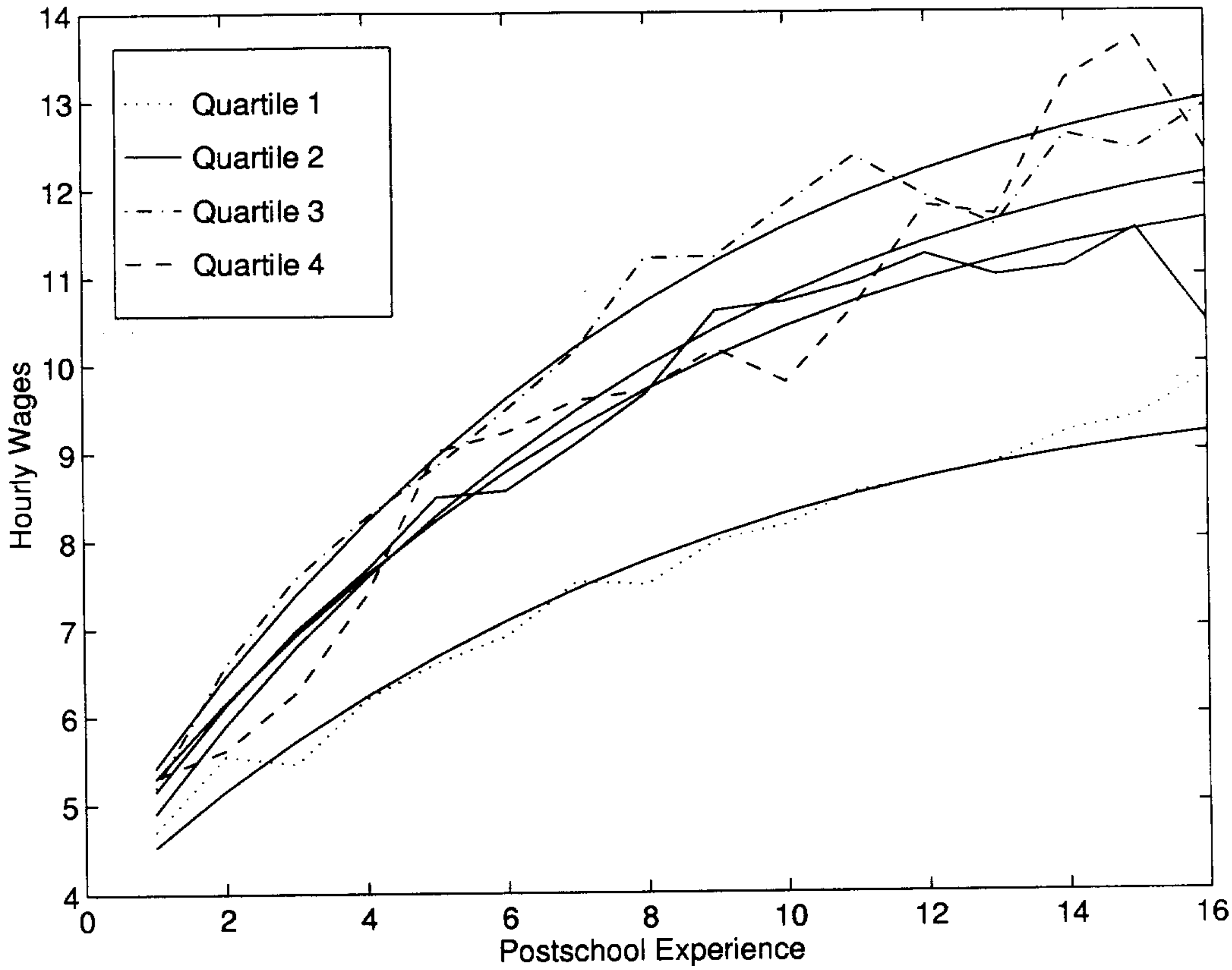
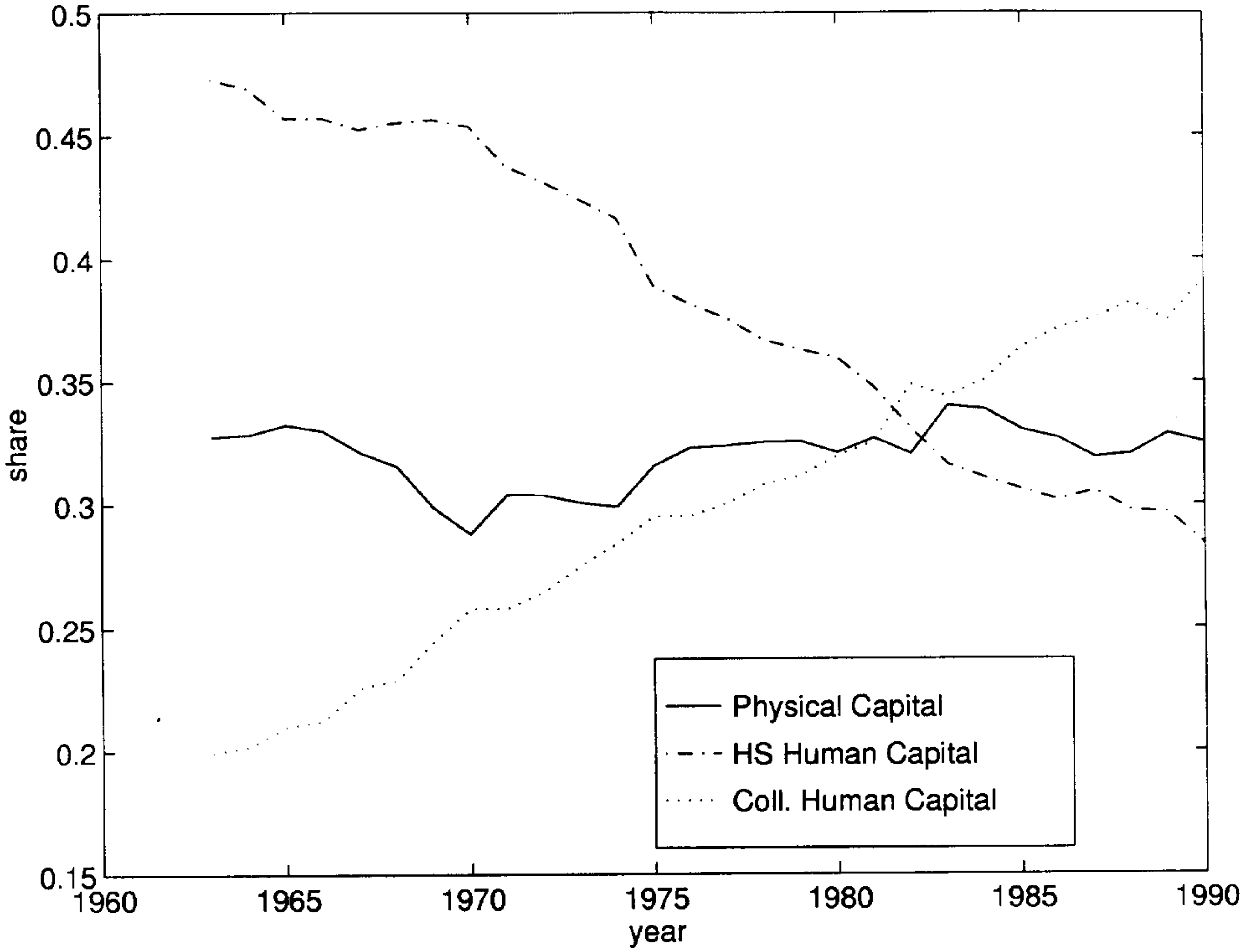


Figure 2: Labor and Capital Shares over Time



Note: The breakdown of labor's share is based on wages and excludes other forms of compensation.

Figure 3: Estimated Trend in a_1 for 30 years
Open Economy

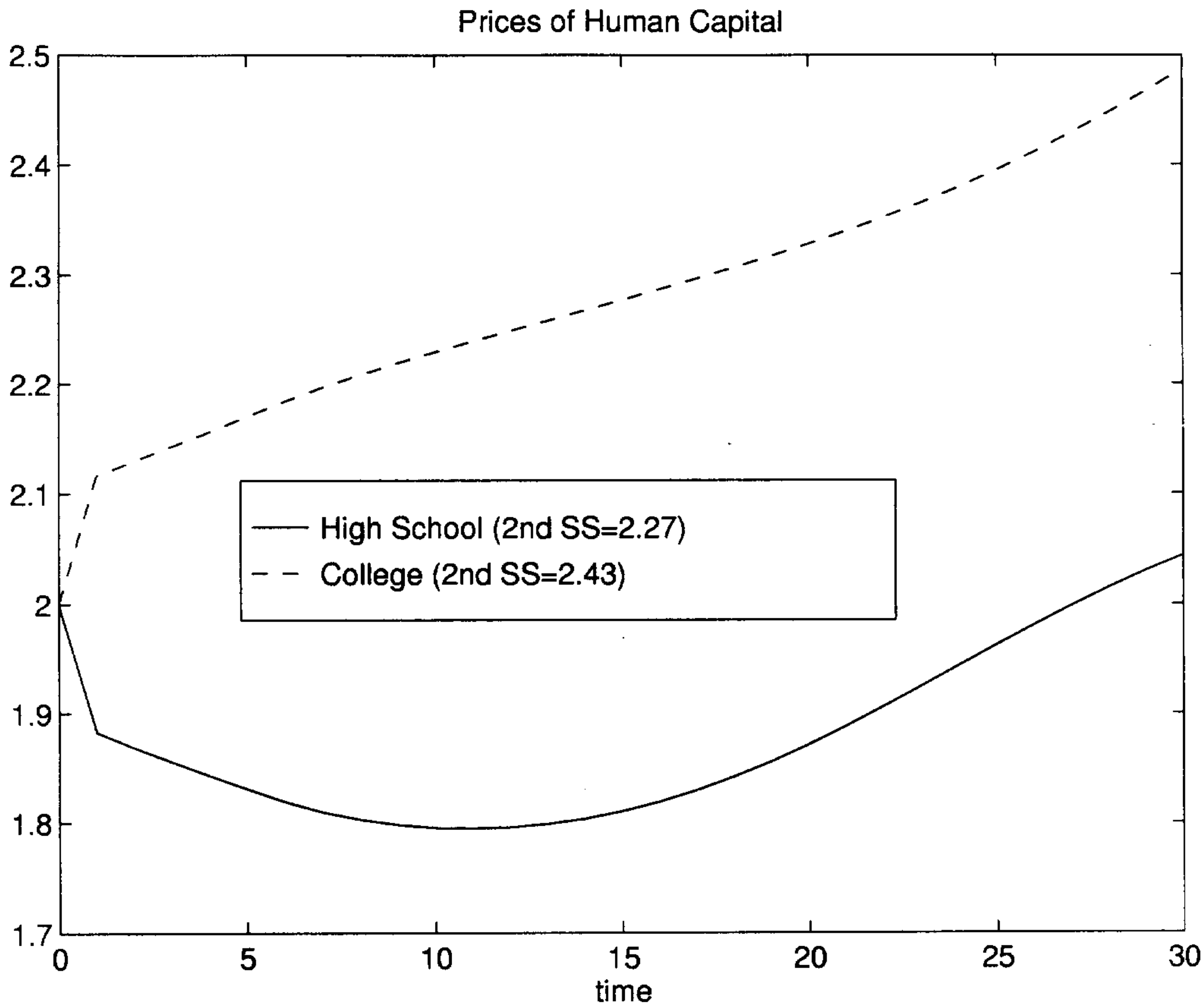


Figure 5: Estimated Trend in a_1 for 30 years
Open Economy

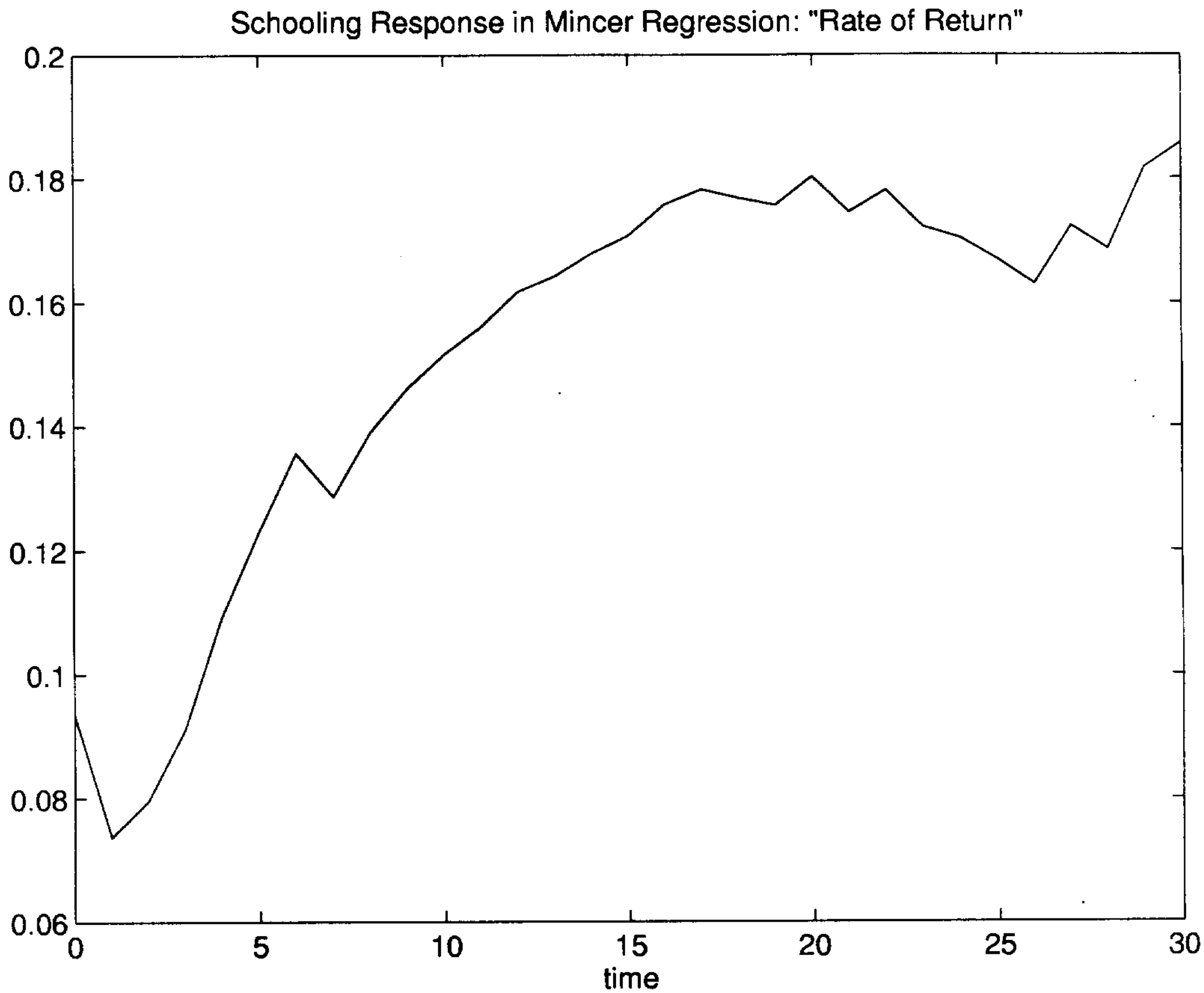


Figure 6: Estimated Trend in a_1 for 30 years
Open Economy

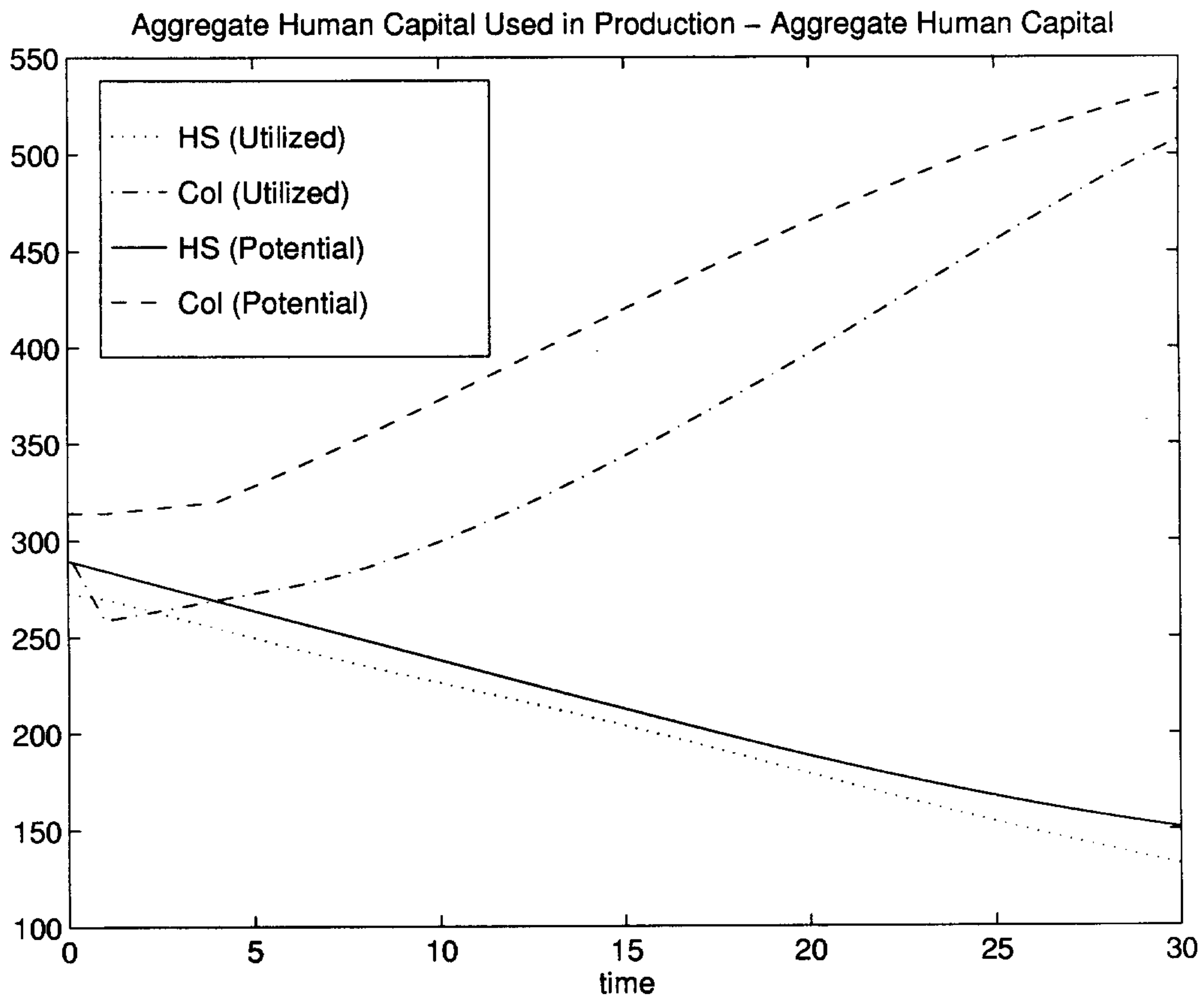


Figure 7: Estimated Trend in a_1 for 30 years
Open Economy

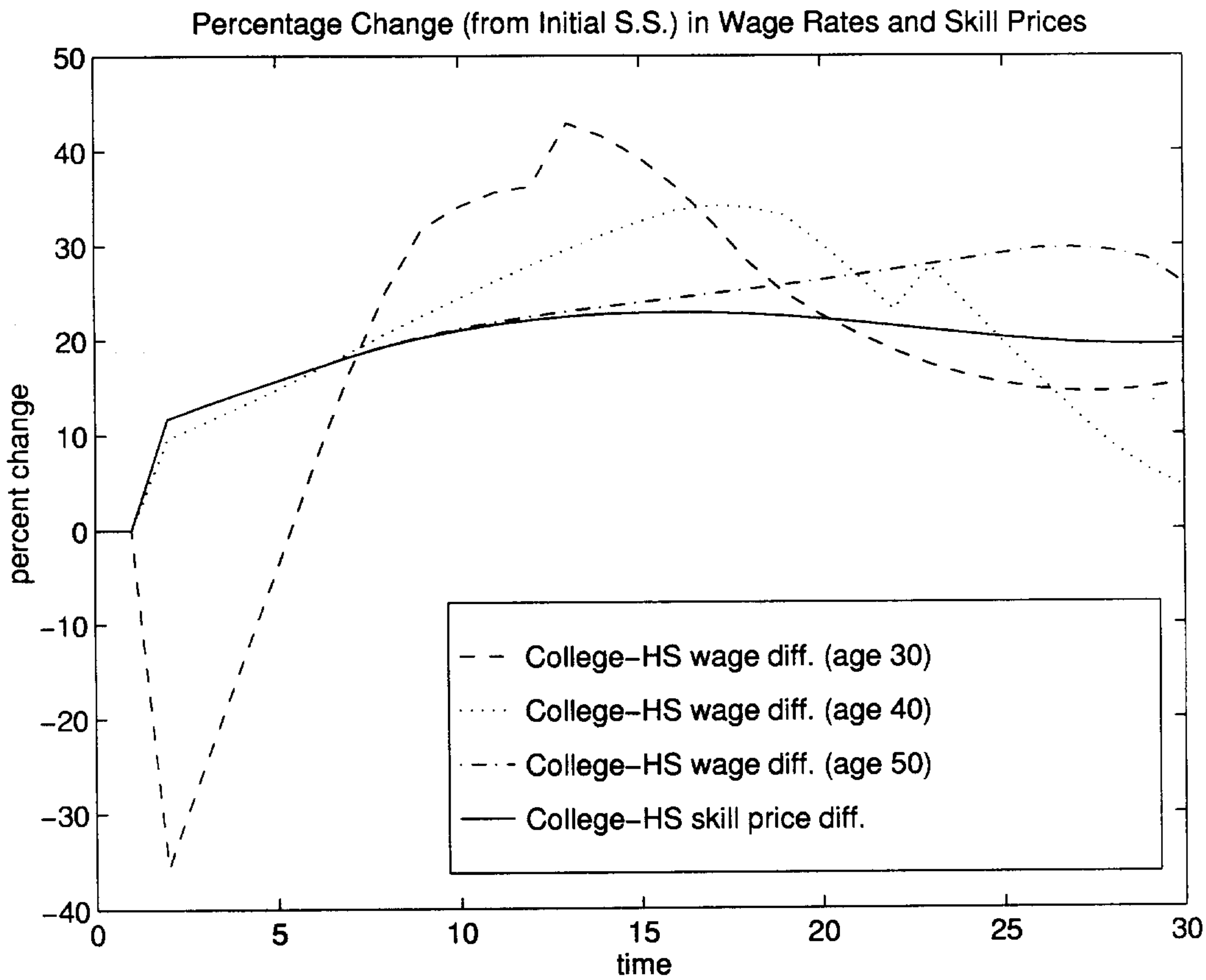


Figure 8: Estimated Trend in a_1 for 30 years
Open Economy

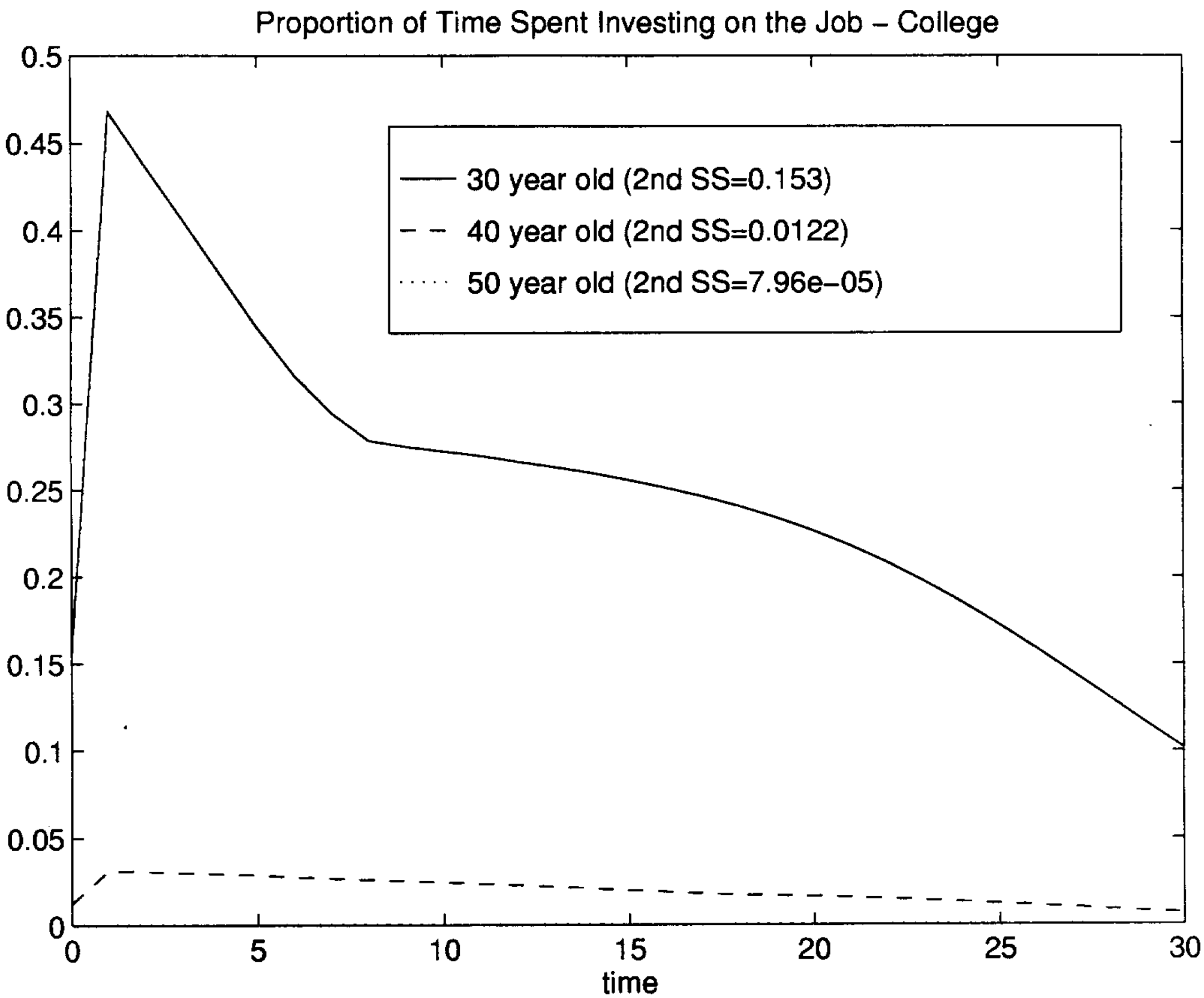


Figure 9: Estimated Trend in a_1 for 30 years
Open Economy

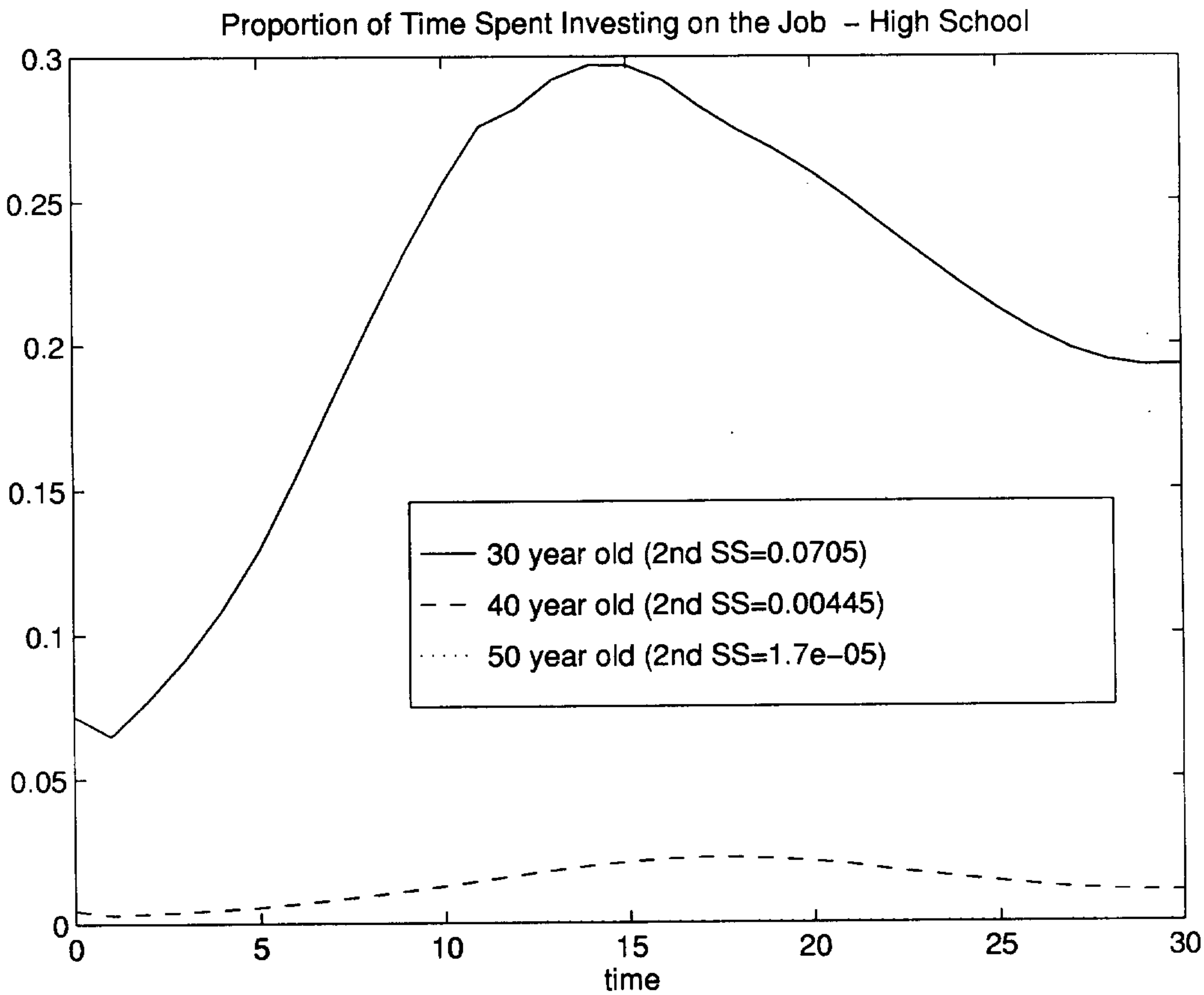


Figure 10: Estimated Trend in a_1 for 30 years Open Economy

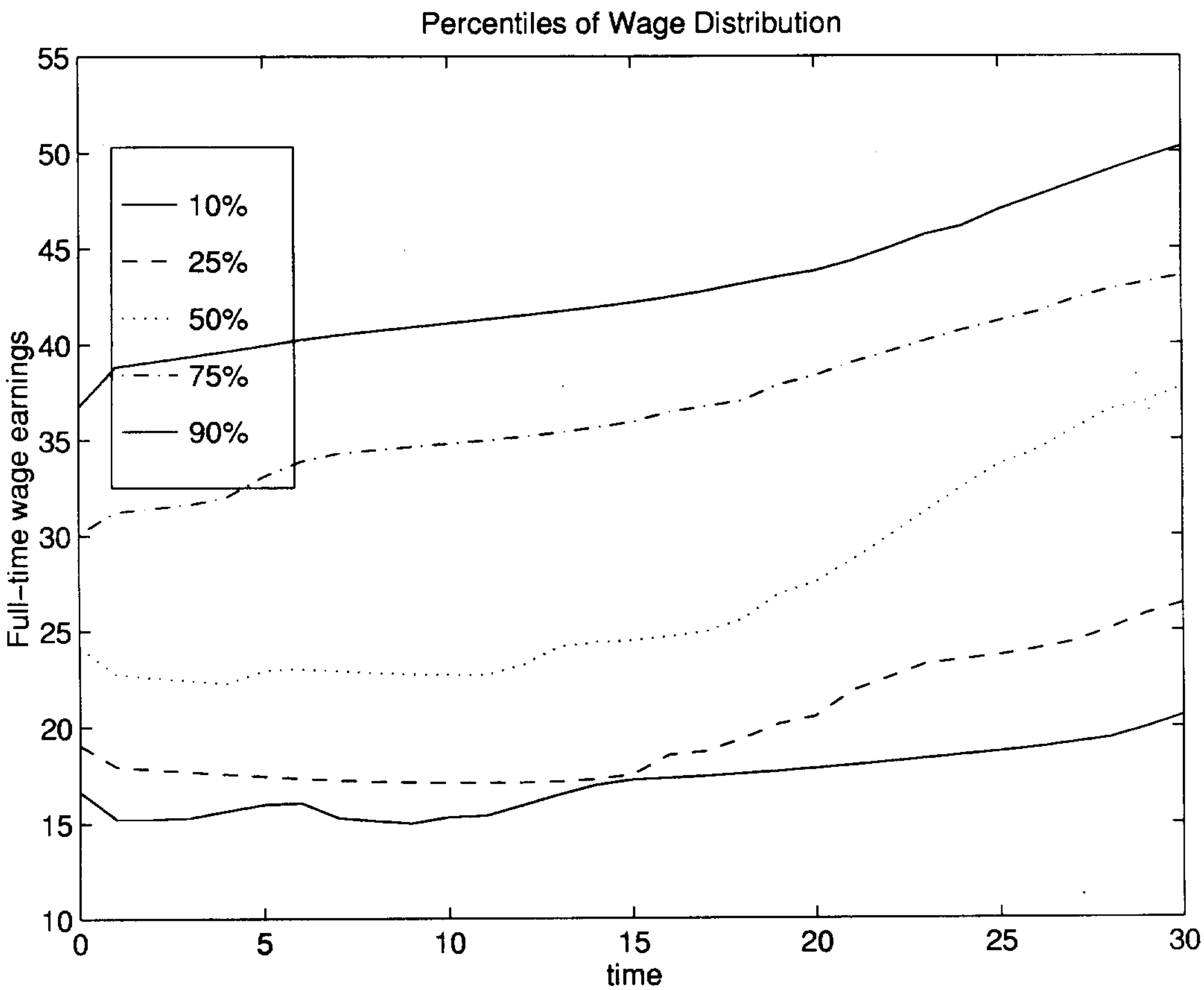


Figure 11A: Estimated Trend in a_1 for 30 years
Open Economy

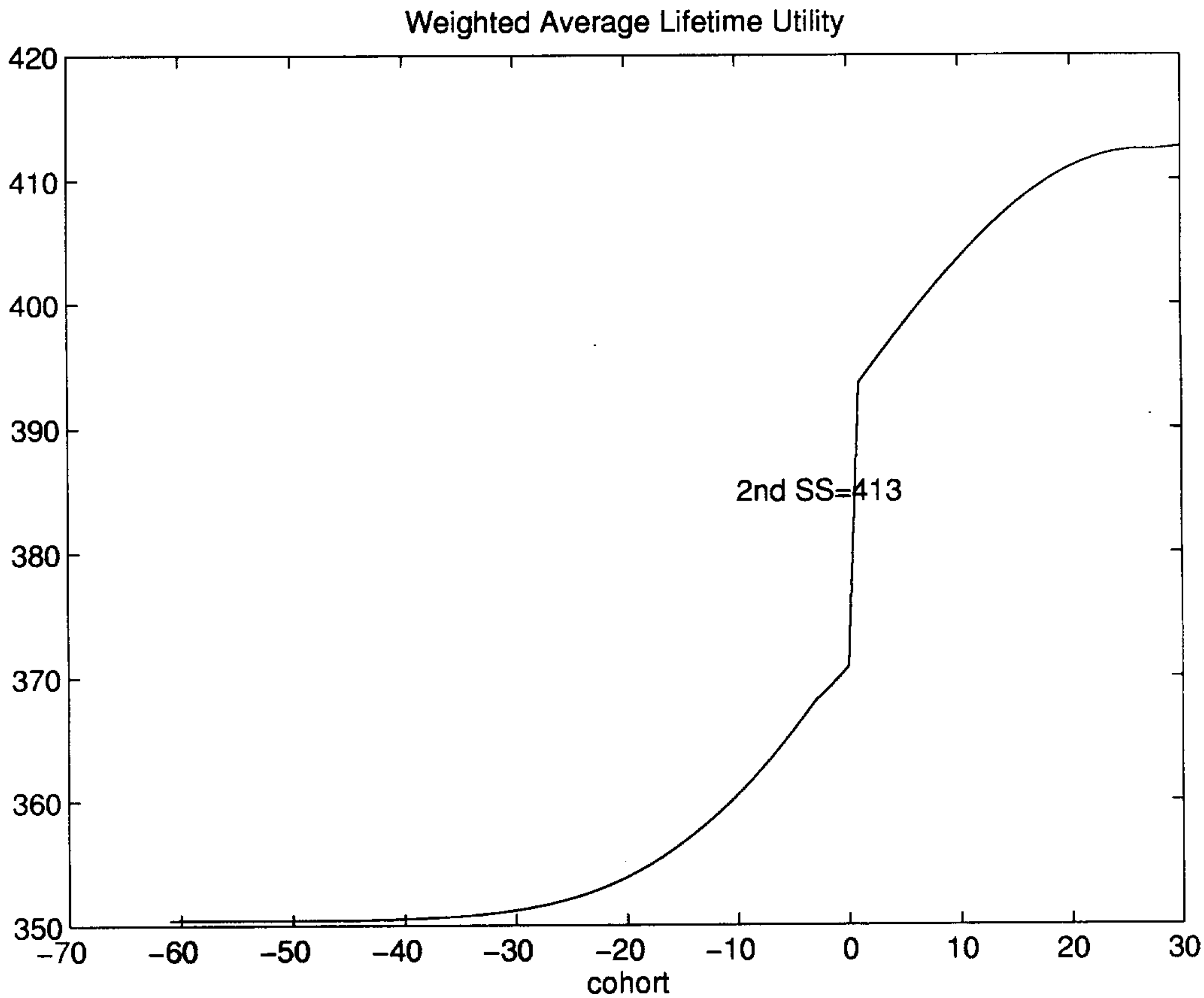


Figure 11B: Estimated Trend in a_1 for 30 years
Open Economy

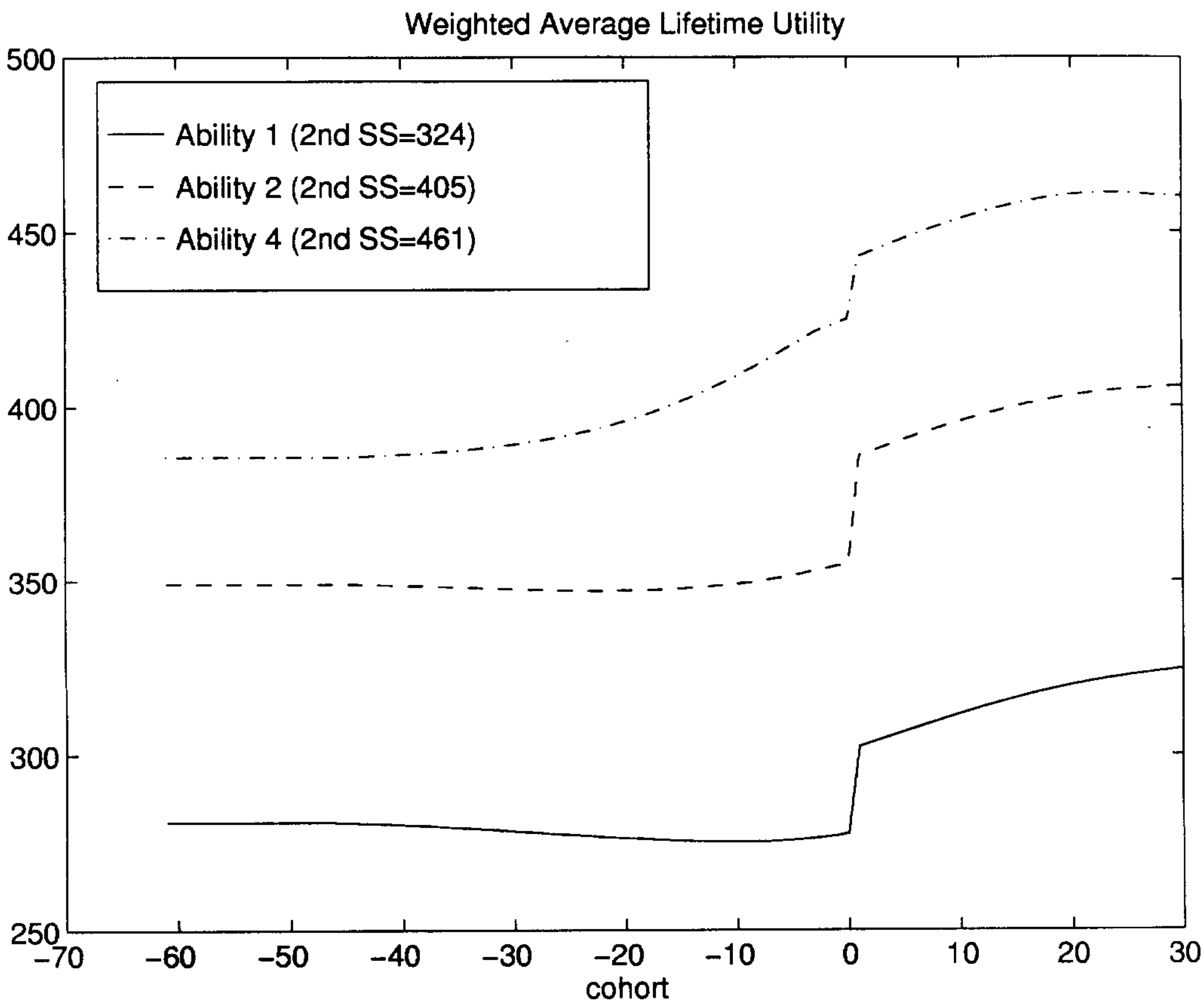


Figure 11C: Estimated Trend in a_1 for 30 years
Open Economy

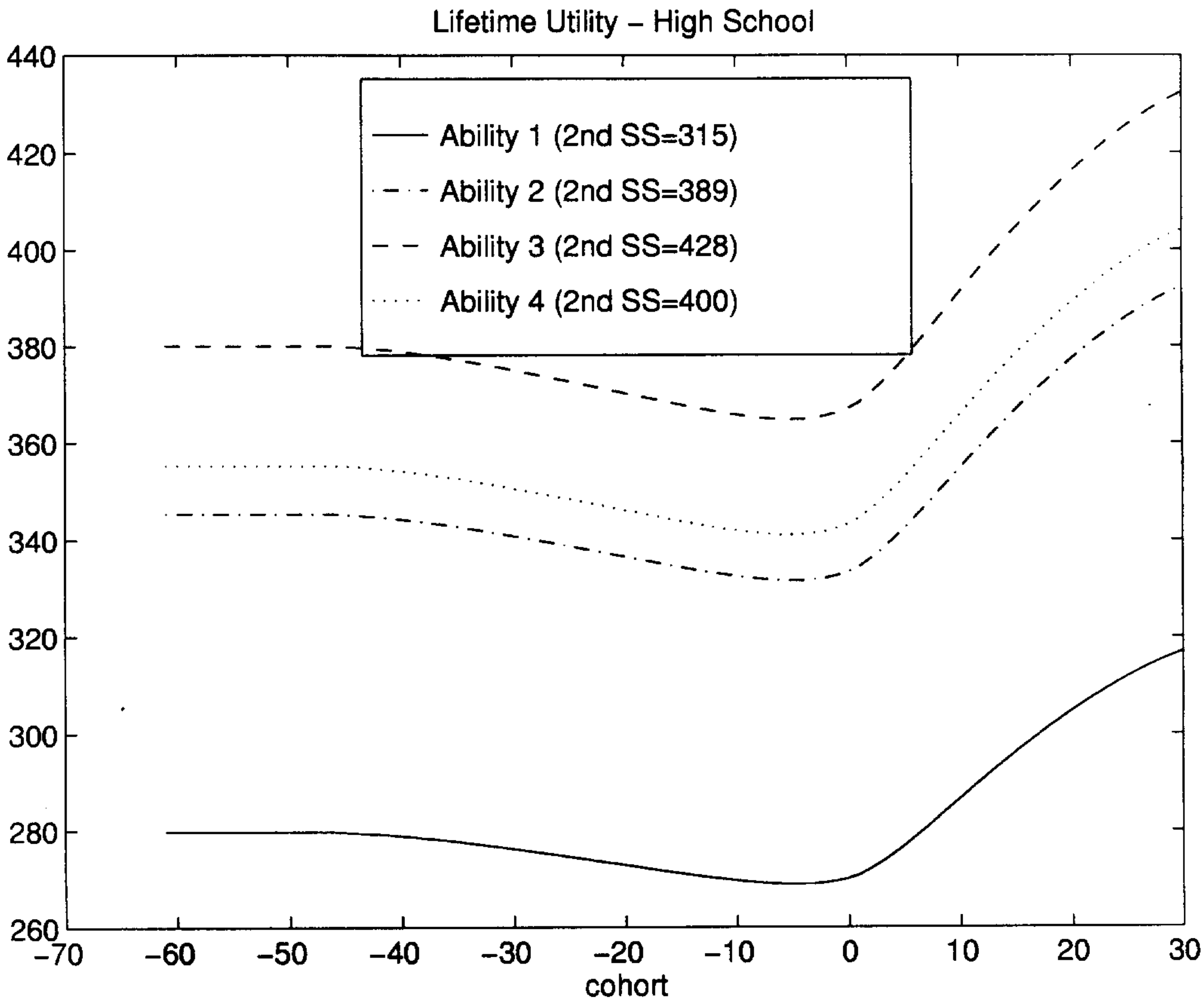


Figure 11D: Estimated Trend in a_1 for 30 years
Open Economy

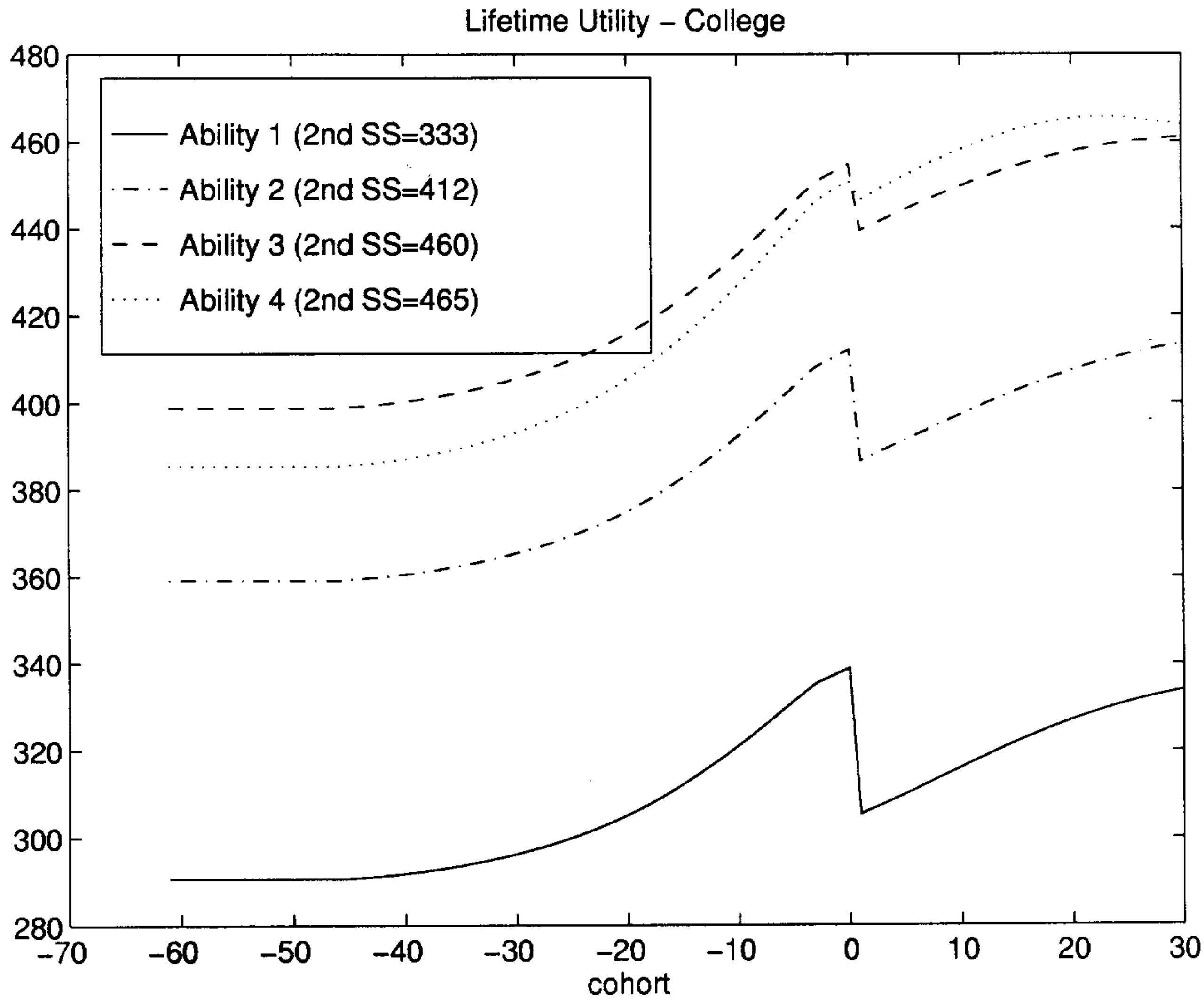


Figure 12: Estimated Trend in a_1 for 30 years
Open Economy

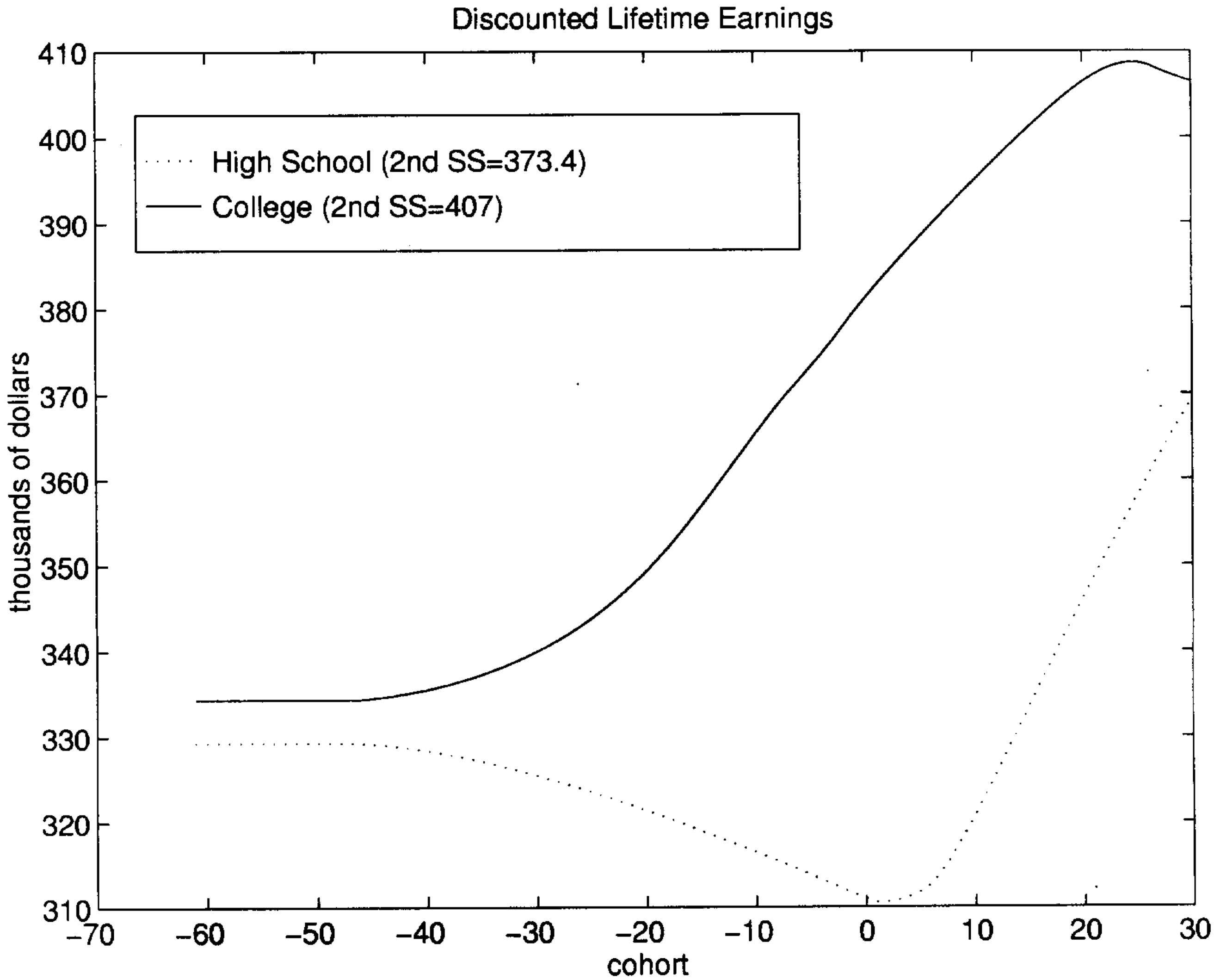


Figure 13: Estimated Trend in a_1 for 30 years
Open Economy

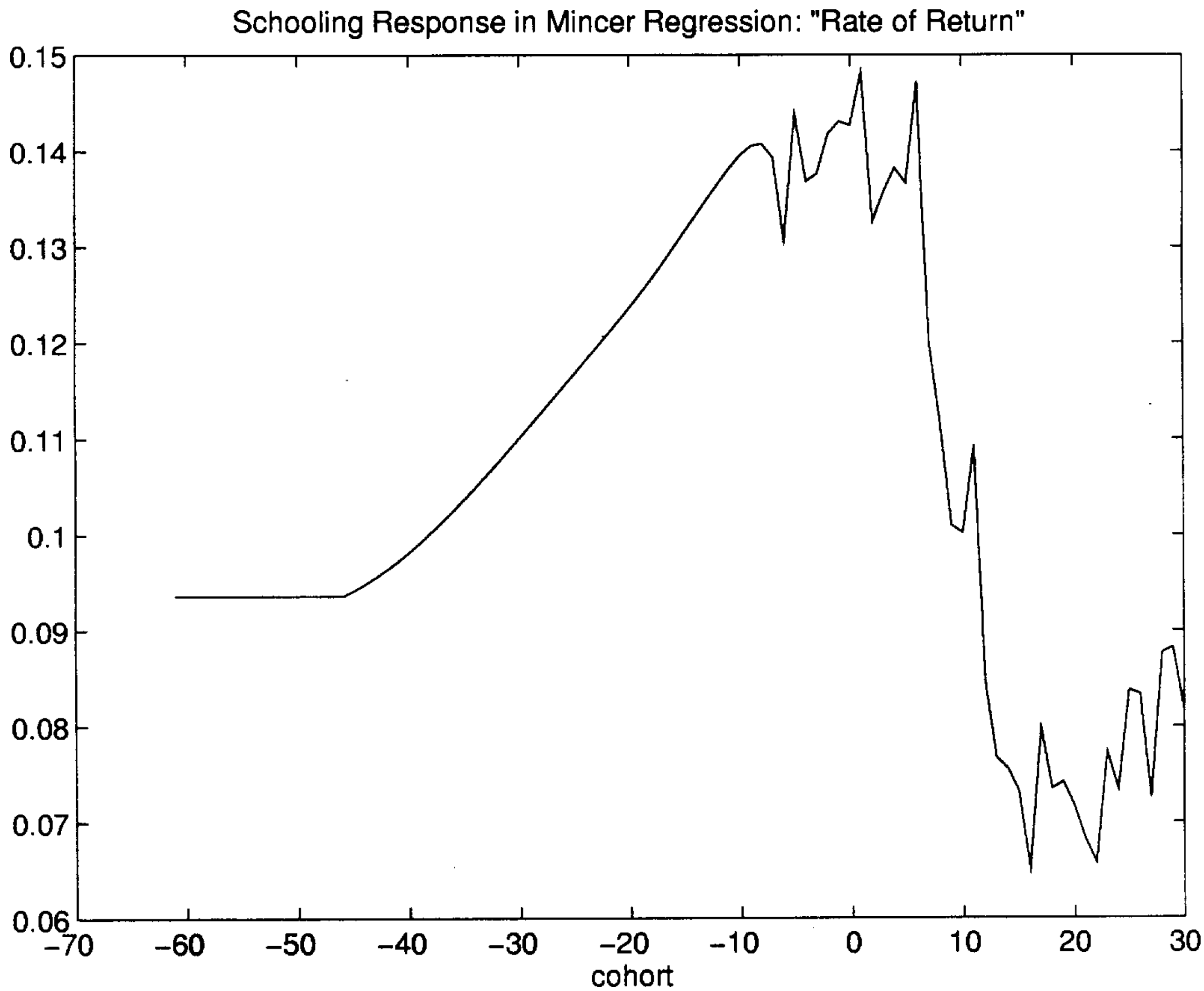


Figure 14: Estimated Trend in a_1 for 30 years Open Economy

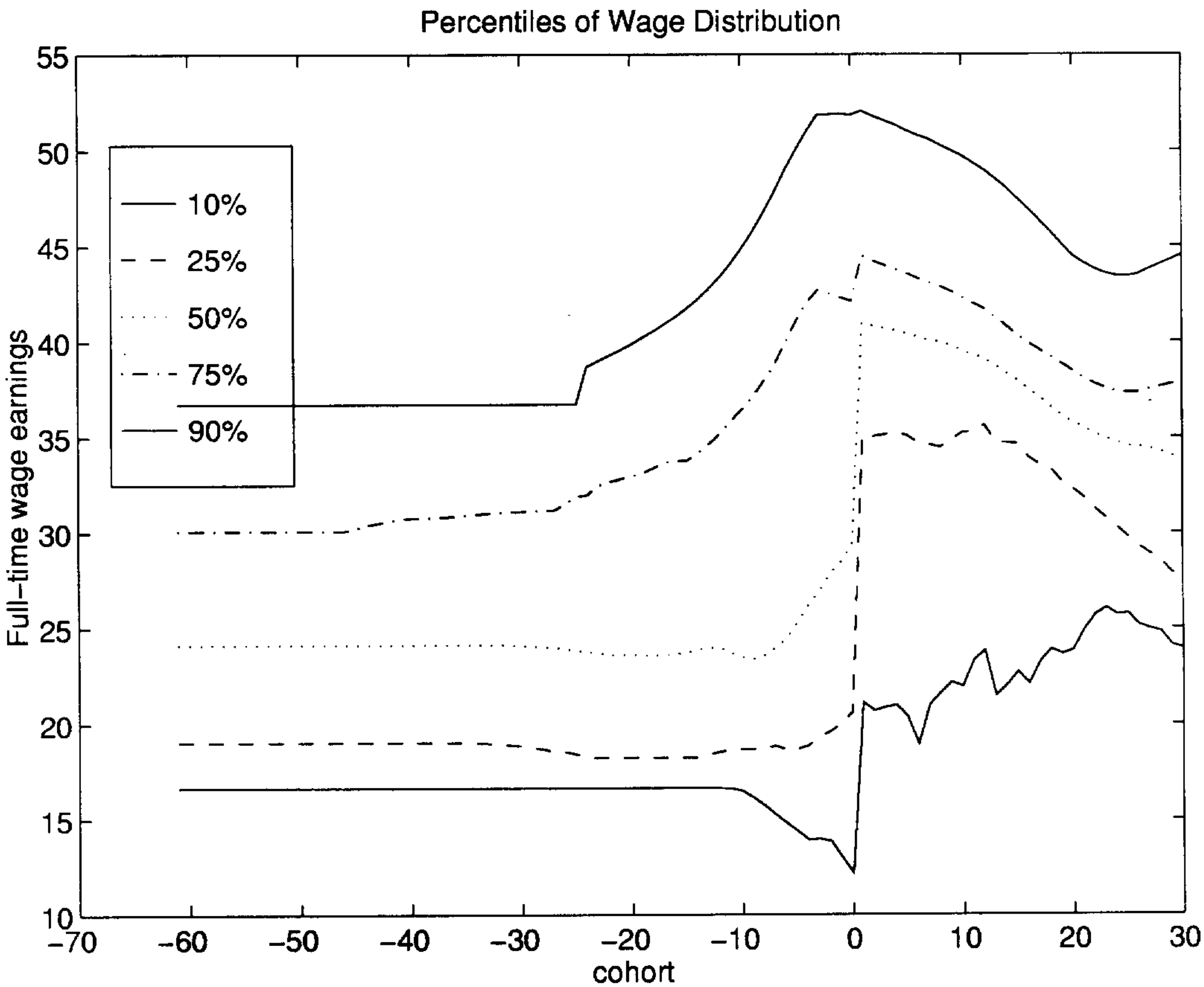


Figure 15: Estimated Trend in a_1 for 30 years - Open Economy Baby boom (Expansion of Cohort Size by 32%) between years 1965-80

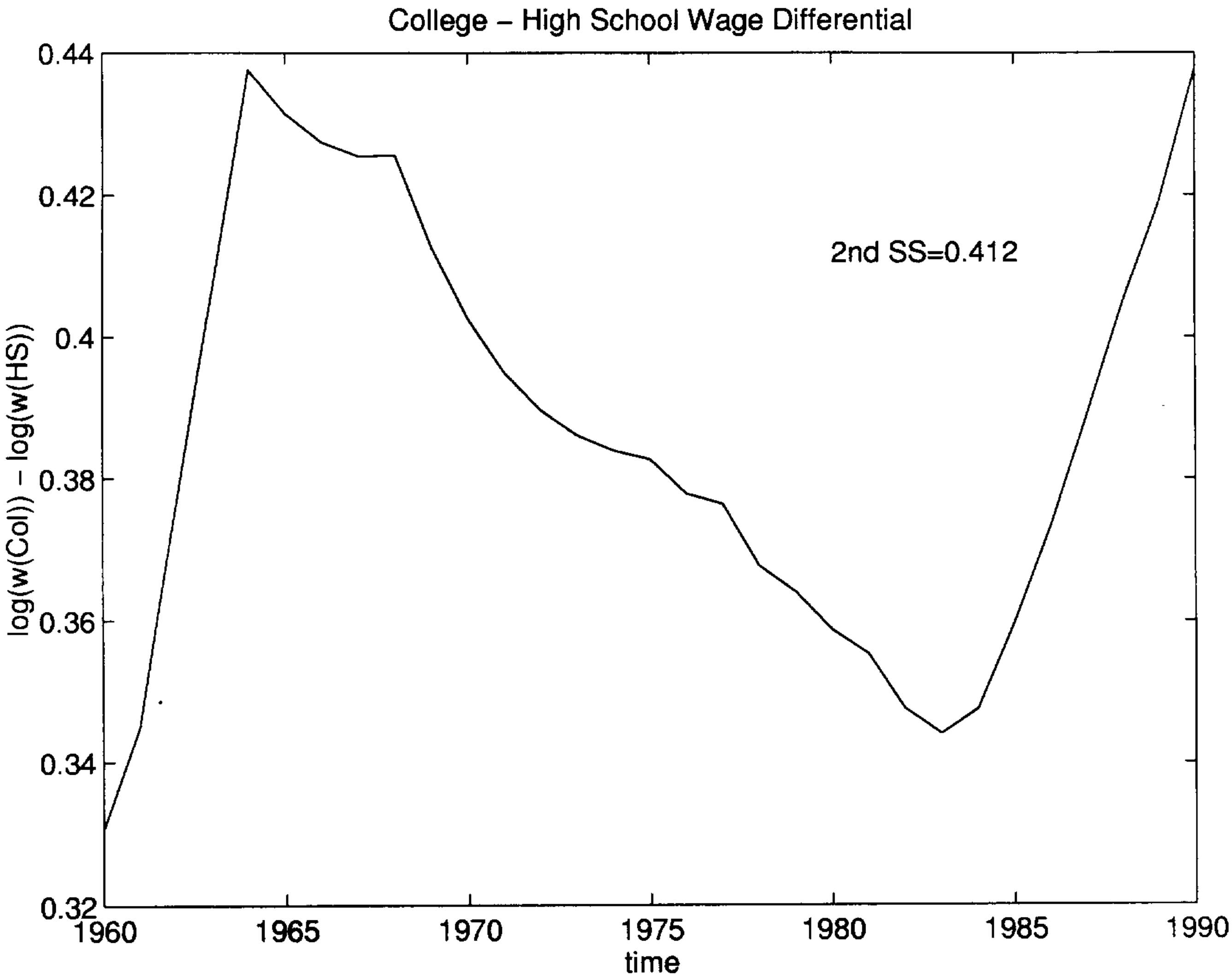


Figure 16: Estimated Trend in a_1 for 30 years - Open Economy Baby boom (Expansion of Cohort Size by 32%) between years 1965-80

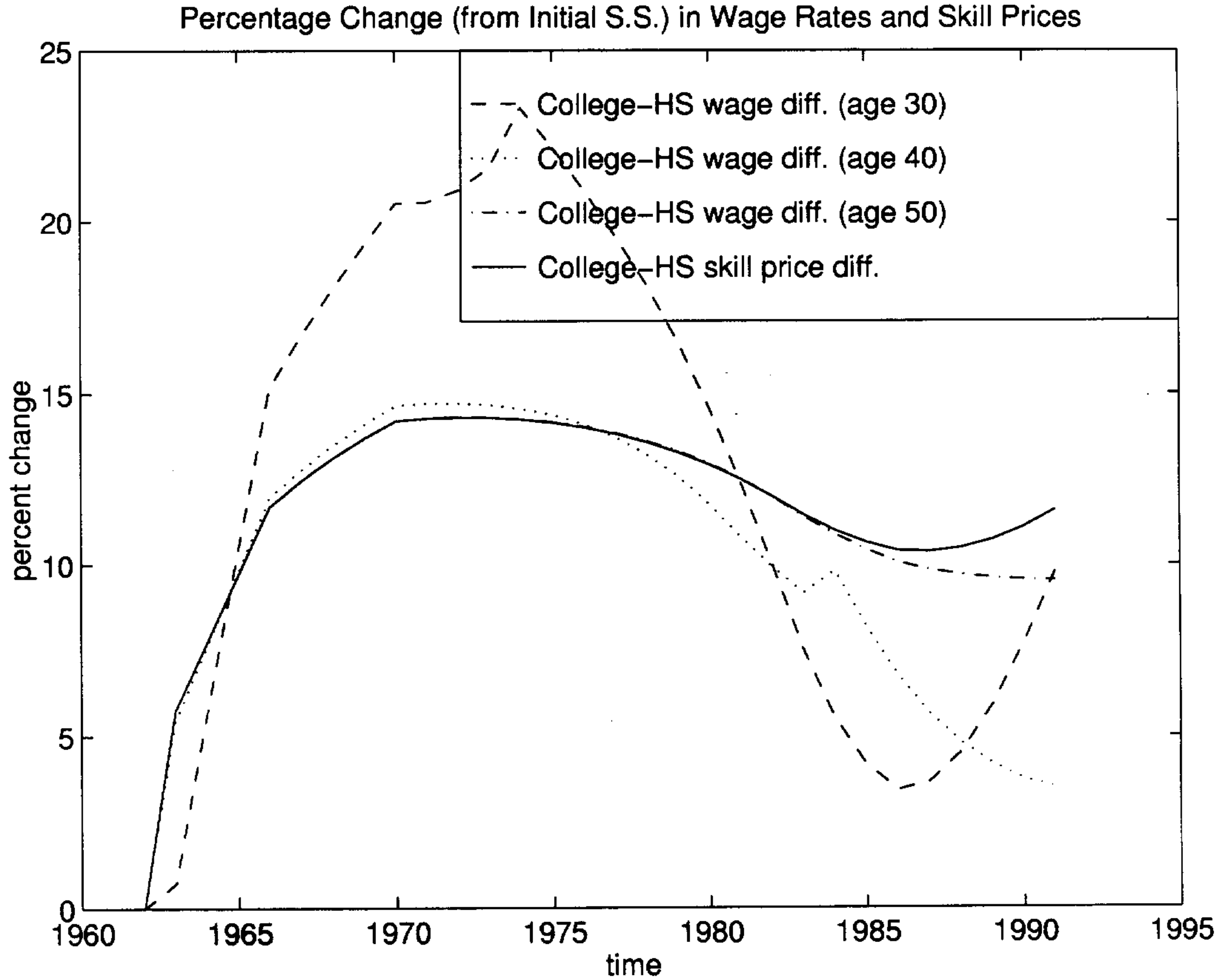


Figure 17: Closed Economy of Interest Rates for a Technology Shock Originating in the Early 70s