The Career Decisions of Young Men

Keane and Wolpin (1997, *Journal of Political Economy*)

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Introduction

- This paper uses basic investment theory and a Generalized Roy model to explain observed patterns of school attendance, work, occupational choice, and wages.
- A structural estimation framework.
- Impose the restrictions of the theory and investigate whether the model can succeed in fitting data.

- The structural model isolates the quantitative importance of school attainment and occupation-specific work experience in the production of occupation-specific skills.
- **Policy experiments:** They alter the monetary incentives to attend college and thus assess how interventions such as college tuition subsidies would affect college attendance rates.
- Furthermore, since schooling, work and occupational choices are interrelated, **they can estimate the impact of an intervention** on subsequent occupational choice decisions.
- **Finally, they consider welfare analysis.**

Basic Idea

In a nutshell

- Four endogenous dimensions:
  - Schooling decisions are endogenous.
  - Work experience is endogenous.
  - Occupational choice is endogenous.
  - Wages depend on schooling and occupational choice and work experience in the occupation.
- The decision making is sequential and the environment is uncertain.
- The models incorporated unobserved “types” (heterogeneity).

Implementation

Estimation

- The estimation involves the **repeated numerical solution of a discrete-choice, finite horizon optimization problem**.
- Its formulation is based on a dynamic programming problem.
- The model is estimated using 1,400 white males (ages 16-26) from the NLSY79.

- In each period, the individual chooses one of five mutually exclusive alternatives:
  - Working in a blue-collar occupation ($m = 1$)
  - Working in a white-collar occupation ($m = 2$)
  - Working in the military ($m = 3$)
  - Attending school ($m = 4$)
  - Engaging in home production ($m = 5$)
- Schooling and occupation-specific experience are endogenously accumulated.
- Individual's skill endowments differ among alternatives.
- Each alternative has associated stochastic elements.

Model

- At age a, individuals choose among five mutually exclusive and exhaustive alternatives.
- Let $d_m(a) = 1$ if alternative m is chosen at age a and 0 otherwise.
- The reward per period at any age a is:

$$R(a) = \sum_{m=1}^{5} R_m(a) d_m(a)$$

where $R_m(a)$ is the reward per period associated with m-th alternative.

Working

- The current-period reward for working in occupation m:

$$R_m(a) = e_m(a) \times r_m$$

r_m is rental price,
$e_m(a)$ number of occupation specific skill units.

- **The model for (log) wages is:**

$$\begin{aligned} e_m(a) = \exp \big(& e_m(16) + e_{m1} g(a) \\ & + e_{m2} x_m(a) - e_{m3} x_m^2(a) + \epsilon_m(a) \big) \end{aligned}$$

$m = 1, 2, 3$; $a = 16, ..., A$; $e_m(16)$ is the initial skill endowment; $g(a)$ number of years of schooling completed; $x_m(a)$ is on work experience in that occupation.

Non-working

The reward function for schooling has two components:

- Indirect cost of schooling associated with effort $(e_4(16) + \epsilon_4(a))$
- Direct schooling costs of attending college (tc_1) or of attending graduate school (tc_2)

Thus,

$$R_4(a) = e_4(16) - tc_1 1[g(a) \geq 12] - tc_2 1[g(a) \geq 16] + \epsilon_4(a)$$

For home production (leisure):

$$R_5(a) = e_5(16) + \epsilon_5(a)$$

Decision

Shocks and Initial Conditions

- $(\epsilon_1(a), \epsilon_2(a), \epsilon_3(a), \epsilon_4(a), \epsilon_5(a)) \sim N(0, \Sigma)$
- Shocks are serially uncorrelated
- Initial conditions are the given schooling level of schooling completed at age 16
- Accumulated work experience at age 15 assumed to be zero

Let $V(\boldsymbol{S}(a), a)$ be the value function:

$$V(\boldsymbol{S}(a), a) = \max_{d_m(a)} E\left[\sum_{\tau=a}^{A} \delta^{\tau-a} \sum_{m=1}^{5} R_m(a) d_m(a) | \boldsymbol{S}(a)\right]$$

where $\boldsymbol{S}(a) = \{\boldsymbol{e}(16), g(a), \boldsymbol{x}(a), \epsilon(a)\}$ with $m = 1, ..., 5$.

- Individual knows all relevant prices and functions.
- The maximization is achieved by choice of the optimal sequence of control variables $d_m(a) : m =, 1..., 5$ for $a = 16, ..., A$.
- Strong information processing assumption relaxed in Navarro and Zhou (2017), Cunha and Heckman (2016), and Cunha, Heckman, and Navarro (2005).

Individual's Objective

The value function can be written as the maximum over alternative-specific value functions, each of which obeys the Bellman equation:

$$V(\boldsymbol{S}(a), a) = \max_{m \in M} \{V_m(\boldsymbol{S}(a), a)\}$$

where

$$\begin{aligned} V_m(\boldsymbol{S}(a), a) &= R_m(\boldsymbol{S}(a), a) \\ &\quad + \delta E[V(\boldsymbol{S}(a+1), a+1) | \boldsymbol{S}(a), d_m(a) = 1] \ a < A \\ V_m(\boldsymbol{S}(A), A) &= R_m(\boldsymbol{S}(A), A) \end{aligned}$$

- The expectation is taken over the distribution of random components of $\boldsymbol{S}(a+1)$ conditional on $\boldsymbol{S}(a)$, i.e. $\epsilon(a+1)$.
- Predetermined state variables evolve in a Markovian manner: $x_m(a+1) = x_m(a) + d_m(a)$ and $g_m(a+1) = g_m(a) + d_4(a)$, respectively.

Individual's Objective:

Intuitive description of the decision process

- At age 16 the individual observes the realization of 5 random draws
- He uses them to calculate the realized current rewards and thus the alternative-specific value functions
- He chooses the alternative that yields the highest value.
- The state space is then updated according to the alternative chosen and the process is repeated.

The problem is solved using backward induction. The solution of the optimization problem serves as the input into the likelihood function. Notice that the solution is probabilistic from the point of view of the econometrician.

Estimation

Likelihood

Likelihood Function

- For each individual the data consist of $\{d_{nm}(a), d_{nm}(a)w_{nm}(a)\}$ for $m = 1, .., 3$ and $d_{nm}(a)$ for $m = 4, 5$.
- Let $c(a)$ denote the choice-reward combination at age a.
- Let $\overline{\boldsymbol{S}}(a) = \{\boldsymbol{e}(16), g(a), x(a)\}$
- Serial independence implies:

$$\Pr[c(16), .., c(\bar{a}) | g(16), \boldsymbol{e}(16)] = \prod_{a=16}^{\bar{a}} \Pr[c(a) | \overline{\boldsymbol{S}}(a)]$$

- The likelihood is the product of this probability over N individuals.

Likelihood Function

- Estimation involves an iterative process: solving numerically the dynamic programming problem for given parameter values and then computing the likelihood function, until the likelihood is maximized.
- The likelihood involves the calculation of multivariate integrals (Keane and Wolpin, 1994).

Unobserved Heterogeneity

- To allow for the possibility that individuals do not have identical age 16 endowments: K types.
- Endowments are type-specific:

$$\boldsymbol{e}_k(16) = \{e_{mk}(16) : m = 1, ..., 5\} \ , \ k \in \{1, ..., K\}$$

- **Agents know their type.**
- The econometrician does not observe types.
- This can be relaxed.
- The model is consistent with a model of comparative advantages among the different alternatives.

- Initial schooling is probably endogenous.
- Assumption: Initial schooling is exogenous conditional on the age 16 endowment vector.
- Individual's contribution to the likelihood:

$$\Pr[c_n(16), .., c_n(\bar{a}) | g_n(16)] =$$

$$\sum_{k=1}^{K} \prod_{a=16}^{\bar{a}} \pi_{k|g_n(16)} \Pr[c_n(a) | g_n(16), type = k]$$

Types vs. Factors

- The factor (conditional independence) approach used, e.g., in Eisenhauer, Heckman, and Mosso (2015) (from now on EHM) in matching differs from Keane and Wolpin (2007) in its specification of the distribution of the unobserved components.
- In their specification, agents have different initial conditions for each state variable.
- The distribution of initial conditions is multinomial with five components.
- They assume that there are only four types (values) of initial conditions in the population.
- Serial dependence is induced through the persistence of the initial conditions as determinants of current state variables.
- In addition, at each age the agent receives five shocks associated with the rewards of each choice.
- The shocks are joint normally distributed, serially uncorrelated, and they are assumed to be i.i.d. over time.

- EHM allow for state dependence in the distribution of the unobservables by letting earnings and cost shocks be drawn from normal distributions with different variances at each state and at each transition.
- Moreover, they allow unobserved portions of cost and return functions to be contemporaneously and serially correlated through their common dependence on the factors θ.
- EHM θ are normally distributed so they have a continuum of types.
- The Keane and Wolpin (2007) specification of persistent heterogeneity is a version of a factor model in which all factor loadings are implicitly determined (through Bellman iterations) by the parameters of the deterministic portions of cost and return functions and the distribution functions of unobserved variables and the sample distribution of observables.
- In EHM, the factor loadings are specified independently of the parameters of the deterministic portions of the cost and return

Estimation Appendix

Empirical Analysis of Keane and Wolpin

- National Longitudinal Surveys of Youth 1979
- They use the core sample of white males who were age 16 or less as of October 1, 1977.
- Sample = 1,373 individuals.
- NLSY79 contains retrospective data.
- They generate detailed schooling and labor market histories.

- They take data in the fortieth week of each year (October 1), the first week of each year (January 1), and then fourteenth week (April 1).
- Individual attended school during the year if she attended in any of the three weeks and individual reported completing one grade level by October first next year.
- Work assignment used data on work status in nine weeks between October 1 and June 30. An individual has worked during the year if was not attending school and was employed in at least two-third of the weeks for at least 20 hours per week on average.

- Three occupations: blue-collar, white-collar, or the military. The occupation is the one in which the individual worked the most weeks during the year.
- Real wages are obtained by multiplying the average real weekly wage for the weeks worked in the occupation times 50 weeks.
- An individual is at home if he neither was enrolled in school nor working during the year.

TABLE 1

CHOICE DISTRIBUTION: WHITE MALES AGED 16–26

AGE	School	Home	White-Collar	Blue-Collar	Military	TOTAL
	CHOICE					
16	1,178	145	4	45	1	1,373
	85.8	10.6	.3	3.3	.1	100.0
17	1,014	197	15	113	20	1,359
	74.6	14.5	1.1	8.3	1.5	100.0
18	561	296	92	331	70	1,350
	41.6	21.9	6.8	24.5	5.2	100.0
19	420	293	115	406	107	1,341
	31.3	21.9	8.6	30.3	8.0	100.0
20	341	273	149	454	113	1,330
	25.6	20.5	11.2	34.1	8.5	100.0
21	275	257	170	498	106	1,306
	21.1	19.7	13.0	38.1	8.1	100.0
22	169	212	256	559	90	1,286
	13.1	16.5	19.9	43.5	7.0	100.0
23	105	185	336	546	68	1,240
	8.5	14.9	27.1	44.0	5.5	100.0
24	65	112	284	416	44	921
	7.1	12.2	30.8	45.2	4.8	100.0
25	24	61	215	267	24	591
	4.1	10.3	36.4	45.2	4.1	100.0
26	13	32	88	127	2	262
	5.0	12.2	33.6	48.5	.81	100.0
Total	4,165	2,063	1,724	3,762	645	12,359
	33.7	16.7	14.0	30.4	5.2	100.0

NOTE.—Number of observations and percentages.

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TABLE 2

Transition Matrix: White Males Aged 16–26

Choice $(t-1)$	Choice (t): School	Home	White-Collar	Blue-Collar	Military
School:					
Row %	69.9	12.4	6.5	9.9	1.3
Column %	91.2	32.6	2.5	14.2	11.2
Home:					
Row %	9.8	47.2	8.1	31.3	3.7
Column %	4.4	42.9	8.8	15.6	10.7
White-collar:					
Row %	5.7	6.3	67.4	19.9	.7
Column %	1.8	4.0	51.4	7.0	1.4
Blue-collar:					
Row %	3.4	12.4	9.9	73.4	.9
Column %	2.6	19.0	18.2	61.7	4.3
Military:					
Row %	1.4	5.5	3.1	9.6	80.5
Column %	.2	1.6	1.0	1.5	72.4

TABLE 3

SELECTED CHOICE-STATE COMBINATIONS

Highest grade completed	9	10	11	12	13	14	15	16	17
Percentage choosing school	26.9	59.8	49.1	13.5	45.1	44.8	62.5	13.5	42.5
If in school previous period	73.5	91.1	85.0	44.2	72.9	70.6	68.8	23.5	55.6
White-collar experience	0	1	2	3	4	5	6		
Percentage choosing white-collar employment	6.8	38.0	55.3	63.3	76.2	74.6	79.2		
If white-collar previous period	...	57.5	71.7	76.7	78.8	82.0	86.4		
Blue-collar experience	0	1	2	3	4	5	6	7	
Percentage choosing blue-collar employment	15.0	51.6	64.9	74.0	74.9	81.2	77.1	88.3	
If blue-collar previous period	...	62.0	71.4	78.7	81.7	85.3	78.7	85.4	
Military experience	0	1	2	3	4	5			
Percentage choosing military employment	1.5	68.0	56.6	44.6	32.7	61.9			
If military previous period	...	90.7	86.5	74.0	57.1	78.8			

TABLE 4

Average Real Wages by Occupation: White Males Aged 16–26

Age	Mean Wage: All Occupations	White-Collar	Blue-Collar	Military
16	10,217 (28)	. . .	10,286 (26)	. . .
17	11,036 (102)	10,049 (14)	11,572 (75)	9,005 (13)
18	12,060 (377)	11,775 (71)	12,603 (246)	10,171 (60)
19	12,246 (507)	12,376 (97)	12,949 (317)	9,714 (93)
20	13,635 (587)	13,824 (128)	14,363 (357)	10,852 (102)
21	14,977 (657)	15,578 (142)	15,313 (419)	12,619 (96)
22	17,561 (764)	20,236 (214)	16,947 (476)	13,771 (74)
23	18,719 (833)	20,745 (299)	17,884 (481)	14,868 (53)
24	20,942 (667)	24,066 (259)	19,245 (373)	15,910 (35)
25	22,754 (479)	24,899 (207)	21,473 (250)	17,134 (22)
26	25,390 (206)	32,756 (79)	20,738 (125)	. . .

Note.—Number of observations is in parentheses. Not reported if fewer than 10 observations.

Implementation

Implementation and Estimation

- A is set at 65
- K is 4
- Initial schooling : (7,8,9) or (10,19).
- The authors allow linear cross-experience terms in the skill production function.

TABLE B1

Estimates of the Basic Model

A. Occupation-Specific Parameters

	White-Collar		Blue-Collar		Military	
Skill functions:						
Schooling	.0938	(.0014)	.0189	(.0014)	.0443	(.0027)
White-collar experience	.1170	(.0015)	.0674	(.0017)	. . .	
Blue-collar experience	.0748	(.0017)	.1424	(.0011)	. . .	
Military experience	.0077	(.0007)	.1021	(.0021)	.3391	(.0122)
"Own" experience squared/100	−.0461	(.0032)	−.1774	(.0041)	−2.9900	(.2156)
Constants:						
Type 1	8.8043	(.0124)	8.9156	(.0126)	8.4704	(.0234)
Deviation of type 2 from type 1	−.0668	(.0047)	.2996	(.0094)	. . .	
Deviation of type 3 from type 1	−.4221	(.0100)	−.1223	(.0079)	. . .	
Deviation of type 4 from type 1	−.4998	(.0176)	.0756	(.0058)	. . .	
True error standard deviation	.3301	(.0077)	.3329	(.0070)	.3308	(.0156)
Measurement error standard deviation	.4133	(.0065)	.3089	(.0055)	.1259	(.0166)
Error correlation matrix:						
White-collar	1.0010	(· · ·)				
Blue-collar	−.3806	(.0252)	1.0000	(· · ·)		
Military	−.3688	(.0245)	.4120	(.0505)	1.0000	(· · ·)

B. School and Home Parameters

	School			Home	
Constants:					
Type 1	43,948	(850)		16,887	(413)
Deviation of type 2 from type 1	−26,352	(757)		215	(377)
Deviation of type 3 from type 1	−30,541	(754)		−16,966	(542)
Deviation of type 4 from type 1	226	(594)		−13,128	(1,000)
Net tuition costs:					
College	2,983	(156)		...	
Graduate school	26,357	(737)		...	
Error standard deviation	2,312	(105)		13,394	(460)
Discount factor			.7870 (.0048)		

C. Type Proportions by Initial School Level and Type-Specific Endowment Rankings

	Type 1	Type 2	Type 3	Type 4
Initial schooling:				
Nine years or less	.1751 (· · ·)	.2396 (.0172)	.5015 (.0199)	.0838 (.0125)
10 years or more	.0386 (· · ·)	.4409 (.0344)	.4876 (.0350)	.0329 (.0131)
Rank ordering:				
White-collar	1	2	3	4
Blue-collar	3	1	4	2
Schooling	2	3	4	1
Home	2	1	4	3

Note.—Standard errors are in parentheses.

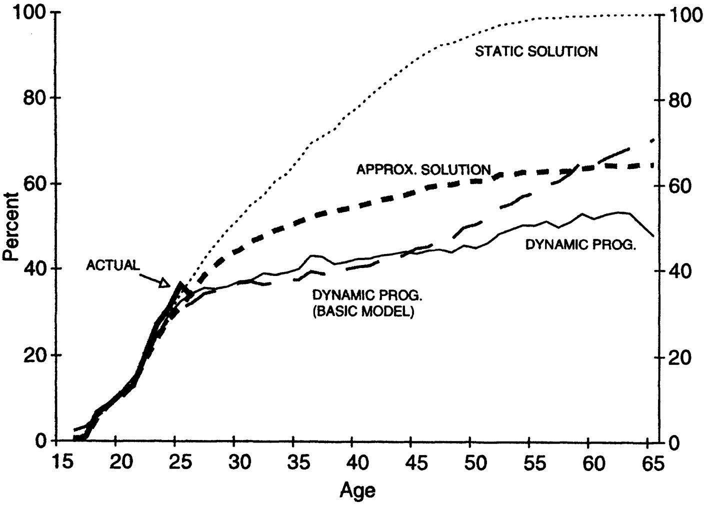

FIG. 1.—Percentage white-collar by age

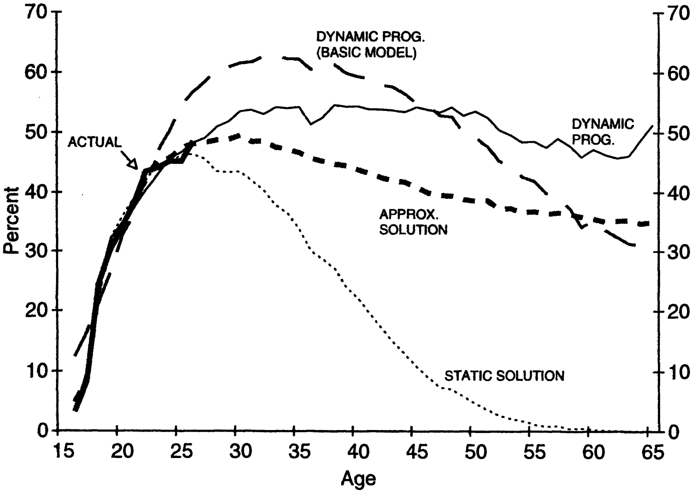

FIG. 2.—Percentage blue-collar by age

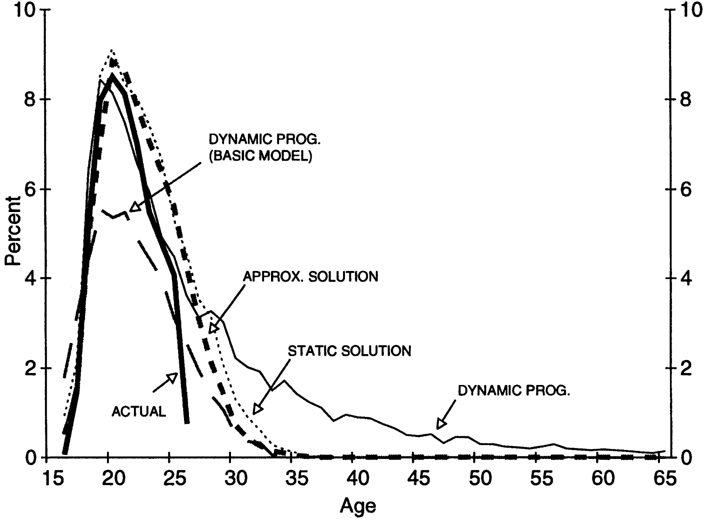

FIG. 3.—Percentage in the military by age

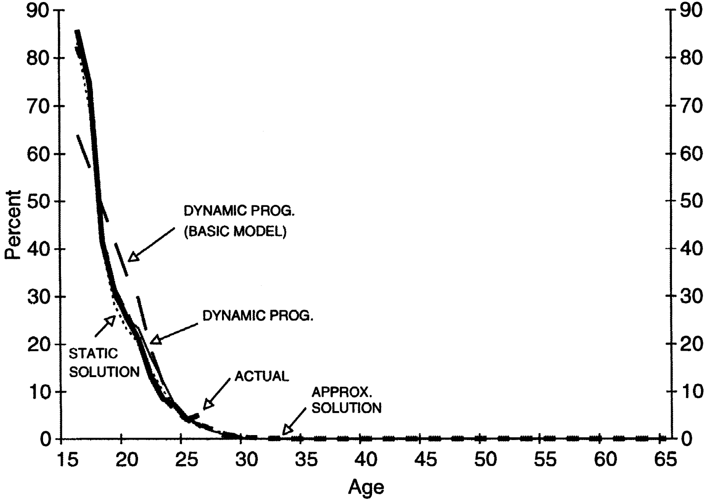

FIG. 4.—Percentage in school by age

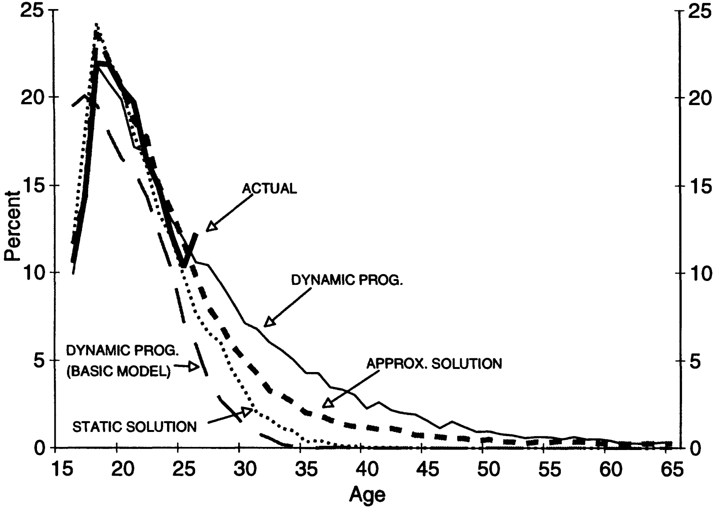

FIG. 5.—Percentage at home by age

TABLE 5

χ^2 GOODNESS-OF-FIT TESTS OF THE WITHIN-SAMPLE CHOICE DISTRIBUTION: DYNAMIC PROGRAMMING MODEL AND MULTINOMIAL PROBIT

Age	School	Home	White-Collar	Blue-Collar	Military	Row
16:						
DP-basic	103.05*	17.10*	†	92.61*	†	213.2*
DP-extended	.00	.07	†	.15	†	.22
APP	2.00	.19	†	7.05*	†	9.24*
17:						
DP-basic	74.13*	7.37*	21.14*	54.63*	11.86*	169.15*
DP-extended	.95	.02	.28	3.31	.42	4.98
APP	.02	.00	1.78	.03	.00	1.84
18:						
DP-basic	15.02*	1.60	2.18	6.75*	1.71	27.26*
DP-extended	.03	.00	.93	.01	3.09	4.06
APP	.09	.94	3.03	.42	.17	4.65
19:						
DP-basic	35.83*	5.04*	.26	7.23*	14.41*	62.77*
DP-extended	.83	.51	.07	1.27	.34	3.02
APP	.00	.02	.01	.17	1.53	1.73
20:						
DP-basic	31.10*	6.24*	.14	.92	24.47*	62.86*
DP-extended	.16	.25	.24	.22	.22	.94
APP	.25	.01	.82	.06	.17	1.31
21:						
DP-basic	31.28*	6.54*	.01	1.46	16.61*	55.89*
DP-extended	2.91	3.50	2.45	.23	.72	9.81*
APP	.00	.65	.05	.03	.41	1.14
22:						
DP-basic	23.78*	2.94	1.01	.08	11.84*	39.66*
DP-extended	12.43*	.11	.61	3.04	.38	16.60*
APP	.12	1.49	.72	.64	1.21	4.19
23:						
DP-basic	12.63*	7.78*	2.99	2.00	3.15	28.56*
DP-extended	14.66*	.12	3.76	.42	.44	19.40*
APP	.23	.14	5.90*	.44	4.38	10.97*
24:						
DP-basic	.18	4.76*	2.28	4.61*	1.40	13.30*
DP-extended	.18	.99	.81	.04	.04	1.89
APP	1.21	2.77	2.20	.05	2.77	10.01*
25:						
DP-basic	.30	12.35*	6.21*	9.31*	1.84	30.01*
DP-extended	.14	3.45	2.71	.29	.23	6.82
APP	.01	2.98	5.00*	.61	2.56	11.16*
26:						
DP-basic	4.96*	38.64*	.17	3.13	†	46.90*
DP-extended	2.61	2.14	.45	.00	†	5.20
APP	2.84	4.95*	.10	.01	†	7.90*

NOTE.—The basic dynamic programming (DP-basic) model has 50 parameters, the extended dynamic programming (DP-extended) model has 83 parameters, and the approximate decision rule (APP) model has 75 parameters.

* Statistically significant at the .05 level.

† Fewer than five observations.

TABLE 6

WITHIN-SAMPLE WAGE FIT

	White-Collar				Blue-Collar			
	NLSY*	DP-Basic	DP-Extended	Static	NLSY†	DP-Basic	DP-Extended	Static
Wage:								
Mean	19,691	17,456	19,605	19,688	16,224	16,230	15,805	15,914
Standard deviation	12,461	10,324	12,091	13,664	8,631	8,437	8,431	9,837
Wage regression:								
Highest grade completed	.095	.033	.090	.091	.048	.006	.047	.056
	(.007)‡	(.007)	(.006)	(.007)	(.008)	(.006)	(.006)	(.007)
Occupation-specific experience	.103	.017	.080	.123	.096	.082	.078	.108
	(.009)	(.011)	(.012)	(.010)	(.005)	(.004)	(.004)	(.005)
Constant	8.33	9.15	8.44	8.22	8.80	9.25	8.84	8.54
	(.102)	(.087)	(.080)	(.100)	(.096)	(.069)	(.078)	(.082)
R^2	.213	.021	.182	.172	.150	.117	.104	.142
Observations	1,509	1,605	1,685	1,698	3,143	4,013	3,761	3,772

* Three wage outliers of over $250,000 were discarded. The only important effect was to reduce the wage standard deviation significantly.
† Two wage outliers of over $200,000 were discarded. The only important effect was to reduce the wage standard deviation significantly.
‡ Heteroskedasticity-corrected standard errors are in parentheses.

The basic model human capital model does not provide a good fit to the quantitative features of the data (within-of-sample fit and out-of-sample fit). Keane and Wolpin turned the attention to an extended version (83 parameters) of the basic model (50 parameters).

Extended Model

Work alternatives: Skill technology functions $e_m(a)$

- Skill depreciation effect (dummy variable for whether or not the individual worked in the same occupation in the previous period). (Lagged dependent variable.)
- A first year experience effect,
- Age effects,
- High school and college graduation effects.

Work alternatives: Mobility and job search costs

- The model includes a direct monetary job-finding cost if one did not work in the occupation in the previous period,
- An additional job-finding cost if the individual had no prior work-experience in the occupations.

Work alternatives: Nonpecuniary rewards plus indirect compensations

- Additive parameter was included in each civilian reward function reflecting the net monetary-equivalent of working conditions, indirect compensations, or fixed costs of working.

School Attendance

- The schooling reward is more generally interpreted to include a consumption value of school attendance.
- It is allowed to depend systematically on age.
- It includes a cost of reentry into high school, and a separate reentry cost into post-secondary school.

Remaining at Home

- The reward is allowed to differ by age (includes dummy variables indicating whether the individual is in the age range 18-12, and 21 and over).

Common Returns

- A psychic value associated with earning a high school diploma
- A psychic value associated with earning a college diploma
- A cost of leaving military without having remained there for at least two years.

1. Reward Functions

$$
\begin{aligned}
R_{mk}(a) &= w_{mk}(a) - c_{m1} \cdot I[d_m(a-1) = 0] \\
&\quad - c_{m2} \cdot I[x_m(a) = 0] + \alpha_m \\
&\quad + \beta_1 I[g(a) \geq 12] + \beta_2 I[g(a) \geq 16] \\
&\quad + \beta_3 I[x_3(a) = 1], \quad m = 1, 2, \\
R_{3k}(a) &= \exp[\alpha_3(a)] w_3(a) - c_{32} \cdot I[x_3(a) = 0] \\
&\quad + \beta_1 I[g(a) \geq 12] + \beta_2 I[g(a) \geq 16], \\
R_{4k}(a) &= e_{4k}(16) - tc_1 \cdot I[12 \leq g(a)] - tc_2 \cdot I[g(a) \geq 16] \\
&\quad - rc_1 \cdot I[d_4(a-1) = 0, g(a) \leq 11] \\
&\quad - rc_2 \cdot I[d_4(a-1) = 0, g(a) \geq 12] \\
&\quad + \beta_1 I[g(a) \geq 12] + \beta_2 I[g(a) \geq 16] \\
&\quad + \beta_3 I[x_3(a) = 1] + \gamma_{41} a + \gamma_{42} I(16 \leq a \leq 17) + \epsilon_4(a), \\
R_{5k}(a) &= e_{5k}(16) + \beta_1 I[g(a) \geq 12] + \beta_2 I[g(a) \geq 16] \\
&\quad + \beta_3 I[x_3(a) = 1] + \gamma_{51} I(18 \leq a \leq 20) \\
&\quad + \gamma_{52} I(a \geq 21) + \epsilon_5(a).
\end{aligned}
\tag{C1}
$$

2. Skill Technology Functions

$$
\begin{aligned}
e_{mk}(a) = \exp\{ & e_{mk}(16) + e_{m11} g(a) + e_{m12} I[g(a) \geq 12] \\
& + e_{m13} I[g(a) \geq 16] + e_{m2} x_m(a) - e_{m3} x_m^2(a) \\
& + e_{m4} I(x_m > 0) + e_{m5}(a) + e_{m6} I(a < 18) \\
& + e_{m7} d_m(a-1) + e_{m8} x_{m' \neq m}(a) + e_{m9} x_3(a)\} \\
& \times \exp[\epsilon_m(a)], \quad m, m' = 1, 2;\ a = 16, \ldots, 65.
\end{aligned} \tag{C2}
$$

$$
\begin{aligned}
e_3(a) = \exp[& e_3(16) + e_{31} g(a) + e_{32} x_3(a) - e_{33} x_3^2(a) \\
& + e_{34} I(x_3 > 0) + e_{35}(a) + e_{36} I(a < 18)].
\end{aligned} \tag{C3}
$$

3. Initial Conditions ($S(16)$)

Skill endowments: $e_{1k}(16)$, $e_{2k}(16)$, $e_{3k}(16)$, $e_{4k}(16)$, and $e_{5k}(16)$.
School attainment: $g(16)$ given.
Work experience: $x_m(16) = 0$.
State space: $\mathbf{S}(a) = \{S(16),\ a,\ g(a),\ x_m(a): \{m = 1, 2, 3\},\ d_m(a-1): \{m = 1, 2, 4\},\ \epsilon_m(a): \{1, \ldots, 5\}\}$.

A. Notation

Alternatives (m): employed in white-collar occupation ($m = 1$), employed in blue-collar occupation ($m = 2$), employed in military ($m = 3$), attending school ($m = 4$), and staying at home ($m = 5$).
$d_m(a)$: equals one if alternative m is chosen at age a, zero otherwise.
$R_m(a)$: utility of the mth alternative at age a, $m = 1, \ldots, 5$.
r_m: occupation-specific skill rental price.
$e_m(a)$: occupation-specific skill at age a, $m = 1, 2, 3$.
$w_m(a)$: occupation-specific wage offer received at age a, $m = 1, 2, 3$; equal to $r_m e_m(a)$.
$g(a)$: school attainment at age a: $g(a) = g(a-1) + d_4(a-1)$, $6 < g(a) < 21$.
$x_m(a)$: work experience in occupation m ($m = 1, 2, 3$); $x_m(a) = x_m(a-1) + d_m(a-1)$.
$I(\cdot)$: indicator function equal to one if term inside parentheses is true, zero otherwise.
k: endowment type: $k = 1, 2, 3, 4$.
$\epsilon_m(a)$: stochastic productivity shocks, $m = 1, \ldots, 5$.

TABLE 7

ESTIMATED OCCUPATION-SPECIFIC PARAMETERS

	White-Collar	Blue-Collar	Military
		1. Skill Functions	
Schooling	.0700 (.0018)	.0240 (.0019)	.0582 (.0039)
High school graduate	−.0036 (.0054)	.0058 (.0054)	. . .
College graduate	.0023 (.0052)	.0058 (.0080)	. . .
White-collar experience	.0270 (.0012)	.0191 (.0008)	. . .
Blue-collar experience	.0225 (.0008)	.0464 (.0005)	. . .
Military experience	.0131 (.0023)	.0174 (.0022)	.0454 (.0037)
"Own" experience squared/100	−.0429 (.0032)	−.0759 (.0025)	−.0479 (.0140)
"Own" experience positive	.1885 (.0132)	.2020 (.0128)	.0753 (.0344)
Previous period same occupation	.3054 (.1064)	.0964 (.0124)	. . .
Age*	.0102 (.0005)	.0114 (.0004)	.0106 (.0022)
Age less than 18	−.1500 (.0515)	−.1433 (.0308)	−.2539 (.0443)
Constants:			
Type 1	8.9370 (.0152)	8.8811 (.0093)	8.540 (.0234)
Deviation of type 2 from type 1	−.0872 (.0089)	.3050 (.0138)	. . .
Deviation of type 3 from type 1	−.6091 (.0143)	−.2118 (.0144)	. . .
Deviation of type 4 from type 1	−.5200 (.0199)	−.0547 (.0177)	. . .
True error standard deviation	.3864 (.0094)	.3823 (.0074)	.2426 (.0249)
Measurement error standard deviation	.2415 (.0140)	.1942 (.0134)	.2063 (.0207)
Error correlation:			
White-collar	1.0000	. . .	. . .
Blue-collar	.1226 (.0430)	1.0000	. . .
Military	.0182 (.0997)	.4727 (.0848)	1.0000

	2. Nonpecuniary Values					
Constant	−2,543	(272)	−3,157	(253)	−.0900	(.0448)
Age	. . .		. . .		−.0313	(.0057)
	3. Entry Costs					
If positive own experience but not in occupation in previous period	1,182	(285)	1,647	(199)	. . .	
Additional entry cost if no own experience	2,759	(764)	494	(698)	560	(509)
	4. Exit Costs					
One-year military experience	. . .		. . .		1,525	(151)

NOTE.—Standard errors are in parentheses.
* Age is defined as age minus 16.

TABLE 8

Estimated School and Home Parameters

	School		Home	
Constants:				
Type 1	11,031	(626)	20,242	(608)
Deviation of type 2 from type 1	−5,364	(1,182)	−2,135	(753)
Deviation of type 3 from type 1	−8,900	(957)	−14,678	(679)
Deviation of type 4 from type 1	−1,469	(1,011)	−2,912	(768)
Has high school diploma	804	(137)	. . .	
Has college diploma	2,005	(225)	. . .	
Net tuition costs: college	4,168	(838)	. . .	
Additional net tuition costs: graduate school	7,030	(1,446)	. . .	
Cost to reenter high school	23,283	(1,359)	. . .	
Cost to reenter college	10,700	(926)	. . .	
Age*	−1,502	(111)	. . .	
Aged 16–17	3,632	(1,103)	. . .	
Aged 18–20	. . .		−1,027	(538)
Aged 21 and over	. . .		−1,807	(568)
Error standard deviation	12,821	(735)	9,350	(576)
Discount factor	.9363 (.0014)			

Note.—Standard errors are in parentheses.
* Age is defined as age minus 16.

TABLE 9

ESTIMATED TYPE PROPORTIONS BY INITIAL SCHOOLING LEVEL AND TYPE-SPECIFIC ENDOWMENT RANKINGS

	Type 1	Type 2	Type 3	Type 4
Initial schooling:				
Nine years or less	.0491 (· · ·)	.1987 (.0294)	.4066 (.0357)	.3456 (.0359)
10 years or more	.2343 (· · ·)	.2335 (.0208)	.3734 (.0229)	.1588 (.0183)
Rank ordering:				
School attainment at age 16	1	2	3	4
White-collar skill endowment	1	2	4	3
Blue-collar skill endowment	2	1	4	3
Consumption value of school net of effort cost	1	3	4	2
Value of home production	1	2	4	3

NOTE.—Standard errors are in parentheses.

- Basic DP
- Extended Model
- Static model: $\delta = 0$
- Approximation model: $V_m(a) = S_m(a)\alpha_m + \epsilon_m(a)$. It includes exclusion restrictions, and unobserved heterogeneity. This is a five-alternative multinomial probit.
- $S_m(a)$ is a linearized version of value function (follows Heckman, 1981)
- Many versions of approximation
- E.g., exact form of current reward and approximate continuation value (Geweke and Keane, 2001)

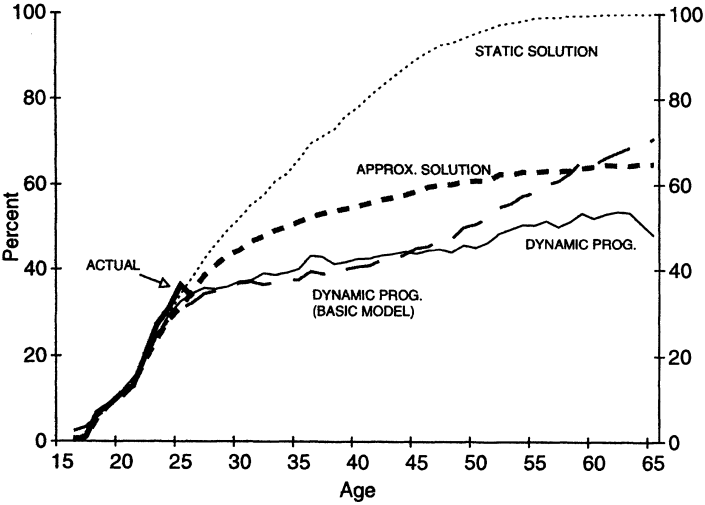

Fig. 1.—Percentage white-collar by age

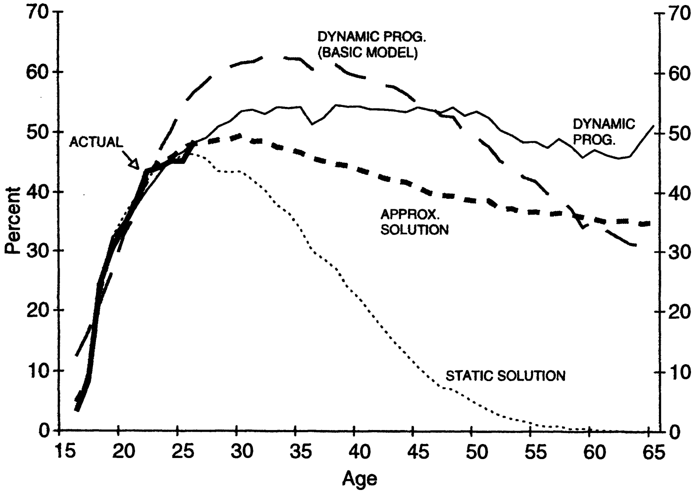

FIG. 2.—Percentage blue-collar by age

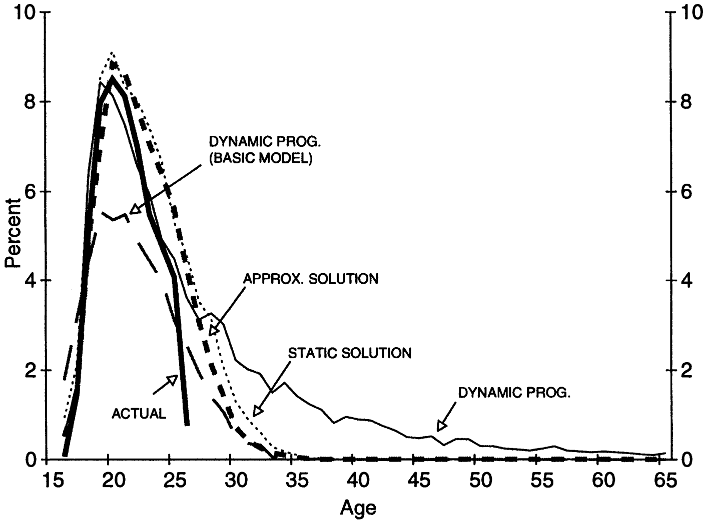

FIG. 3.—Percentage in the military by age

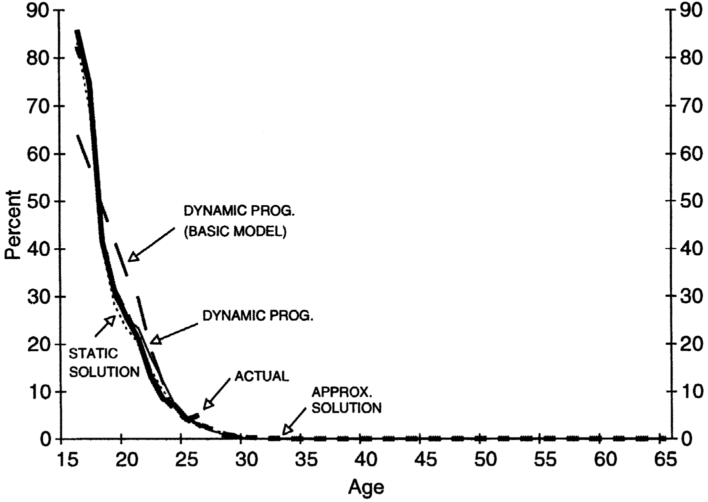

FIG. 4.—Percentage in school by age

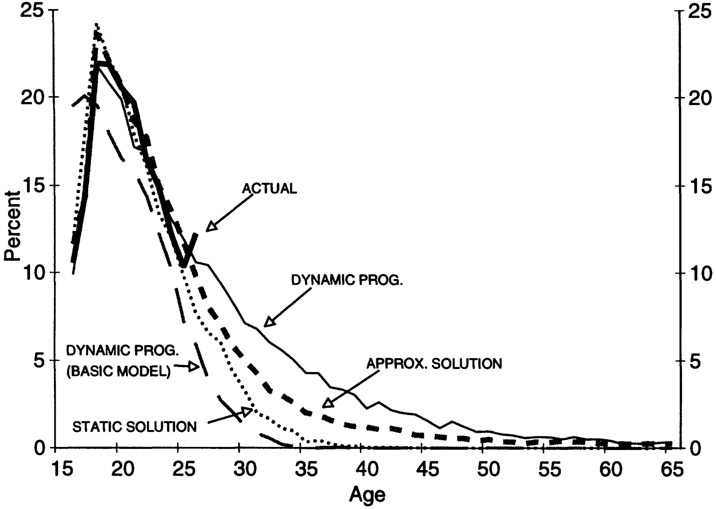

FIG. 5.—Percentage at home by age

TABLE 5

χ^2 GOODNESS-OF-FIT TESTS OF THE WITHIN-SAMPLE CHOICE DISTRIBUTION: DYNAMIC PROGRAMMING MODEL AND MULTINOMIAL PROBIT

Age	School	Home	White-Collar	Blue-Collar	Military	Row
16:						
DP-basic	103.05*	17.10*	†	92.61*	†	213.2*
DP-extended	.00	.07	†	.15	†	.22
APP	2.00	.19	†	7.05*	†	9.24*
17:						
DP-basic	74.13*	7.37*	21.14*	54.63*	11.86*	169.15*
DP-extended	.95	.02	.28	3.31	.42	4.98
APP	.02	.00	1.78	.03	.00	1.84
18:						
DP-basic	15.02*	1.60	2.18	6.75*	1.71	27.26*
DP-extended	.03	.00	.93	.01	3.09	4.06
APP	.09	.94	3.03	.42	.17	4.65
19:						
DP-basic	35.83*	5.04*	.26	7.23*	14.41*	62.77*
DP-extended	.83	.51	.07	1.27	.34	3.02
APP	.00	.02	.01	.17	1.53	1.73
20:						
DP-basic	31.10*	6.24*	.14	.92	24.47*	62.86*
DP-extended	.16	.25	.24	.22	.22	.94
APP	.25	.01	.82	.06	.17	1.31
21:						
DP-basic	31.28*	6.54*	.01	1.46	16.61*	55.89*
DP-extended	2.91	3.50	2.45	.23	.72	9.81*
APP	.00	.65	.05	.03	.41	1.14
22:						
DP-basic	23.78*	2.94	1.01	.08	11.84*	39.66*
DP-extended	12.43*	.11	.61	3.04	.38	16.60*
APP	.12	1.49	.72	.64	1.21	4.19
23:						
DP-basic	12.63*	7.78*	2.99	2.00	3.15	28.56*
DP-extended	14.66*	.12	3.76	.42	.44	19.40*
APP	.23	.14	5.90*	.44	4.38	10.97*
24:						
DP-basic	.18	4.76*	2.28	4.61*	1.40	13.30*
DP-extended	.18	.99	.81	.04	.04	1.89
APP	1.21	2.77	2.20	.05	2.77	10.01*
25:						
DP-basic	.30	12.35*	6.21*	9.31*	1.84	30.01*
DP-extended	.14	3.45	2.71	.29	.23	6.82
APP	.01	2.98	5.00*	.61	2.56	11.16*
26:						
DP-basic	4.96*	38.64*	.17	3.13	†	46.90*
DP-extended	2.61	2.14	.45	.00	†	5.20
APP	2.84	4.95*	.10	.01	†	7.90*

NOTE.—The basic dynamic programming (DP-basic) model has 50 parameters, the extended dynamic programming (DP-extended) model has 83 parameters, and the approximate decision rule (APP) model has 75 parameters.

* Statistically significant at the .05 level.

† Fewer than five observations.

TABLE 6

WITHIN-SAMPLE WAGE FIT

	White-Collar				Blue-Collar			
	NLSY*	DP-Basic	DP-Extended	Static	NLSY†	DP-Basic	DP-Extended	Static
Wage:								
Mean	19,691	17,456	19,605	19,688	16,224	16,230	15,805	15,914
Standard deviation	12,461	10,324	12,091	13,664	8,631	8,437	8,431	9,837
Wage regression:								
Highest grade completed	.095	.033	.090	.091	.048	.006	.047	.056
	(.007)‡	(.007)	(.006)	(.007)	(.008)	(.006)	(.006)	(.007)
Occupation-specific experience	.103	.017	.080	.123	.096	.082	.078	.108
	(.009)	(.011)	(.012)	(.010)	(.005)	(.004)	(.004)	(.005)
Constant	8.33	9.15	8.44	8.22	8.80	9.25	8.84	8.54
	(.102)	(.087)	(.080)	(.100)	(.096)	(.069)	(.078)	(.082)
R^2	.213	.021	.182	.172	.150	.117	.104	.142
Observations	1,509	1,605	1,685	1,698	3,143	4,013	3,761	3,772

* Three wage outliers of over $250,000 were discarded. The only important effect was to reduce the wage standard deviation significantly.
† Two wage outliers of over $200,000 were discarded. The only important effect was to reduce the wage standard deviation significantly.
‡ Heteroskedasticity-corrected standard errors are in parentheses.

TABLE 10

Model Predictions vs. CPS Choice Frequencies

Age Range	NLSY*	CPS (Year)†	DP-Basic*	DP-Extended†	Approximation*
			White-Collar		
16–19	.043	.064 (1981)	.052	.043	.041
20–23	.190	.187 (1985)	.176	.187	.180
24–26	.344	.345 (1989)	.307	.335	.332
24–27	···	.348 (1989)	.323	.343	.349
28–31	···	.384 (1993)	.365	.375	.443
30–33	···	.413 (1995)	.370	.388	.472
35–44	···	.449 (1995)	.405	.430	.547
			Blue-Collar		
16–19	.171	.265 (1981)	.199	.182	.176
20–23	.430	.432 (1985)	.416	.418	.434
24–26	.475	.472 (1989)	.544	.490	.498
24–27	···	.476 (1989)	.565	.494	.498
28–31	···	.465 (1993)	.616	.539	.495
30–33	···	.460 (1995)	.624	.547	.487
35–44	···	.423 (1995)	.595	.541	.440

* Military is excluded to facilitate comparison with CPS (which is a civilian sample).

† Choice frequencies pertain to whites in the March CPS from the years indicated. We classify a person as working if, over the previous calendar year, he worked at least 35 weeks and, in those weeks, he worked at least 20 hours per week on average. The occupation is that held longest in the previous year.

Conclusion

It would be difficult to choose between the dynamic programming model and the approximation model on the basis of their ability to accurately forecast the choice distribution.

Discussion

Heterogeneity

Discussion: The Importance of Unobserved Skill Heterogeneity

TABLE 11

SELECTED CHARACTERISTICS AT AGE 24 BY TYPE: NINE OR 10 YEARS INITIAL SCHOOLING

	Initial Schooling 9 Years or Less				Initial Schooling 10 Years or More			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
Schooling	15.6	10.6	10.9	11.0	16.4	12.5	12.4	13.0
Experience:								
White-collar	.528	.704	.742	.279	1.07	1.06	1.05	.436
Blue-collar	.189	4.05	2.85	1.61	.176	3.65	2.62	1.77
Military	.000	.000	1.35	.038	.000	.000	1.10	.034
Proportion who chose:								
White-collar	.509	.123	.176	.060	.673	.236	.284	.155
Blue-collar	.076	.775	.574	.388	.039	.687	.516	.441
Military	.000	.000	.151	.010	.000	.000	.116	.005
School	.416	.008	.013	.038	.239	.024	.025	.074
Home	.000	.095	.086	.505	.050	.053	.059	.325

NOTE.—Based on a simulation of 5,000 persons.

TABLE 12

Expected Present Value of Lifetime Utility for Alternative Choices at Age 16 and at Age 26 by Type ($)

	All Types	Type 1	Type 2	Type 3	Type 4
	Initial Schooling 10 Years or More				
School:					
Age 16	321,008	415,435	394,712	228,350	289,683
Age 26	384,352	499,162	494,107	272,985	314,708
Home:					
Age 16	298,684	380,660	376,945	207,768	274,901
Age 26	426,837	611,167	516,547	291,932	338,653
White-collar:					
Age 16	293,683	372,544	372,733	207,586	262,370
Age 26	439,970	637,616	528,107	303,228	338,967
Blue-collar:					
Age 16	296,736	373,156	377,618	210,699	266,206
Age 26	438,240	617,873	534,578	305,641	342,195
Military:					
Age 16	285,686	350,655	356,202	210,461	261,944
Age 26	415,374	581,996	492,531	298,431	329,938
Maximum over choices:					
Age 16	321,921	415,503	396,108	229,265	291,122
Age 26	445,488	638,820	537,226	308,259	346,695

	Initial Schooling Nine Years or Less				
School:					
Age 16	273,186	387,384	371,369	211,942	276,040
Age 26	308,808	564,590	446,163	243,734	274,979
Home:					
Age 16	260,668	352,274	360,495	197,288	268,047
Age 26	334,643	578,637	468,465	268,815	305,262
White-collar:					
Age 16	253,764	342,833	354,261	196,294	253,686
Age 26	339,093	602,915	474,796	277,488	300,917
Blue-collar:					
Age 16	257,720	343,873	359,370	199,945	257,697
Age 26	344,179	583,895	486,456	282,223	305,520
Military:					
Age 16	251,710	322,293	340,126	199,737	254,386
Age 26	328,916	550,521	447,443	275,660	295,996
Maximum over choices:					
Age 16	275,634	387,384	374,154	213,823	286,311
Age 26	347,741	604,549	487,466	284,073	310,598

Conclusion

- The difference in lifetime utility due to variation in initial schooling are small relative to some of the differences due to endowment heterogeneity.
- Skill endowment heterogeneity is potentially an important determinant of inequality in lifetime welfare. On the basis of simulated data, the between-type variance in expected lifetime utility is calculated to account for 90 percent of the total variance.
- Is heterogeneity a black box?

TABLE 13

Relationship of Initial Schooling and Type to Selected Family Background Characteristics

	Initial Schooling Nine Years or Less and Person Is of Type				Initial Schooling 10 Years or More and Person Is of Type				Observations	Expected Present Value of Lifetime Utility at Age 16
	1 (1)	2 (2)	3 (3)	4 (4)	1 (5)	2 (6)	3 (7)	4 (8)	(9)	(10)
All	.010	.051	.103	.090	.157	.177	.289	.123	1,373	307,673
Mother's schooling:										
Non–high school graduate	.004	.099	.177	.161	.038	.141	.276	.103	333	286,642
High school graduate	.011	.043	.086	.071	.143	.210	.305	.131	685	309,275
Some college	.023	.021	.043	.058	.294	.166	.263	.133	152	328,856
College graduate	.007	.005	.049	.023	.388	.151	.222	.154	142	339,593
Household structure at age 14:										
Live with mother only	.001	.062	.133	.119	.123	.137	.297	.128	178	296,019
Live with father only	.026	.037	.088	.120	.062	.180	.378	.106	44	291,746
Live with both parents	.011	.049	.097	.082	.169	.184	.284	.124	1,123	310,573
Live with neither parent	.0001	.090	.154	.184	.037	.175	.275	.085	28	290,469
Number of siblings:										
0	.002	.041	.086	.092	.142	.227	.285	.126	50	310,833
1	.002	.029	.064	.051	.236	.199	.287	.133	261	320,697
2	.016	.048	.104	.063	.191	.157	.275	.146	364	311,053
3	.013	.056	.119	.090	.147	.182	.288	.104	320	306,395
4+	.009	.067	.117	.141	.081	.171	.303	.111	378	296,089
Parental income in 1978:										
$Y \leq 1/2$ median*	.002	.078	.155	.181	.071	.132	.221	.161	214	292,565
$1/2$ median $< Y \leq$ median	.007	.053	.120	.103	.103	.173	.328	.113	382	296,372
Median $\leq Y \leq 2 \cdot$ median	.015	.044	.071	.051	.177	.204	.304	.134	446	314,748
$Y \geq 2 \cdot$ median	.014	.025	.024	.021	.479	.167	.182	.087	83	358,404

* Median income in the sample is $20,000.

Tuition

Discussion: The Impact of a College Tuition Subsidy on School Attainment and Inequality

TABLE 14

EFFECT OF A $2,000 COLLEGE TUITION SUBSIDY ON SELECTED CHARACTERISTICS BY TYPE

	All Types	Type 1	Type 2	Type 3	Type 4
Percentage high school graduates:					
No subsidy	74.8	100.0	68.6	70.2	67.0
Subsidy	78.3	100.0	73.2	74.0	72.2
Percentage college graduates:					
No subsidy	28.3	98.7	11.1	8.6	19.5
Subsidy	36.7	99.5	21.0	17.1	32.9
Mean schooling:					
No subsidy	13.0	17.0	12.1	12.0	12.4
Subsidy	13.5	17.0	12.7	12.5	13.0
Mean years in college:					
No subsidy	1.34	3.97	.69	.59	1.05
Subsidy	1.71	3.99	1.14	1.00	1.58

NOTE.—Subsidy of $2,000 each year of attendance. Based on a simulation of 5,000 persons.

TABLE 15

Distributional Effects of a $2,000 College Tuition Subsidy

	Type 1	Type 2	Type 3	Type 4
Mean expected present value of lifetime utility at age 16:				
No subsidy	413,911	391,162	225,026	286,311
Subsidy	419,628	392,372	226,313	288,109
Gross gain	5,717	1,210	1,287	1,798
Net gain:				
Subsidy to all types*	3,513	−994	−917	−406
Subsidy to types 2, 3, and 4†	−1,134	76	153	664
Subsidy to types 3 and 4‡	−862	−862	425	936

* The per capita cost of the subsidy program is $2,204.
† The per capita cost of the subsidy program is $1,134.
‡ The per capita cost of the subsidy program is $862.

Conclusions

- Augmented human capital investment model does a good job of fitting the data.
- The more parsimonious model could not explain either the degree of persistence in occupational choices or the rapid decline in schooling with age.
- The results suggest that a tuition subsidy would increase high school graduation rate and college graduation rates. However, it would have a negligible impact on the expected value of lifetime utility.
- Inequality in skill endowment (measured at age 16) explains the bulk of the variation in lifetime utility.