The Skill Content of Recent Technological Change: An Empirical Exploration

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Introduction

What explains skill-biased technical change?

- There is a positive correlation between the adoption of computers and relative demand for college workers.
- This has been interpreted as evidence of Skill-Biased Technical Change (SBTC).
- However, this interpretation labels the correlation without explaining its cause.
- Why do computers shift relative labor demand?

Preview of findings

- Computerization will reduce demand for routine labor tasks and increase demand for non-routine labor tasks, and workers reallocate from routine tot non-routine tasks (I.A).
- These effects are stronger in industries that are initially more intensive in routine labor tasks (I.B).
- The paper tests these predictions using task measures (II-V).
- It shows that task changes due to computerization explain a substantial fraction of the increase in relative demand for college workers (VI).

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I. The task model

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Routine and non-routine tasks

- Technological progress is seen as routine labor tasks than can be automated.
- Routine labor tasks follow explicit rules that can be written in computer code.
- Non-routine labor tasks cannot be specified in computer code.
- Labor task can also be analytic and interactive or manual.

TABLE I

PREDICTIONS OF TASK MODEL FOR THE IMPACT OF COMPUTERIZATION ON FOUR CATEGORIES OF WORKPLACE TASKS

	Routine tasks	Nonroutine tasks
	Analytic and interactive tasks	
Examples	• Record-keeping • Calculation • Repetitive customer service (e.g., bank teller)	• Forming/testing hypotheses • Medical diagnosis • Legal writing • Persuading/selling • Managing others
Computer impact	• Substantial substitution	• Strong complementarities
	Manual tasks	
Examples	• Picking or sorting • Repetitive assembly	• Janitorial services • Truck driving
Computer impact	• Substantial substitution	• Limited opportunities for substitution or complementarity

Intuitive assumptions

Consider the following 3 assumptions:

1. Routine and non-routine tasks are imperfect substitutes.
2. Computers substitute for routine labor tasks.
3. Computers increase the productivity of non-routine labor tasks.

The paper develops a formal model based on these assumptions.

Production function

- Assume an aggregate Cobb-Douglas production function:

$$Q = [L_R + C]^{1-\beta} L_N^{\beta} \text{ with } \beta \in (0,1) \tag{1}$$

  with L_R and L_N routine and non-routine labor and C computer capital, in efficiency units.

- C is supplied perfectly elastically at price ρ.

- ρ is falling exogenously with time due to technological progress. This is the causal force in the model.

Assumptions (formally)

This production function implies the following 3 assumptions:

1. The elasticity of substitution between L_R or C and L_N is 1, i.e. routine and non-routine tasks are imperfect substitutes.
2. C substitutes for routine labor tasks because the elasticity of substitution between C and L_R is ∞.
3. The marginal productivity of non-routine labor tasks rises with computerization because C and L_N are q-complements.

Labor supply: Roy framework

- Each worker i inelastically supplies one unit of labor.
- Workers have heterogeneous productivity endowments in both routine and non-routine labor tasks:

$$\forall i : E_i = [r_i, n_i] \text{ with } 1 \geqslant r_i, n_i > 0$$

- Worker i chooses $0 \leqslant \lambda_i \leqslant 1$ to maximize income:

$$L_i = [\lambda_i r_i, [1 - \lambda_i] n_i]$$

- Workers will choose a task based on comparative advantage as in Roy [51] and some will re-allocate following a decline in ρ.

Equilibrium

- The wage per efficiency unit of routine labor tasks must be equal to the price of computer capital:

$$w_R = \rho \tag{2}$$

- Define $\eta_i \equiv n_i / r_i \in (0, \infty)$ as i's relative efficiency at doing non-routine versus routine labor tasks.
- Define the relative efficiency of marginal workers as:

$$\eta^* = w_R / w_N \tag{3}$$

- Worker i supplies routine labor tasks ($\lambda_i = 1$) if $\eta_i < \eta^*$ and supplies non-routine labor tasks otherwise ($\lambda_i = 0$).

Equilibrium: Sorting

- Labor supply in efficiency units to routine and non-routine labor tasks is given by:

$$g(\eta) = \sum_i r_i I(\eta_i < \eta) \text{ and } h(\eta) = \sum_i n_i I(\eta_i \geqslant \eta)$$

  with I an index function.

- Further assume that η_i has nonzero support at all $\eta_i \in (0, \infty)$, so that $g(\eta)$ is continuously upward sloping and $h(\eta)$ is continuously downward sloping in η.

- This ensures that L_R^* and L_N^* are not zero.

Equilibrium: Productive efficiency

- Productive efficiency requires:

$$w_R = \frac{\partial Q}{\partial L_R} = [1-\beta]\theta^{-\beta} \text{ and } w_N = \frac{\partial Q}{\partial L_N} = \beta\theta^{1-\beta} \qquad (4)$$

where θ is the ratio of routine to non-routine tasks:

$$\theta \equiv [C + g(\eta^*)] / h(\eta^*) \qquad (5)$$

- Equations (2) to (5) provide equilibrium conditions for the model's variables (w_R, w_N, θ, η).
- How does a decline in the price of computers affect task inputs, relative wages, and labor supply?

Technological progress, relative wages, and labor supply

- From the expression for $w_R = \rho$ in equation (4) we get that:

$$\frac{\partial ln(\theta)}{\partial ln(\rho)} = -\frac{1}{\beta} < 0$$

- Combining this with equations (2)-(4) we get that:

$$\boxed{\frac{\partial ln(w_N / w_R)}{\partial ln(\rho)} = -\frac{\partial ln(\eta^*)}{\partial ln(\rho)} = \frac{\partial ln(\theta)}{\partial ln(\rho)} = -\frac{1}{\beta} < 0 \quad (7)}$$

- The relative wage of workers doing non-routine tasks increases and marginal workers will reallocate from routine to non-routine labor tasks.

Summary so far

- An exogenous decline in the price of computers increases the demand for computers.
- The demand for routine labor tasks declines because computers and routine labor tasks are perfect substitutes.
- The demand for non-routine labor tasks increases because routine and non-routine tasks are q-complements.
- Marginal workers reallocate their labor supply from routine tot non-routine labor tasks.

I. The task model

I.A The demand for routine and non-routine tasks

I.B Industry-level implications

Industry-level implications

- An aggregate production function and decline in the price of computers only gives a single time series to test the model.
- Additional leverage comes from assuming different sectors j with different task technologies, i.e. with different β_j.
- The more routine-task intensive an industry initially is (β_j small), the more will be invested in computers and the larger will be the decline in routine labor tasks and the rise in non-routine labor tasks.

Industry-level implications

- Assume industry j's production function is:

$$q_j = r_j^{1-\beta_j} n_j^{\beta_j} \text{ with } \beta_j \in (0,1) \tag{8}$$

- Assume Dixit-Stiglitz monopolistic competition with utility of the representative consumer given by:

$$U(q_1, ..., q_j, ...) = [\sum_j q_j^{1-\nu}]^{1/[1-\nu]} \text{ with } 0 < \nu < 1 \tag{9}$$

- Consumer demand for each good j is given by:

$$q_j = [p_j / P^{1-\nu}]^{-1/\nu} Q$$

with P the aggregate price index and $p_j = MC/[1-\nu]$.

Industry factor demands

- Profit maximization by firms gives demands for routine and non-routine tasks in each industry:
- Demand for routine tasks is given by:

$$r_j = \rho^{-1/\nu}[[1-\beta_j][1-\nu]]^{1/\nu}\left[\frac{w_N}{\rho}\frac{[1-\beta_j]}{\beta_j}\right]^{[\beta_j[\nu-1]]/\nu} \tag{11a}$$

- Demand for non-routine labor tasks is given by:

$$n_j = w_N^{-1/\nu}[\beta_j[1-\nu]]^{1/\nu}\left[\frac{w_N}{\rho}\frac{[1-\beta_j]}{\beta_j}\right]^{[[1-\beta_j][1-\nu]]/\nu} \tag{11b}$$

Industry-level predictions

1. The proportionate increase in routine tasks is larger in routine-task intensive industries (β_j small) (P1):

$$\boxed{\frac{\partial ln(r_j)}{\partial \rho} = \frac{\beta_j[1-\nu]-1}{\nu\rho} < 0 \text{ and } \frac{\partial^2 ln(r_j)}{\partial \rho \partial \beta_j} = \frac{1-\nu}{\nu\rho} > 0}$$

2. The proportionate increase in non-routine tasks is larger in routine-task intensive industries (P2):

$$\boxed{\frac{\partial ln(n_j)}{\partial \rho} = \frac{[\beta_j - 1][1-\nu]}{\nu\rho} < 0 \text{ and } \frac{\partial^2 ln(n_j)}{\partial \rho \partial \beta_j} = \frac{1-\nu}{\nu\rho} > 0}$$

3. Similar predictions can be made for j an occupation. (P3)

II. Empirical Implementation

II. Empirical implementation

II.A Selecting measures of routine and non-routine tasks

II.B A predictive test

Main data

- Task measures: Fourth [1977] Edition and Revised Fourth [1991] Edition of Dictionary of Occupational Titles (DOT) examine 12K occupations along 44 dimensions.
- Worker-level data: Census 1% extracts for 1960, 1970, 1980 and 1990 and CPS (MORG) files for 1980, 1990, 1998. Variables are FTE hours worked per year, gender, education, 485 Census Occupation Codes (COC) and 140 industries.
- Changes in labor tasks have an extensive margin (i.e. changes in occupational employment holding task content within occupations at the 1977 DOT level) and an intensive margin (i.e. changes in labor tasks within occupations comparing the 1977 and 1991 DOT).

Appendix 1: Definitions of Task Measures from the 1977 Dictionary of Occupational Titles

Variable	DOT definition	Task interpretation	Example tasks from *Handbook for Analyzing Jobs*
1. GED Math (MATH)	General educational development, mathematics	Measure of nonroutine analytic tasks	Lowest level: Adds and subtracts 2-digit numbers; performs operations with units such as cup, pint, and quart. Midlevel: Computes discount, interest, profit, and loss; inspects flat glass and compiles defect data based on samples to determine variances from acceptable quality limits. Highest level: Conducts and oversees analyses of aerodynamic and thermodynamic systems . . . to determine suitability of design for aircraft and missiles.
2. Direction, Control, Planning (DCP)	Adaptability to accepting responsibility for the direction, control, or planning of an activity	Measure of nonroutine interactive tasks	Plans and designs private residences, office buildings, factories, and other structures; applies principles of accounting to install and maintain operation of general accounting system; conducts prosecution in court proceedings . . . gathers and analyzes evidence, reviews pertinent decisions . . . appears against accused in court of law; commands fishing vessel crew engaged in catching fish and other marine life.
3. Set Limits, Tolerances, or Standards (STS)	Adaptability to situations requiring the precise attainment of set limits, tolerances, or standards	Measure of routine cognitive tasks	Operates a billing machine to transcribe from office records data; calculates degrees, minutes, and second of latitude and longitude, using standard navigation aids; measures dimensions of bottle, using gauges and micrometers to verify that setup of bottle-making conforms to manufacturing specifications; prepares and verifies voter lists from official registration records.
4. Finger Dexterity (FINGDEX)	Ability to move fingers, and manipulate small objects with fingers, rapidly or accurately	Measure of routine manual tasks	Mixes and bakes ingredients according to recipes; sews fasteners and decorative trimmings to articles; feeds tungsten filament wire coils into machine that mounts them to stems in electric light bulbs; operates tabulating machine that processes data from tabulating cards into printed records; packs agricultural produce such as bulbs, fruits, nuts, eggs, and vegetables for storage or shipment; attaches hands to faces of watches.
5. Eye Hand Foot Coordination (EYEHAND)	Ability to move the hand and foot coordinately with each other in accordance with visual stimuli	Measure of nonroutine manual tasks	Lowest level: Tends machine that crimps eyelets, grommets; next level: attends to beef cattle on stock ranch; drives bus to transport passengers; next level: pilots airplane to transport passengers; prunes and treats ornamental and shade trees; highest level: performs gymnastic feats of skill and balance.

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 size:        10,670
-------------------------------------------------------------------------------------------------
              storage   display    value
variable name   type    format     label      variable label
-------------------------------------------------------------------------------------------------
math77          float   %8.0g                 nonroutine analytic
dcp77           float   %9.0g                 nonroutine interactive
sts77           float   %9.0g                 routine cognitive
finger77        float   %8.0g                 routine manual
ehf77           float   %8.0g                 nonroutine manual
occ8090         int     %9.0g                 Consistent COC occupation code
-------------------------------------------------------------------------------------------------
Sorted by: occ8090

. sum

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
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       dcp77 |        485    2.355269    3.287831          0         10
       sts77 |        485    5.027087    3.879249          0         10
    finger77 |        485    3.876036    1.246284          0   8.987334
       ehf77 |        485    1.303395    1.459722          0         10
-------------+---------------------------------------------------------
     occ8090 |        485     426.134    259.3619          3        889
```

DOT task measures: 1960 centiles

- The DOT measures don't have a natural scale.
- Each DOT measure is transformed into percentile values corresponding to their occupational rank weighted by occupational employment using the 1960 Census.
- Task measures are relative to the 1960 distribution of tasks across workers, measured in centiles.
- Not normalizing the raw DOT scores gives results that are qualitatively identical.

II. Empirical implementation

II.A Selecting measures of routine and non-routine tasks

II.B A predictive test

A predictive test using the merged DOT and 1960 Census

- Define routine tasks across occupations m in industry j as:

$$r_j \equiv \sum_m [STS_{jm} + FINGDEX_{jm}]$$

- Define the sum of all 5 task inputs k in industry j as:

$$r_j + n_j \equiv \sum_m \sum_k T_{jmk}$$

- The percentage Routine Task Share for industry j then is:

$$RTS_{j,1960} = 100 \times r_{j,1960} / [r_{j,1960} + n_{j,1960}]$$

A predictive test using the merged DOT and 1960 Census

- To measure computer adoption, use CPS to calculate an industry's percentile rank of computer use in 1997.
- Estimate the regression equation:

$$C_{j,1997} = \underset{(19.18)}{-24.56} + \underset{(0.48)}{1.85} \times RTS_{j,1960} \tag{12}$$

- An industry that is 10 percentage points intenser in routine tasks is 19 percentage points higher up in the distribution of computer adoption.

III. Trends in Job Task Input, 1960-1998

III. Trends in job task input, 1960-1998

III.A Aggregate trends

III.B Task changes within and between industries

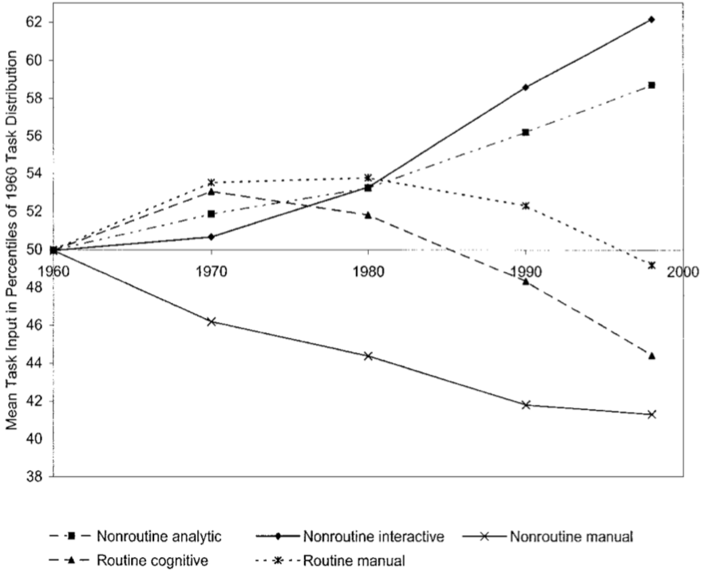
Mean Task Input in Percentiles of 1960 Task Distribution
62
60
58
56
54
52
50
48
46
44
42
40
38
1960
1970
1980
1990
2000
Nonroutine analytic
Nonroutine interactive
Nonroutine manual
Routine cognitive
Routine manual

FIGURE I

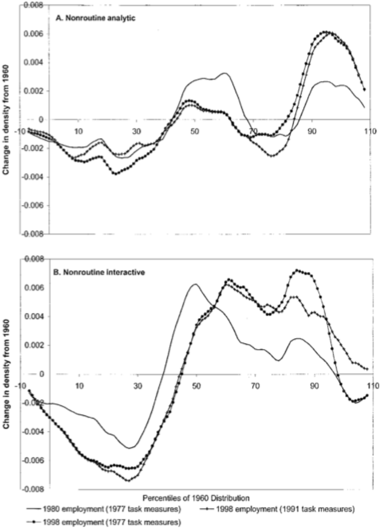

FIGURE II

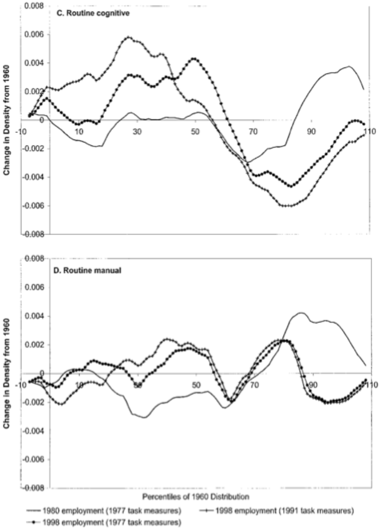

FIGURE II (CONTINUED)

III. Trends in job task input, 1960-1998

III.A Aggregate trends

III.B Task changes within and between industries

Task shifts within- and between-industries

- The change over time in mean task input k can be decomposed as (dropping time subscripts):

$$\Delta T_k = \sum_j \Delta E_j \bar{\alpha}_{jk} + \sum_j \Delta \alpha_{jk} \bar{E}_j$$

  with ΔE_j the change over time in employment in industry j; $\bar{\alpha}_{jk}$ the mean of task k in industry j averaged across years; $\Delta \alpha_{jk}$ the change over time in the mean of task k in industry j; and $\bar{E}_j$ employment in industry j averaged over time.

- The first term is the between-industry component and the second term is the within-industry component.

TABLE II

Means of Task Input by Decade and Decomposition into Within and Between Industry Components, 1960–1998

A. Weighted means of economywide task input by decade (percentiles of 1960 task distribution)

	1. Nonroutine analytic			2. Nonroutine interactive			3. Routine cognitive			4. Routine manual			5. Nonroutine manual		
	All	Male	Fem	All	Male	Fem	All	Male	Fem	All	Male	Fem	All	Male	Fem
1960 (Census)	50.0	54.6	37.0	50.0	58.4	26.4	50.0	48.6	53.8	50.0	43.2	69.2	50.0	56.5	31.6
1970 (Census)	52.5	57.5	41.5	51.1	61.7	27.5	52.2	49.8	57.5	54.0	44.9	74.4	46.9	54.1	30.8
1970 (Census)	51.9	56.4	41.8	50.7	60.8	28.1	53.1	50.8	58.2	53.5	44.7	73.3	46.2	53.2	30.7
1980 (Census)	54.9	58.2	49.2	55.4	63.3	41.8	52.9	50.0	58.0	55.1	44.6	73.3	44.0	53.2	28.1
1980 (CPS)	53.2	56.6	47.9	53.3	61.4	40.4	51.8	50.0	54.8	53.8	43.3	70.4	44.4	55.0	27.5
1990 (CPS)	56.2	57.4	54.6	58.6	62.7	53.0	48.3	48.1	48.6	52.3	42.8	65.5	41.8	53.1	26.3
1998 (CPS)	58.7	59.3	58.0	62.2	63.9	59.9	44.4	46.6	41.6	49.2	41.5	59.3	41.3	52.6	26.5

B. Decomposition of task shifts into between and within industry components for combined genders (10 × annual changes in mean task percentile)

	Total	Btwn	Wthn	Total	Btwn	Wthn	Total	Bwtn	Wthn	Total	Btwn	Wthn	Total	Btwn	Wthn
1960–1970	2.57	1.74	0.83	1.15	−0.34	1.49	2.20	1.14	1.06	4.01	2.39	1.62	−3.03	−2.28	−0.74
1970–1980	3.02	1.54	1.48	4.68	0.26	4.42	−0.14	0.33	−0.47	1.63	0.79	0.84	−2.25	−1.00	−1.25
1980–1990	2.97	0.92	2.05	5.31	0.52	4.79	−3.48	−1.42	−2.07	−1.47	−0.16	−1.31	−2.58	−1.27	−1.31
1990–1998	3.12	0.67	2.45	4.48	0.54	3.94	−4.88	−1.31	−3.57	−3.88	−0.38	−3.50	−0.63	−0.31	−0.31

IV. Computerization and Task Change: Industry-Level Relationships

IV. Computerization and task changes within industries

Industry computerization and task trends, 1960-1998

- The model predicts that industries that adopt computers more will reduce routine and increase non-routine labor tasks more.
- Estimate:

$$\Delta T_{jk\tau} = \alpha + \phi \Delta C_j + \epsilon_{jk\tau} \quad (13)$$

  with $\Delta T_{jk\tau}$ the change in j's input of task k between t and τ and ΔC_j the annual change in the percentage of industry workers using a computer between 1984 and 1997 from CPS.
- Estimate this equation for each of the four decades to compare 1960s-1970s (pre-computer era) to 1980s-1990s.

TABLE III

COMPUTERIZATION AND INDUSTRY TASK INPUT, 1960–1998

DEPENDENT VARIABLE: 10 × ANNUAL WITHIN-INDUSTRY CHANGE IN TASK INPUT, MEASURED IN PERCENTILES OF 1960 TASK DISTRIBUTION

		1. 1990–1998	2. 1980–1990	3. 1970–1980	4. 1960–1970
A. Δ Nonroutine analytic	Δ Computer use 1984–1997	12.04	14.02	9.11	7.49
		(4.74)	(4.97)	(4.17)	(5.28)
	Intercept	0.07	−0.66	−0.26	−0.55
		(1.00)	(1.03)	(0.86)	(1.05)
	R^2	0.04	0.05	0.03	0.01
	Weighted mean Δ	2.45	2.05	1.48	0.83
B. Δ Nonroutine interactive	Δ Computer use 1984–1997	14.78	17.21	10.81	7.55
		(5.48)	(6.32)	(5.71)	(6.64)
	Intercept	1.02	1.46	2.35	0.10
		(1.15)	(1.31)	(1.17)	(1.32)
	R^2	0.05	0.05	0.03	0.01
	Weighted mean Δ	3.94	4.79	4.42	1.49
C. Δ Routine cognitive	Δ Computer use 1984–1997	−17.57	−13.94	−11.00	−3.90
		(5.54)	(5.72)	(5.40)	(4.48)
	Intercept	−0.11	0.63	1.63	1.78
		(1.17)	(1.19)	(1.11)	(0.89)
	R^2	0.07	0.04	0.03	0.01
	Weighted mean Δ	−3.57	−2.07	−0.47	1.06
D. Δ Routine manual	Δ Computer use 1984–1997	−24.72	−5.94	−6.56	4.15
		(5.77)	(5.64)	(4.84)	(3.50)
	Intercept	1.38	−0.16	2.09	0.85
		(1.22)	(1.17)	(0.99)	(0.70)
	R^2	0.12	0.01	0.01	0.01
	Weighted mean Δ	−3.50	−1.31	0.84	1.62

IV. Computerization and task changes within industries

Appendix 2: Computerization and Industry Task Input, 1960–1998: Using Composite Task Measures

Dependent Variable: 10 × Annual within-Industry Change in Task Input, Measured in Percentiles of 1960 Task Distribution

		1. 1990–1998	2. 1980–1990	3. 1970–1980	4. 1960–1970
A. Δ Nonroutine analytic	Δ Computer use 1984–1997	8.21	12.09	6.50	8.57
		(4.55)	(4.55)	(4.21)	(5.74)
	Intercept	0.64	−0.67	0.07	−0.07
		(0.96)	(0.94)	(0.86)	(1.14)
	R^2	0.02	0.05	0.02	0.02
	Weighted mean Δ	2.26	1.67	1.32	1.51
B. Δ Nonroutine interactive	Δ Computer use 1984–1997	9.83	9.93	5.67	10.45
		(4.39)	(4.74)	(3.47)	(5.00)
	Intercept	0.54	0.53	1.42	0.00
		(0.92)	(0.98)	(0.71)	(1.00)
	R^2	0.04	0.03	0.02	0.03
	Weighted mean Δ	2.48	2.45	2.51	1.93
C. Δ Routine cognitive	Δ Computer use 1984–1997	−13.40	−4.59	−4.76	−7.02
		(4.44)	(5.58)	(3.70)	(4.75)
	Intercept	0.23	−0.39	0.56	−0.05
		(0.94)	(1.16)	(0.76)	(0.95)
	R^2	0.06	0.00	0.01	0.02
	Weighted mean Δ	−2.41	−1.28	−0.35	−1.35
D. Δ Routine manual	Δ Computer use 1984–1997	−23.17	−15.27	−13.25	3.98
		(6.99)	(6.86)	(5.34)	(4.13)
	Intercept	−0.52	−0.80	1.97	1.35
		(1.47)	(1.42)	(1.09)	(0.82)
	R^2	0.07	0.03	0.04	0.01
	Weighted mean Δ	−5.09	−3.76	−0.56	2.09

IV. Computerization and task changes within industries

IV.A Industry computerization and task trends over four decades

IV.B Using composite DOT variables

IV.C Employing contemporaneous measures of computer and capital investment

Using measures of computer and capital investment

- The CPS computer use measure only exists for the 1980s and 1990s. Use computer and capital investments for 1959-1998 from the National Income and Product Accounts (NIPA).

- Estimate the following stacked first-difference models:

$$\Delta T_{jk\tau} = \alpha + \delta_{70-80} + \delta_{80-90} + \delta_{90-98} + \varphi CI_{j\tau} + \theta KI_{j\tau} + \epsilon_{jk\tau} \tag{14}$$

  with CI computer and KI capital investment per FTE.

- Cluster standard errors at NIPA sector and decade ($168 = 42x4$ clusters) to account for aggregation or at NIPA sector (42 clusters) to also account for serial correlation.

TABLE IV

COMPUTER INVESTMENT, CAPITAL INTENSITY, AND TASK INPUT IN THREE-DIGIT INDUSTRIES 1960–1998: STACKED FIRST-DIFFERENCE ESTIMATES

DEPENDENT VARIABLE: 10 × ANNUAL CHANGE IN QUANTILES OF TASK MEASURE, MEASURED IN PERCENTILES OF 1960 TASK DISTRIBUTION

	A. Δ Nonroutine analytic		B. Δ Nonroutine interactive		C. Δ Routine cognitive		D. Δ Routine manual	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Log(CI/L)	6.65	6.76	11.59	10.03	−8.27	−8.30	−9.11	−8.20
	(4.13)	(3.97)	(3.21)	(3.31)	(3.63)	(3.26)	(2.57)	(2.29)
	[6.36]	[5.90]	[3.97]	[4.50]	[4.74]	[3.76]	[3.27]	[2.86]
Log(KI/L)	1.22		−3.41		−2.93		−2.42	
	(4.36)		(4.58)		(4.76)		(3.95)	
	[6.36]		[4.45]		[7.31]		[5.87]	
Δ Log(K/L)		0.24		3.01		−1.32		−3.89
		(2.35)		(2.24)		(2.12)		(1.92)
		[2.36]		[2.19]		[2.18]		[2.38]
1970–1980 dummy	−0.64	−0.54	1.38	2.49	−0.32	−0.84	0.68	−0.80
	(1.08)	(1.29)	(1.50)	(1.62)	(1.31)	(1.58)	(0.96)	(1.17)
	[1.02]	[1.23]	[2.07]	[2.12]	[1.13]	[0.93]	[0.94]	[1.03]
1980–1990 dummy	−0.34	−0.25	0.58	1.83	−1.62	−2.14	−1.32	−2.90
	(1.57)	(1.60)	(1.81)	(1.70)	(1.56)	(1.86)	(1.11)	(1.38)
	[1.43]	[1.67]	[1.58]	[1.46]	[1.33]	[1.35]	[0.86]	[1.07]
1990–1998 dummy	−1.19	−1.13	−1.91	−0.90	−1.33	−1.71	−1.15	−2.36
	(1.55)	(1.62)	(1.83)	(1.70)	(1.66)	(1.64)	(1.32)	(1.47)
	[1.77]	[1.93]	[1.85]	[1.88]	[1.93]	[1.63]	[0.95]	[1.13]
Intercept	8.89	8.23	12.40	11.30	−9.29	−7.09	−9.62	−5.55
	(4.08)	(4.42)	(4.25)	(3.59)	(4.12)	(3.63)	(3.14)	(2.67)
	[5.45]	[6.38]	[4.76]	[4.80]	[4.48]	[4.36]	[3.75]	[3.30]
R^2	0.06	0.06	0.11	0.12	0.14	0.14	0.20	0.21
	Weighted mean of dependent variable							
1960–1970	1.16		1.74		1.30		1.63	
1970–1980	1.23		4.59		−0.20		0.98	
1980–1990	2.07		4.69		−2.05		−1.74	
1990–1998	2.15		3.76		−3.03		−2.82	

V. Task Change Within Education Groups and Occupations

V. Task change within education groups and occupations

V.A Within-industry task shifts by education group: 1980-1998

V.B Task shifts within occupations

Task changes within education groups

- Assume that educated workers have a comparative advantage in doing non-routine labor tasks:

$$\eta_i \equiv n_i / r_i \in (0, \infty) \text{ is higher for educated workers}$$

- Shifts towards non-routine tasks against routine labor tasks could then be explained by an increase in the relative demand for educated workers due to computerization.
- To show that changes in labor task demands are an underlying cause and not a symptom of changes in relative demand for skills, we look at labor task changes within education groups.

Within-industry task shifts by education

- We can test whether industries change task assignments of workers with given levels of education.
- Estimate equation (13) by education group:

$$\Delta T_{ijk\tau} = \alpha_i + \phi_i \Delta C_j + \epsilon_{ijk\tau} \tag{15}$$

  with i one of four education groups.
- Use industry task measures for 1980-1998 and (almost) contemporaneous computer use data for 1984-1997.

TABLE V
COMPUTERIZATION AND INDUSTRY TASK INPUT 1980–1998:
OVERALL AND BY EDUCATION GROUP
DEPENDENT VARIABLE: 10 × ANNUAL CHANGE IN QUANTILES OF TASK MEASURE,
MEASURED IN PERCENTILES OF 1960 TASK DISTRIBUTION

	1. Δ Nonroutine analytic	2. Δ Nonroutine interactive	3. Δ Routine cognitive	4. Δ Routine manual
	A. Aggregate within-industry change			
Δ Computer use	12.95	15.97	−15.84	−14.32
1984–1997	(3.68)	(4.32)	(4.73)	(4.73)
Intercept	−0.33	1.27	0.38	0.54
	(0.77)	(0.90)	(0.99)	(0.99)
Weighted mean task Δ	2.20	4.39	−2.71	−2.25
	B. Within industry: High school dropouts			
Δ Computer use	4.64	11.92	−2.64	−8.85
1984–1997	(6.07)	(8.73)	(7.95)	(6.76)
Intercept	−2.51	−4.39	0.02	1.11
	(1.26)	(1.82)	(1.66)	(1.41)
Weighted mean task Δ	−1.61	−2.07	−0.49	−0.62
	C. Within industry: High school graduates			
Δ Computer use	0.04	13.49	−28.18	−25.50
1984–1997	(4.17)	(5.40)	(6.13)	(6.05)
Intercept	−1.49	1.07	1.55	0.48
	(0.87)	(1.13)	(1.28)	(1.26)
Weighted mean task Δ	−1.48	3.70	−3.95	−4.49

	D. Within industry: Some college			
Δ Computer use	7.95	18.14	−15.68	−17.77
1984–1997	(5.03)	(5.54)	(5.27)	(5.61)
Intercept	−1.88	−0.58	0.35	1.39
	(1.05)	(1.15)	(1.10)	(1.17)
Weighted mean task Δ	−0.33	2.96	−2.71	−2.08
	E. Within industry: College graduates			
Δ Computer use	1.61	5.57	−0.78	−4.46
1984–1997	(3.42)	(3.35)	(4.85)	(5.70)
Intercept	0.25	0.10	−0.96	−0.12
	(0.71)	(0.70)	(1.01)	(1.19)
Weighted mean task Δ	0.57	2.22	−1.48	−1.98
	F. Decomposition into within and between education group components			
Explained task Δ	2.52	3.11	−3.09	−2.79
Within educ groups (%)	23.7	77.9	91.7	111.1
Between educ groups (%)	76.3	22.1	8.3	−11.1

Within-industry task shifts by education (Table V)

- Industry-level computerization is strongly predictive of shifts towards non-routine and against routine labor tasks within education groups.
- A decomposition of industry task changes into within and between education groups shows that the within component is quantitatively important.
- This suggests that labor task changes due to computerization are an antecedent to educational upgrading, rather than a symptom of it.

V. Task change within education groups and occupations

V.A Within-industry task shifts by education group: 1980-1998

V.B Task shifts within occupations

Task shifts within occupations

- Task measures were taken from 1977 DOT and are occupation specific.
- This assumes that tasks done within occupations are static, which is an unrealistic assumption in the long-run.
- In particular, computerization is expected to reduce routine and increase non-routine labor tasks also within occupations.
- We can analyse within-occupation task changes by comparing the 1977 and 1991 DOT measures.

Description of the job of "Secretary"

Occupation Outlook Handbook, 1976

"Secretaries relieve their employers of routine duties so they can work on more important matters. Although most secretaries type, take shorthand, and deal with callers, the time spent on these duties varies in different types of organizations."

Occupation Outlook Handbook, 2000

"As technology continues to expand in offices, the role of the secretary has greatly evolved. Office automation and organizational restructuring have led secretaries to assume a wide range of new responsibilities once reserved for managerial and professional staff. Many secretaries now provide training and orientation to new staff, conduct research on the internet, and learn to operate new office technologies."

Task shifts within occupations

- Merge 1977 DOT with 1991 DOT to capture changes in task content within occupations.
- Estimate the following equation:

$$\Delta T_{mk} = \alpha + \xi \Delta C_m + \epsilon_{mk} \tag{16}$$

with ΔT_{mk} the change in occupation m of task k between 1977 and 1991.

- Note that variation in ΔT_{mk} stems exclusively from DOT examiners' reevaluation of the task content of individual occupations between 1977 and 1991.

TABLE VI

COMPUTERIZATION AND CHANGES IN JOB TASK CONTENT WITHIN OCCUPATIONS 1977–1991
DEPENDENT VARIABLE: 10 × ANNUAL WITHIN-OCCUPATION CHANGE IN QUANTILE OF TASK MEASURE, MEASURED IN PERCENTILES OF 1984 TASK DISTRIBUTION

	A. Δ Nonroutine analytic			B. Δ Nonroutine interactive			C. Δ Routine cognitive			D. Δ Routine manual		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Δ Computer use	2.94	3.57	4.02	5.70	5.86	7.08	−18.18	−16.56	−18.48	1.74	0.83	0.37
1984–1997	(1.84)	(1.92)	(2.06)	(1.88)	(1.97)	(2.11)	(3.29)	(3.41)	(3.65)	(2.89)	(3.01)	(3.23)
Δ College grad emp.		−4.79	−4.83		−4.47	−4.58		22.59	22.76		−16.07	−16.03
1984–1997		(5.54)	(5.54)		(5.68)	(5.67)		(9.86)	(9.85)		(8.70)	(8.71)
Δ HS grad emp.		2.83	3.09		−0.19	0.52		16.97	15.86		−10.42	−10.70
1984–1997		(3.78)	(3.81)		(3.88)	(3.90)		(6.73)	(6.77)		(5.94)	(5.99)
Δ Female emp.			−2.37			−6.47			10.14			2.47
1984–1997			(3.94)			(4.03)			(6.99)			(6.19)
Intercept	−0.92	−0.91	−0.95	−0.46	−0.42	−0.52	0.56	0.14	0.30	0.42	0.70	0.74
	(0.40)	(0.41)	(0.41)	(0.41)	(0.42)	(0.42)	(0.71)	(0.72)	(0.73)	(0.63)	(0.64)	(0.64)
R^2	0.01	0.01	0.01	0.02	0.02	0.03	0.06	0.08	0.08	0.00	0.01	0.01
Weighted mean Δ		−0.39			0.58			−2.76			0.74	

Task shifts within occupations (Table VI)

- Occupations with more computerization had stronger shifts towards non-routine and against routine labor tasks.
- This is not driven by shifts in educational and gender distributions of workers within occupations.
- In net, shifts in job contents are a pervasive feature of the data and are concentrated in industries and occupations that adopted computer technology more rapidly.

VI. Quantifying the Magnitude of Task Structure Changes

Quantifying the magnitude of task changes

- The economic significance of task shifts is not clear given that they do not have a familiar scale.
- To meaningfully quantify task changes, calculate their contribution to changes in the demand for more-educated relative to less-educated workers between 1970 and 1998.
- To do this, three steps are taken.

Quantifying the magnitude of task changes

1. Estimate a fixed-coefficient model of educational requirements in industries and occupations as a function of their task inputs:

$$\text{College share}_j = \alpha + \sum_{k=1}^{4} \pi_k T_j^k + \epsilon_j \tag{17}$$

2. Use $\hat{\pi}_k$ to predict changes in the aggregate college share:

$$\hat{\Delta}\text{College share}_{70-98} = \alpha + \sum_{k=1}^{4} \hat{\pi}_k \Delta T_{70-98}^k \tag{18}$$

   with ΔT_{70-98}^k observed or predicted from (13), (14) or (16).

3. Compare predicted changes with predicted demand changes from the canonical model.

TABLE VII

SHIFTS IN COLLEGE-EQUIVALENT LABOR DEMAND IMPLIED BY CHANGES IN JOB TASKS, 1970–1998

	1. 1970–1980 extensive margin	2. 1980–1990 extensive margin	3. 1990–1998 extensive margin	4. 1970–1998 extensive margin	5. 1980–1998 extensive margin	6. 1980–1998 intensive margin	7. 1980–1998 extensive + intensive
	A. 10 × observed annual changes in DOT task measures (percentile changes relative to 1960 task distribution)						
Nonroutine analytic	3.02	2.97	3.12	3.04	3.05	−0.39	2.67
Nonroutine interactive	4.68	5.31	4.48	4.84	4.85	0.58	5.43
Routine cognitive	−0.14	−3.48	−4.88	−3.03	−4.26	−2.76	−7.02
Routine manual	1.63	−1.47	−3.88	−1.44	−2.81	0.74	−2.07
	B. 10 × predicted annual changes in DOT task measures (percentile changes relative to 1960 task distribution)						
	NIPA computer input measure				CPS computer use measure		
Nonroutine analytic	0.84	1.35	2.30	1.55	2.56	0.54	3.10
Nonroutine interactive	1.47	2.36	4.01	2.70	3.16	1.04	4.20
Routine cognitive	−1.05	−1.68	−2.86	−1.92	−3.14	−3.32	−6.46
Routine manual	−1.15	−1.86	−3.15	−2.12	−2.84	0.32	−2.52
	C. 10 × predicted annual changes in college-equivalent share of employment in percentage points, due to observed task shifts (panel A)						
Nonroutine tasks	1.53	1.40	1.63	1.51	1.53	−0.36	0.83
Routine tasks	−0.20	0.66	1.17	0.50	0.97	0.27	0.87
All tasks	1.33	2.06	2.80	2.01	2.49	−0.09	2.40

TABLE VII
(CONTINUED)

	1. 1970–1980 extensive margin	2. 1980–1990 extensive margin	3. 1990–1998 extensive margin	4. 1970–1998 extensive margin	5. 1980–1998 extensive margin	6. 1980–1998 intensive margin	7. 1980–1998 extensive + intensive
	D. 10× annual changes in college-equivalent share of employment in percentage points, predicted by impact of computerization on task input (panel B)						
	NIPA computer investment measure				CPS computer use measure		
Nonroutine tasks	0.40	0.65	1.10	0.69	1.41	0.40	1.81
Routine tasks	0.29	0.48	0.81	0.51	0.80	1.04	1.84
All tasks	0.70	1.12	1.91	1.19	2.21	1.44	3.65
	E. Estimated log demand shifts for college-equivalent/noncollege-equivalent labor 1970–1998 (100 × annual log changes)						
	Using constant-elasticity of substitution model to estimate changes in college demand						
$\sigma = 0.0$	4.99	2.53	2.25	3.33			2.41
$\sigma = 1.4$	3.95	4.65	2.76	3.86			3.81
$\sigma = 2.0$	3.50	5.56	2.98	4.09			4.41
	Using task model to predict changes in college demand						
Total task Δ (panel C)	1.23	1.29	1.43	1.31	1.56	−0.06	1.51
Predicted by computerization (panel D)	0.64	0.70	0.98	0.76	1.39	0.91	2.29

Quantifying the magnitude of task changes (Table VII)

- For 1980-1998, task changes due to computerization explain 60% to 90% of the estimated increase in the relative demand for college employment.
- 60% of the computer contribution to rising educational demand is due to shifts in the task composition between occupations.
- In net, this illustrates that changes in task demands due to computerization are economically large.

VII. Conclusions

Conclusions

- This paper develops a simple model of how computers substitute for workers performing routine tasks and complements workers doing non-routine tasks.
- The model also predicts that industries intensive in routine labor tasks make larger investments in computers.
- Using DOT data, these predictions are confirmed across several margins of task changes.
- These task shifts are an important contributing factor underlying the increase in the relative demand for educated workers in the 1980s and 1990s.