

# Elmer Zongyang Li

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- **Graduate Fields:** Labor Economics, Macroeconomics
- **Research Interests:** Changing Nature of Work, Inequality, Trade
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- **Job Interests:** Academic (Economics, Business, Policy)

# Optimal Skill Mixing Under Technological Advancements

Elmer Zongyang Li

September, 2023

- The *nature of work* has changed dramatically
  - Decline in “routine” tasks and related worker skills Acemoglu(1999), Autor, Levy and Murane (2003), Autor and Dorn (2013)
  - Rising importance of social skills Cortes, Jaimovich, and Siu (2021), Deming (2017)
- Remains unclear

specific specialized skill  $\iff$  a broad range of skills ("*skill mixing*")
- Different implications
  - Specialization in skill demand  $\rightarrow$  experts in a single dimension
  - Skill mixing  $\rightarrow$  multidisciplinary schooling and training

## 1. Documents **new facts** about [skill mixing](#)

- Rich data: incumbent jobs + new vacancies, employer vs. worker
- New angle-based measure

## 2. A **directed search model** with occupation design

- Multi-dimensional skills + non-linear technology
- Before producing, firms first design the occupation, st a cost (Acemoglu, '99)
- Endogenous human capital involvement

## 3. Quantify the [underlying drivers](#)

- Skill mixing changes and related employment, wage dynamics

# Findings

- Substantial **↑ in skill mixing** 2005-2018, even within granular occ.
  - Mainly for non-routine [analytical, interpersonal, computer, leadership, design...]
  - Mainly for medium- to low-wage occupations
  - Source: within-occupation > worker reallocation
    - ▶ Persists controlling gender, industry, occ, skill supply (edu, exp)
- Important **distribution and wage** implications
  - Explains major part of employment/wage polarization
  - Wage returns: 1.5 - 3 percent in skill mixed occupation/college major
- Main channel: **↑ skill complementarity, cost**
  - Experts of analytical, computer / routine skills becomes ↑/↓ efficient
  - These drive skill mixing + employment & wage dynamics

Intro

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# Contributions to the Literature

- Labor market dynamics that focuses on **skill mixing**
  - **Skill/task biased:** Tinbergen (1975); Katz and Murphy (1992); ALM (2003); Acemoglu and Autor (2011); Autor and Dorn (2013); Deming (2017); Deming and Kahn (2018)
  - **Within-occupation variation:** Autor and Handel (2013); Atalay et al. (2020); Freeman, Ganguli, and Handel (2020); Cortes, Jaimovich, and Siu (2021)
- Directed search model w/. **endogenous demand + multi-d non-linear**
  - Menzio and Shi (2010,2011); Kaas and Kircher (2015); Schaal (2017); Baley, Figueiredo, and Ulbricht (2022); Braxton and Taska (2023)
- Matching focusing on **firm skill demand trade-offs under GE forces**
  - **1-D:** Shi (2001); Hagedorn, Law, and Manovskii (2017)
  - **Multi-D:** Yamaguchi (2012); Lindenlaub (2017); Lise and Vinay (2020); Ocampo (2022)
  - **Bundling:** Rosen (1983); Murphy (1986); Heckman and Sedlacek (1985), Choné and Kramarz (2021); Edmond and Mongey (2021)

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# Evidence of Skill Mixing

Intro

**Evidence**

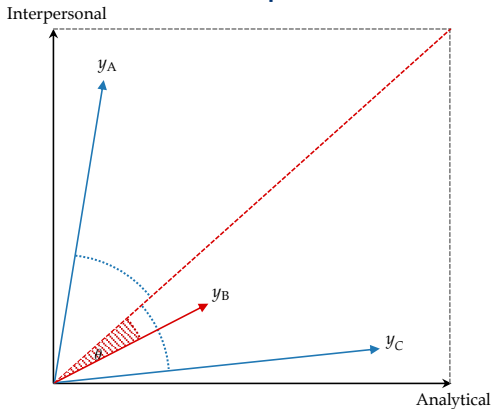
Returns

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# Occupations in Multidimensional Space



## Definition (Degree of Skill Mixing of an occupation)

The skill mixing index for an occupation  $\mathbf{y} = \{y^1, \dots, y^k, \dots, y^K\} \in S \subset \mathbb{R}^{K+}$  is the cosine similarity between its skill vector and the norm  $\hat{\mathbf{v}}$ .

$$\text{Mix}(\mathbf{y}) = \frac{\mathbf{y}\hat{\mathbf{v}}}{||\mathbf{y}|| \cdot ||\hat{\mathbf{v}}||}, \text{ where } \hat{\mathbf{v}} = [1, 1, \dots, 1]' \subseteq \mathbb{R}^{K+}$$

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# Data and Skill Measures

- Occupational Information Network (O\*NET) 2005-2018
  - Detailed descriptors for 970 7-digit occupations [example](#) [content](#)
  - Survey of [incumbent workers](#), Info on skill importance ([intensive margin](#))
- Lightcast (formerly "Burning Glass") 2007-2017
  - Analyzes millions of online job postings into codified skills
  - Info on whether a skill is required for a [vacancy](#) ([extensive margin](#))
- Skill Measures - Acemoglu and Autor (2011) & More
  - Non-routine: [analytical](#), [interpersonal](#), [computer](#); [routine](#) ["RNR"] [details](#)
  - More non-routine: leadership, design, these 5 ["[other non-routine](#)"]
  - Lightcast: keywords based [Braxton & Taska \(2022\)](#) [details](#)

Intro

Evidence

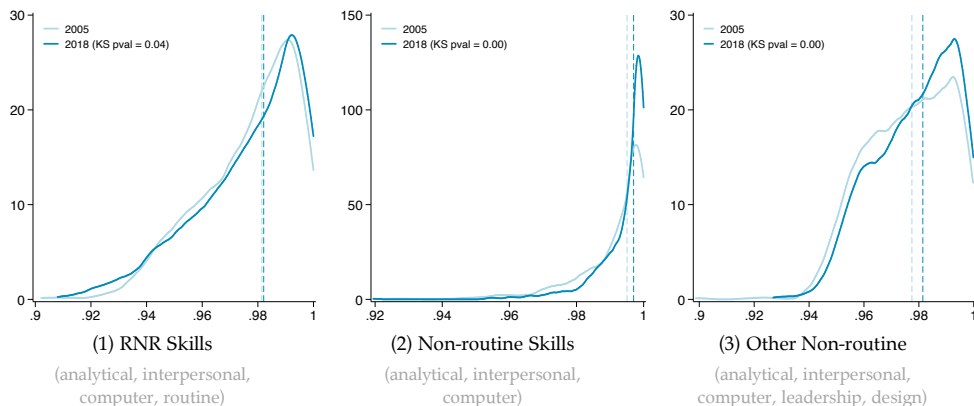
Returns

Model

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# Fact 1: Increase in Skill Mixing at 7-Digit Occupations



**Figure:** Density for Skill Mixing Indexes (Cosine Distances), 2005 vs. 2018

Weighted Density

Non-parametric

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## Fact 2: Growth in Skill Mixing

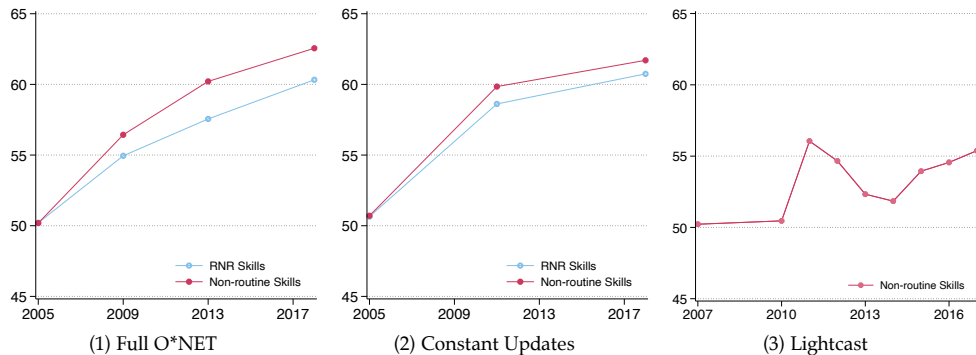


Figure: Trend of Skill Mixing in the US Economy, 2005-2018

Updating issue

Robust - measure

Robust - index

Skill pairs

Composition of updates

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## Fact 2: Growth in Skill Mixing

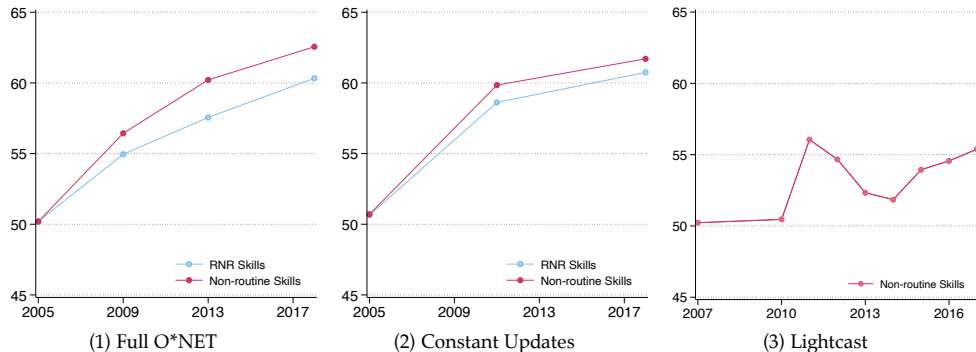


Figure: Trend of Skill Mixing in the US Economy, 2005-2018

total	within	across
10.12	9.46	0.66
12.37	9.72	2.65

total	within	across
10.09	10.74	-0.65
11.00	9.69	1.31

total	within	across
5.16	4.37	0.78

Shift-share decomposition

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## Fact 3: Skill Mixing Increases Regardless of Workforce

	RNR Skills	Non-routine Skills
Full O*NET	0.70*** [0.10]	0.71*** [0.09]
Constant Updates	0.75*** [0.11]	0.65*** [0.11]
Lightcast		0.33** [0.15]
Sex $\times$ Industry $\times$ Occ. FE	X	X
Exp. and edu. controls	X	X

Table: Within Occupation Changes in Skill Mixing Indexes

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## Fact 4: Medium- to Low-Wage Occupations More Mixed

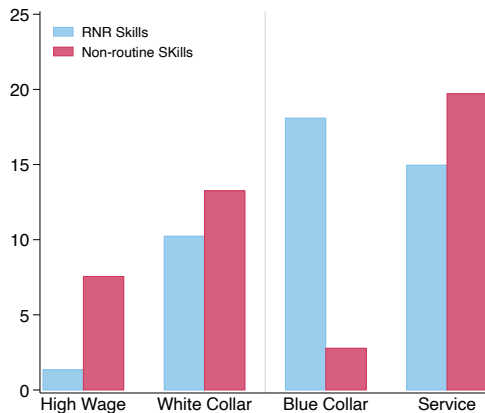


Figure: Skill Mixing Index Change by Occupation Groups, 2005-2018

By industry

Skill pairs

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## Fact 5: Skill Mixing Accounts for Polarization

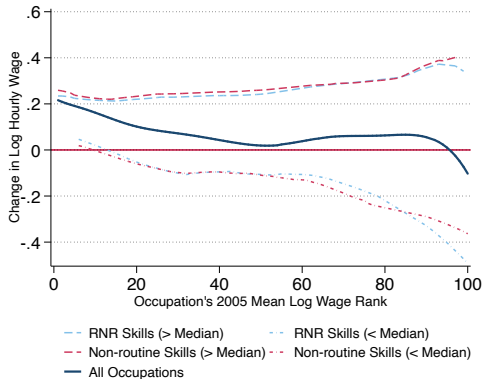
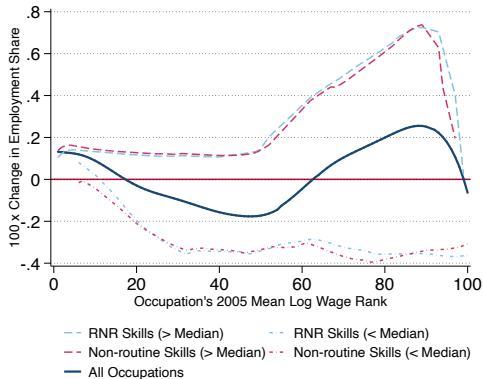


Figure: Smoothed Employment and Wage Changes by Skill Percentile, 2005-2018

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# Returns to Skill Mixing

- National Longitudinal Survey of Youth (NLSY) 2005-2019

- Detailed employment and educational histories + pre-market abilities

Analytical: AFQT; Interpersonal: social (Deming, '17); Computer: occ/major's computer skill

- College major's skill mixing: emp-weighted avg. of O\*NET measures

Dependent: ln(hourly wage)	(1)	(2)	(3)	(4)
Mix (analytical + computer + interpersonal)	0.017*** [0.005]	0.015*** [0.005]	0.014*** [0.005]	0.005 [0.009]
Mix (AFQT + computer + social)		0.065*** [0.017]		0.030** [0.013]
Ethnicity*Gender, Age/Year, Region, Edu FE	X	X	X	X
Occupation FE	X	X	X	X
Worker FE			X	X
Observations	88,391	79,343	88,391	31,029
R-squared	0.416	0.430	0.756	0.704

Table: Return to Skill Mixing: Occupations, Workers, and College Majors

[Full table](#)

[Robust - measures and index](#)

[Correspond skill measures](#)

[Top majors](#)

[Intro](#)

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# A Directed Search Model with Occupation Design

# Environment

- Multi-dimensional Skill Set-up

- Discrete time, 1-1 matching,  $K \geq 2$  skills
- A unit of heterogeneous workers  $\mathbf{x} = \{x_1, \dots, x_k, \dots, x_K\} \in S \subset \mathbb{R}^{K+}$
- A mass of risk-neutral firms  $\mathbf{y} = \{y_1, \dots, y_k, \dots, y_K\} \in S \subset \mathbb{R}^{K+}$
- CES - Matching production [Lindenlaub \(2017\)](#); [Lise & Postel-Vinay \(2020\)](#)

$$f(\mathbf{x}, \mathbf{y}) = \left[ \sum_{k=1}^K (x_k y_k)^{\sigma} \right]^{\frac{1}{\sigma}}$$

- Endogeneous Occupation Design

- Both vacant & incumbent firms optimally choose  $\mathbf{y}$  before producing
- Pay  $C(\mathbf{y}) = \tau [\sum_{k=1}^K (y_k)^{\rho}]$  rep. cost of operating an occ for given  $\mathbf{y}$

- Labor Market

- Continuum submarkets by  $(\mathbf{x}, \mathbf{y})$  and surplus share  $\omega$ , tightness  $\theta(\mathbf{x}, \mathbf{y}, \omega)$
- $\delta$  separateness, matching  $M(s, v) = \mu s^{\eta} v^{1-\eta}$ , markov evolvment  $\pi(x'_j | x_j, y_j)$

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# Model Equilibrium

- Worker's Problem

$$U(\mathbf{x}) = b + \beta E \left\{ \max_{\mathbf{y}', \omega'} p(\theta(\mathbf{x}', \mathbf{y}', \omega')) W(\mathbf{x}', \mathbf{y}', \omega') + [(1 - p(\theta(\mathbf{x}', \mathbf{y}', \omega')))] U(\mathbf{x}') \right\}$$

$$W(\mathbf{x}, \mathbf{y}, \omega) = \omega(f(\mathbf{x}, \mathbf{y}) - C(\mathbf{y})) + \beta(1 - \delta) E \left\{ \max_{\tilde{\mathbf{y}}', \tilde{\omega}'} p(\theta(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}')) W(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}') \right. \\ \left. + [(1 - p(\theta(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}')))] W(\mathbf{x}', \mathbf{y}', \omega) \right\} + \delta U(\mathbf{x}')$$

Intro

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# Model Equilibrium

Intro

Evidence

Returns

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- Worker's Problem

$$U(\mathbf{x}) = b + \beta E \left\{ \max_{\mathbf{y}', \omega'} p(\theta(\mathbf{x}', \mathbf{y}', \omega')) W(\mathbf{x}', \mathbf{y}', \omega') + [(1 - p(\theta(\mathbf{x}', \mathbf{y}', \omega')))] U(\mathbf{x}') \right\}$$

$$W(\mathbf{x}, \mathbf{y}, \omega) = \omega(f(\mathbf{x}, \mathbf{y}) - C(\mathbf{y})) + \beta(1 - \delta) E \left\{ \max_{\tilde{\mathbf{y}}', \tilde{\omega}'} p(\theta(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}')) W(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}') \right. \\ \left. + [(1 - p(\theta(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}')))] W(\mathbf{x}', \mathbf{y}', \omega) \right\} + \delta U(\mathbf{x}')$$

- Firm's Problem

$$J(\mathbf{x}, \mathbf{y}, \omega) = \max_{\mathbf{y}} (1 - \omega)(f(\mathbf{x}, \mathbf{y}) - C(\mathbf{y})) + \beta(1 - \delta) E \left\{ (1 - p(\theta(\mathbf{x}', \tilde{\mathbf{y}}', \tilde{\omega}')) J(\mathbf{x}', \mathbf{y}', \omega) \right\}$$

By free-entry:  $c = \beta E \left\{ q(\theta(\mathbf{x}, \mathbf{y}, \omega)) J(\mathbf{x}, \mathbf{y}, \omega) \right\}$

- Equilibrium Properties

- Block-recursive [Menzio & Shi \(2010,2011\)](#) due to directed search + submarkets
- $\Delta$  skill mixing, wage, employment: complementarity, cost, skill supply

# What Are the Drivers of Skill Mixing and How They Affect Labor Market Dynamics?

# Measurement and Calibration

- Simulated Methods of Moments (NLSY, 2005–2006 and 2016–2019)
  - Occ: high-skill (high-wage & white-collar), low-skill (blue-collar & service)
  - Worker: low-type (avg. of below median  $x_j^{low}$ ), high-type ( $\alpha_j x_j^{low}$ ) Skill supply

A. Externally Calibrated		(Details)	
$\beta, \delta, \omega, b, \eta, \mu$			
B. Internally Estimated		2005	2018
$\sigma$	Elasticity parameter of skills in production	0.5	0.3
$\tau$	Scaler of occupation operation cost	0.8	1.9
$\rho$	Convexity of occupation operation cost	1.3	1.4
$\alpha_a$	Efficiency differential of analytical/computer skill	1.5	1.5
$\alpha_p$	Efficiency differential of interpersonal skill	1.0	1.2
$\alpha_r$	Efficiency differential of routine skill	1.5	1.0
$c$	Vacancy posting over quarterlys output	0.4	0.3

Moments

Identification

Numerical algorithm

Intro

Evidence

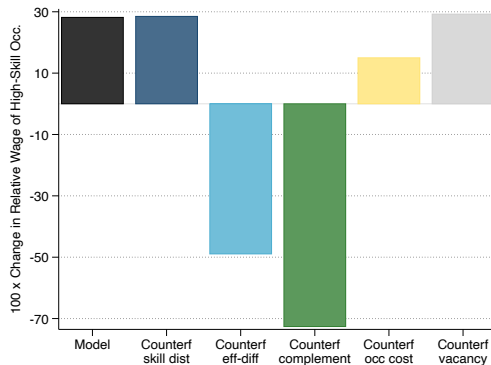
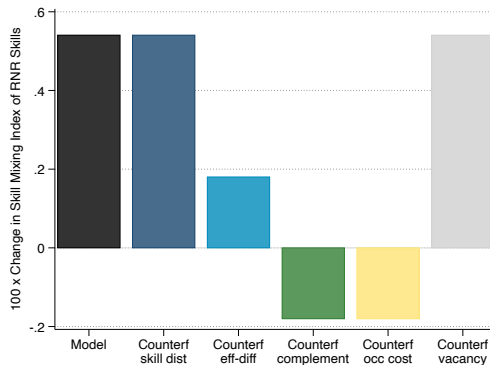
Returns

Model

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# Counterfactual Analysis



Additional counterfactual

Intro

Evidence

Returns

Model

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Conclusion

- Skills are *inevitably* embedded in workers → demand of **skill mixtures**
- **New facts** about skill mixing, important for distributions & workers
- **New framework** of directed search & occ. design, complementarity matters

*Educators and policymakers ought to provide more “mixed” skills to workers to take advantage of the complementarity side of technological change.*



# Optimal Skill Mixing Under Technological Advancements

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September, 2023

# Appendix

**Bringing others together and trying to reconcile differences.**

Not Important\*      Somewhat Important      Important      Very Important      Extremely Important

①      ②      ③      ④      ⑤

Present justification to a manager for altering a work schedule

Contract with a wholesaler to sell items at a given cost

Work as an ambassador in negotiating a new treaty

① — ② — ③ — ④ — ⑤ — ⑥ — ⑦

Highest Level

Survey	Main content
Education/ training	Required education, related work experience, training
Knowledge	Various specific functional and academic areas (e.g., physics, marketing, design, clerical, food production, construction)
Skills	Reading, writing, math, science, critical thinking, learning, resource management, communication, social relations, technology
Abilities	Writing, math, general cognitive abilities, perceptual, sensory-motor, dexterity, physical coordination, speed, strength
Work activities	Various activities (e.g., information processing, making decisions, thinking creatively, inspecting equipment, scheduling work)
Work context	Working conditions (e.g., public speaking, teamwork, conflict resolution, working outdoors, physical strains, exposure to heat, noise, and chemicals, job autonomy)
Work style	Personal characteristics (e.g., leadership, persistence, cooperation, adaptability)

## O\*NET Versions and Corresponding Years [back](#)

	Released Year	Division	Work Context	Work Activities	Knowledge	Considered Year	Percent Updated
<b>O*NET 13.0</b>	2008	Post 2005	73.79%	73.79%	73.79%	2005	–
		Before 2005	26.21%	26.21%	26.21%		
<b>O*NET 18.0</b>	2013	Post 2009	57.15%	57.21%	57.21%	2009	59.8
		Before 2009	42.85%	42.79%	42.79%		
<b>O*NET 22.0</b>	2017	Post 2013	57.84%	57.67%	57.67%	2013	45.8
		Before 2013	42.16%	42.33%	42.33%		
<b>O*NET 25.0</b>	2022	Post 2018	54.52%	54.52%	54.52%	2018	64.2
		Before 2018	45.48%	45.48%	45.48%		

*Notes: The table summarizes different versions of the O\*NET (Occupational Information Network) database, along with their released year, year division for the 5 modules (work context, work activities, knowledge, skills, abilities), and the considered year for each version. The "Post" and "Before" rows indicate whether the data in each version was collected post or before a particular year. The "Considered Year" column represents the year considered to be corresponding to each release of O\*NET based on the year division of data.*

**Non-routine Analytical**

---

- Analyzing data/information
- Thinking creatively
- Interpreting information for others

**Non-routine Interpersonal**

---

- Establishing and maintaining personal relationships
- Guiding, directing and motivating subordinates
- Coaching/developing others

**Computer**

---

- Interacting With Computers
- Programming
- Computers and Electronics

**Design**

---

- Design
- Drafting, Laying Out, and Specifying Technical Devices, Parts, and Equipment

**Routine**

---

- Importance of repeating the same tasks
- Importance of being exact or accurate
- Structured v. Unstructured work (reverse)
- Pace determined by speed of equipment
- Controlling machines and processes
- Spend time making repetitive motions

**Leadership**

---

- Making Decisions and Solving Problems
- Developing Objectives and Strategies
- Organizing, Planning, and Prioritizing Work
- Coordinating the Work and Activities of Others
- Developing and Building Teams
- Guiding, Directing, and Motivating Subordinates
- Provide Consultation and Advice to Others

## Analytical

- "research"
- "analy"
- "decision"
- "solving"
- "math"
- "statistic"
- "thinking"

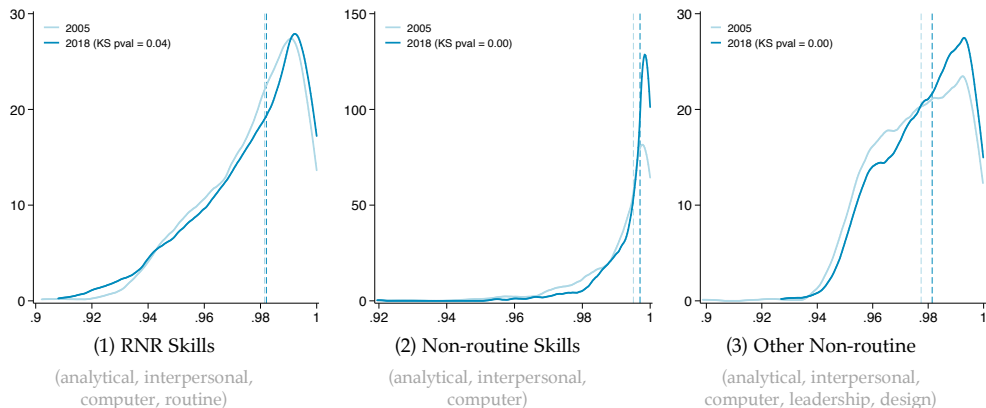
## Interpersonal

- "communication"
- "teamwork"
- "collaboration"
- "negotiation"
- "presentation"

## Computer

- "computer"
- Any skill flagged as software

# First Look: Skill Mixing at 7-digit Occupations [back](#)



**Figure:** Density for Skill Mixing Indexes (Weighted Cosine Distances), 2005 vs. 2018



# Alternative Depiction of Skill Mixing

[back](#)

Appendix

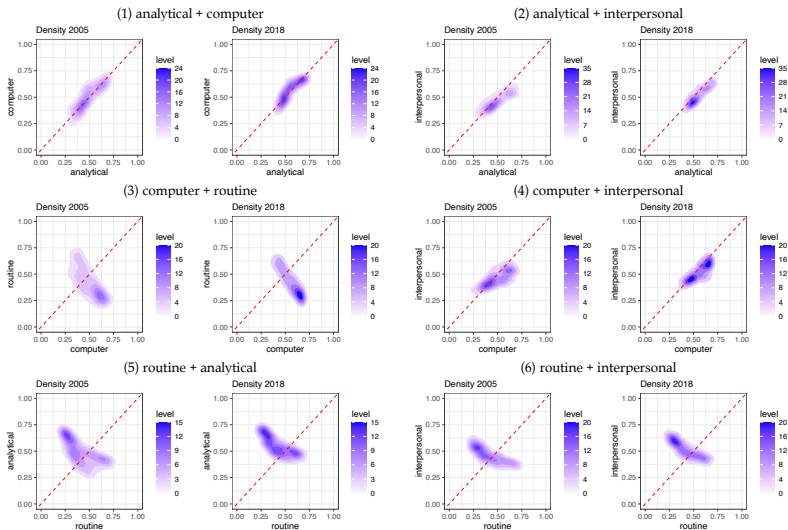
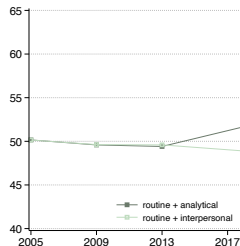
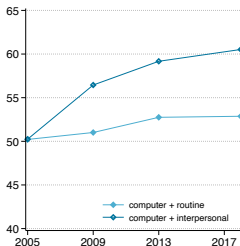
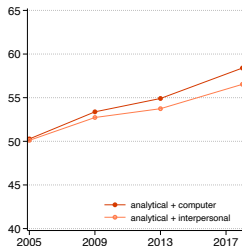
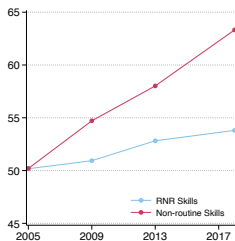


Figure: Non-parametric Depiction of Skill Intensities, 2005 vs. 2018

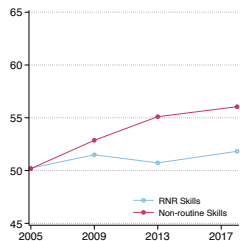
(1) Skill Pairs



(2) Without PCA



(3) Standardized Skill Measures



(4) Broader Skill Measures

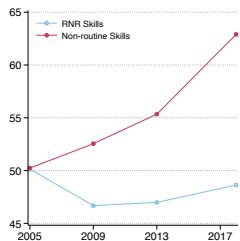
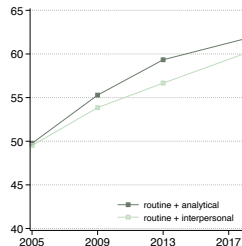
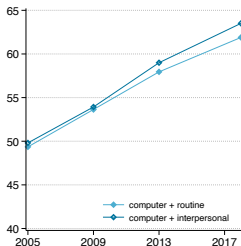
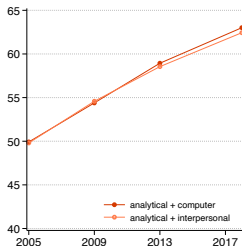


Figure: Trend of Skill Mixing with Alternative Skill Measures

(1) Inverse Herfindahl



(2) Absolute Distance

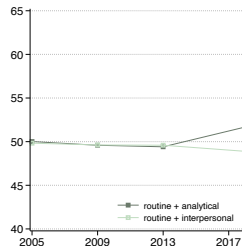
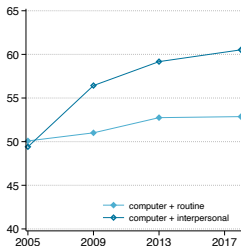
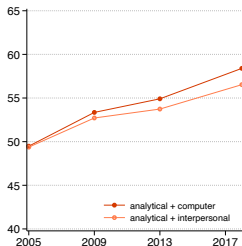
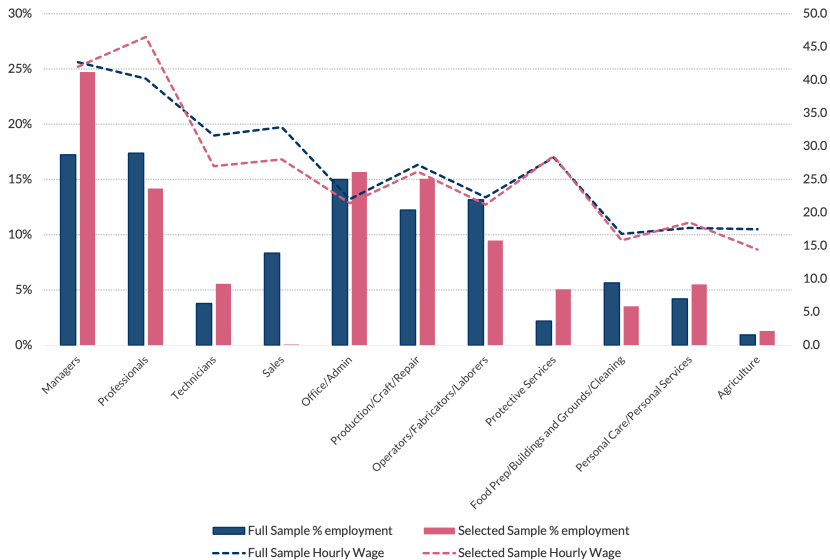


Figure: Trend of Skill Mixing with Alternative Indexes

# Full and Updated O\*NET [back](#)



Skill Groups		6-digit Occupations			4-digit Occupations		
		total	within	across	total	within	across
Full O*NET	RNR Skills	6.78	4.93	1.85	10.12	9.46	0.66
	Non-routine Skills	9.21	5.62	3.59	12.37	9.72	2.65
Constant Updates	RNR Skills	5.59	6.73	-1.14	10.09	10.74	-0.65
	Non-routine Skills	4.05	5.33	-1.29	11.00	9.69	1.31
Lightcast	Non-routine Skills				5.16	4.37	0.78

**Table:** Shift-Share Decomposition of Skill Mixing Index Changes

Notes: This table shows a shift-share decomposition of changes in the average level of different mixing indexes between 2005-2018 in percentile units. Specifically, for a change in the percentile of a mixing index over two periods  $t$  and  $\tau$ , its change  $\Delta T_\tau = T_\tau - T_t$  which can be decomposed to  $\Delta T = \sum_j (\Delta E_{j\tau} \alpha_j) + \sum_j (E_j \Delta \alpha_{j\tau}) = \Delta T^a + \Delta T^w$  where  $E_{j\tau}$  is employment weight in occupation  $j$  in year  $\tau$ , and  $\alpha_{j\tau}$  is the level of mixing index  $h$  in occupation  $j$  in year  $\tau$ ,  $E_j = \frac{1}{2}(E_{jt} + E_{j\tau})$  and  $\alpha_j = \frac{1}{2}(\alpha_{jt} + \alpha_{j\tau})$ .  $\Delta T^a$  and  $\Delta T^w$  then represent across-occupation and within-occupation change.

## Decomposition: Intensive vs. Extensive [back](#)

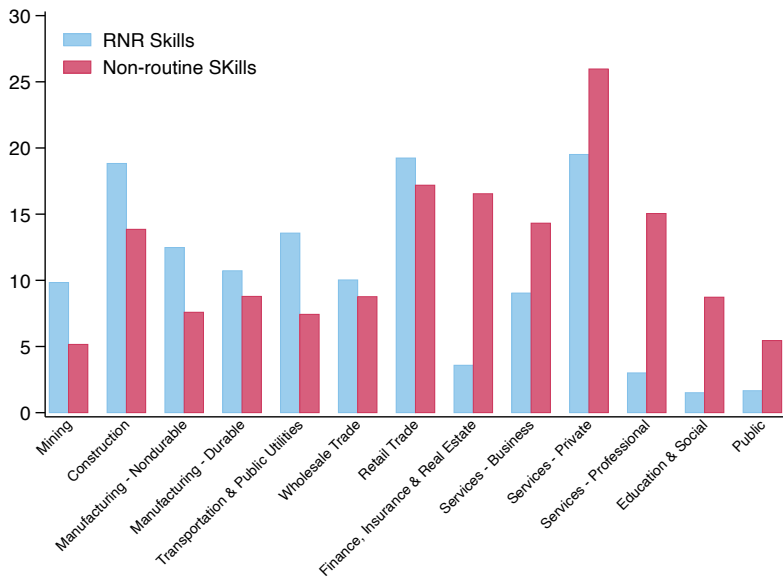
	Skill Groups	6-digit Occupations			4-digit Occupations		
		total	within	across	total	within	across
Full O*NET	analytical + computer	10.52	6.40	4.12	10.49	6.60	3.89
	analytical + interpersonal	5.36	2.90	2.46	8.17	4.08	4.09
	computer + routine	4.38	2.41	1.97	5.16	2.94	2.22
	computer + interpersonal	7.23	3.60	3.63	11.81	7.51	4.30
	routine + analytical	4.00	2.29	1.71	4.23	3.16	1.07
	routine + interpersonal	1.93	0.12	1.81	2.35	1.08	1.26
Constant Updates	analytical + computer	5.59	6.03	-0.44	6.42	5.89	0.53
	analytical + interpersonal	3.53	4.58	-1.05	4.00	3.00	1.00
	computer + routine	2.88	3.69	-0.81	0.52	1.93	-1.42
	computer + interpersonal	0.78	1.86	-1.09	6.86	5.93	0.93
	routine + analytical	2.04	2.13	-0.09	1.48	3.60	-2.12
	routine + interpersonal	0.81	0.82	-0.01	-0.33	1.47	-1.80
Lightcast	analytical + computer				12.64	11.74	0.90
	analytical + interpersonal				2.51	2.20	0.31
	computer + interpersonal				-4.18	-3.79	-0.39

**Table:** Decomposition of Mixing Indexes' Changes by Skill Pairs

## Mixing Index Change by Industries, 2005-2018

[back](#)

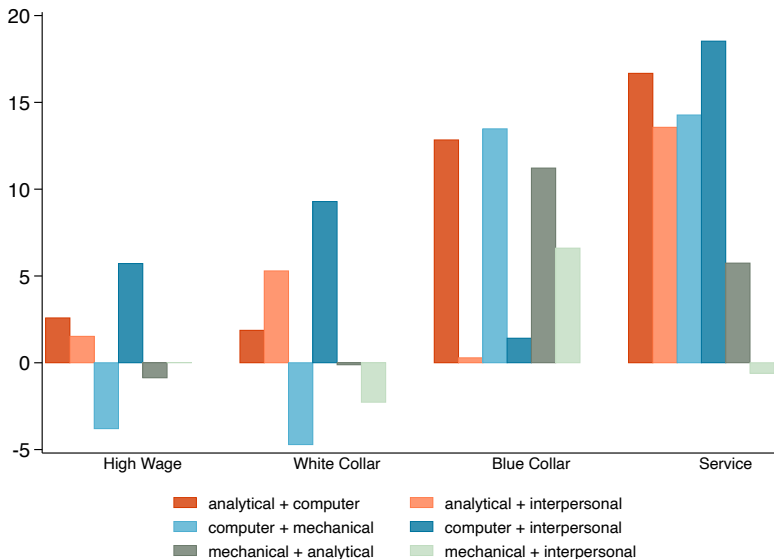
Appendix



## Mixing Index Change by Skill Pairs, 2005-2018

[back](#)

Appendix



Figure



O*NET Measure	NLSY Measure	$\gamma_{school}^{learn}$	$\gamma_j^{up}$	$\gamma_j^{down}$
analytical	AFQT score	0.33	0.36	0.10
interpersonal	Deming (2017) social skill	0.33	0.05	0.00003
routine	ASVAB	0.33	1	0.36
computer	OCC/Major's 2005 Value	0.33	0.36	0.10

**Table:** Skill Measures in NLSY and Annual Skill Learning and Depreciation Rate

*Notes:* This table illustrates for each O\*NET skill measure, its corresponding skill measure using NLSY79&97 data, and the learning and depreciation rate for these different skills. The AFQT is the same as the one used by Altonji, Bharadwaj, and Lange (2012) followed by Deming (2017), which controls for age-at-test, test format, and other idiosyncrasies. Deming (2017)'s social skill measure consists of sociability in childhood and sociability in adulthood in NLSY79, and two questions from the Big 5 inventory gauging the extraversion in NLSY97. The average of workers' ASVAB mechanical orientation and electronics test scores are used for mechanical skill. Since ASVAB scores are not available for the NLSY97 survey, they are imputed based on predictive regression using the NLSY79 survey. Workers' occupations' or college majors' O\*NET computer skill scores in the year 2000 are used as their endowed computer skill. The skill accumulation/depreciation rate is directly from Lise and Postel-Vinay (2020)'s estimates based on monthly data converted to annual values. Skill learning/depreciating while attending college is specified to be 33% per year.

- Estimate  $\sigma$  using relative wage within occupation:

$$\Delta w(\mathbf{x}, \mathbf{y}) = \omega \left[ \sum_{k=1}^K (x^k y^k)^\sigma \right]^{\frac{1}{\sigma}} - A$$

- Adjust wage for occupation fixed effects and other factors; use MLE for  $\sigma$ .
- Cost parameters  $\rho$  and  $\tau$  identified via firms' optimization of skill demand and employment distribution across occupations.
- Vacancy posting cost  $c$  and relative skill level of high-skill worker  $\alpha_k$  determined by unemployment levels and relative wages, respectively.

- Skill supply calibration: between data periods and within model period
- **Across-period Skill Supply Variation:**
  - Skills adjusted based on occupation or college major requirements.
  - Skill accumulation at rate  $\gamma_j \times$  skill gap.
  - Annual rates adjusted by number of working weeks (47).
- **Markov Skill Supply Adjustment:**
  - Skill evolution follows Markov process  $\pi(x'_j | x_j, y_j)$ .
  - Upward adjustment probability:

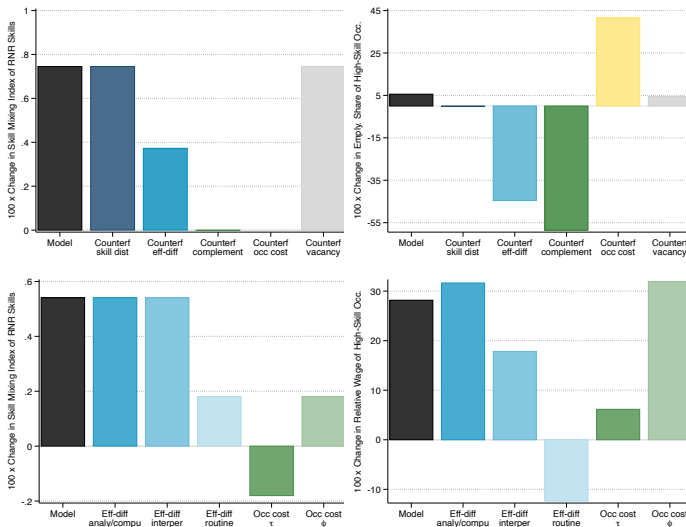
$$\frac{x_j^{up} - x_j}{y_j - x_j} \mathbf{1}(x_j^{up} < y_j) \times \frac{\gamma_j^{up}}{4}$$

- Downward adjustment probability:

$$\frac{x_j^{down} - x_j}{y_j - x_j} \mathbf{1}(y_j < x_j^{down}) \times \frac{\gamma_j^{down}}{4}$$

- Given  $\Theta = \{\sigma, \rho, \tau, c, \alpha_k\}$ , each iteration of SMM first solves the steady state firm and worker policy function
  1. Fix the number of periods  $T$
  2. Starting from the terminal period  $T$ , solve the firm problem
  3. Use the free entry condition to obtain the market tightness  $\theta_T(\mathbf{x}, \mathbf{y}, \omega)$
  4. With the market tightness, solve the worker dynamic programming problem
  5. Repeated stepping back from  $t = T - 1, \dots, 1$
  6. Check if the difference in worker value  $U_{t+1} - U_t$ ,  $W_{t+1} - W_t$  and the firm value  $J_{t+1} - J_t$  is less than a predetermined tolerance level. If yes stop, if not increase  $T$  and go back to first step
- Next, simulate 10,000 workers for  $T(T > 200)$  periods, burning the first 40
- Obtain dist of LM outcomes across different occ. and worker types
- SMM minimizes the distance between the model-implied moments data moments

# Additional Counterfactual Analysis [back](#)



Notes: These figures plot the model generated changes in skill mixing in high-skill occupations (panel 1) and changes in employment share of high-skill occupation (panel 2). Panel (3) and (4) depict the model generated changes in skill mixing in low-skill occupation and the relative wage of high-skill occupations by shutting down the skill efficiency differential for analytical/computer, interpersonal, and routine skills individually; also by shutting down  $\tau$  and  $\phi$  individually.

	First Period		Second Period	
	Data	Model	Data	Model
<b>Worker moments</b>				
Relative wage of high type				
Analytical/computer	1.30	1.36	0.95	1.04
Interpersonal	1.00	1.00	1.25	1.19
Routine	1.52	1.50	1.54	1.55
Unemployment Rate	0.05	0.06	0.04	0.03
<b>Occupation moments</b>				
Relative wage of high skill	1.30	1.24	1.56	1.55
Employ. share (low skill)	0.43	0.41	0.37	0.37
Employ. share (high skill)	0.57	0.59	0.63	0.63
100 $\times$ Skill mixing (low skill)	97.54	98.57	98.96	99.11
100 $\times$ Skill mixing (high skill)	95.74	94.93	94.12	95.67

Parameter	Description	Value	
A. Externally Calibrated			
$\beta$	Discount Rate	0.99	
$\delta$	Job separation rate	0.1	
$\omega$	Worker share of surplus	0.6	
$b$	Unemployment benefit	0.25	
$\eta$	Elasticity of the matching function	0.5	
$\mu$	Matching efficiency	0.65	
B. Internally Estimated		Period 1	Period 2
$\sigma$	Elasticity parameter of skills in production	0.5	0.3
$\tau$	Scaler of occupation operation cost	0.8	1.9
$\phi$	Rate of increasing marginal cost	1.3	1.4
$\alpha_a$	Efficiency differential of analytical/computer skill	1.5	1.5
$\alpha_p$	Efficiency differential of interpersonal skill	1.0	1.2
$\alpha_r$	Efficiency differential of routine skill	1.5	1.0
$c$	Vacancy posting cost as a share of output	0.4	0.3

# Top College Majors in Skill Mixing [back](#)

Hybrid Index – Level	Hybrid Index – Change
<b>analytical + computer + interpersonal</b>	
Physical Sciences	Architecture and Environmental Design
Engineering	Computer and Information Sciences
Letters	Communications
<b>analytical + computer</b>	
Physical Sciences	Interdisciplinary Studies
Engineering	Area Studies
Letters	Computer and Information Sciences
<b>analytical + interpersonal</b>	
Public Affairs and Services	Architecture and Environmental Design
Business and Management	Computer and Information Sciences
Social Sciences	Communications
<b>computer + interpersonal</b>	
Social Sciences	Architecture and Environmental Design
None, General Studies	Computer and Information Sciences
Public Affairs and Services	Engineering
<b>routine + computer</b>	
Transportation	Social Sciences
Fine and Applied Arts	Agriculture and Natural Resources
Engineering	Foreign Languages
<b>routine + analytical</b>	
Transportation	Agriculture and Natural Resources
Health Professions	Social Sciences
Computer and Information Sciences	Foreign Languages
<b>routine + interpersonal</b>	
Transportation	Agriculture and Natural Resources
Health Professions	Architecture and Environmental Design
Military Sciences	Social Sciences



# Return to Skill Mixing Full Table with Individual Skills [back](#)

Dependent: ln(hourly wage)	(1)	(2)	(3)	(4)
<i>Occupation Skills</i>				
Analytical	-0.019** [0.009]	-0.019** [0.009]	-0.012 [0.008]	-0.033*** [0.011]
Computer	-0.002 [0.010]	-0.008 [0.011]	-0.003 [0.009]	-0.017 [0.013]
Interpersonal	-0.019** [0.009]	-0.022** [0.009]	-0.021*** [0.008]	-0.027** [0.011]
Routine	0.027*** [0.010]	0.035*** [0.011]	0.025*** [0.009]	0.047*** [0.015]
Mix (analytical + computer)	0.007 [0.005]	0.011** [0.005]	0.013*** [0.005]	0.012 [0.008]
Mix (analytical + interpersonal)	0.016*** [0.005]	0.016*** [0.005]	0.015*** [0.004]	0.028*** [0.007]
Mix (computer + routine)	-0.022** [0.009]	-0.029*** [0.009]	-0.021*** [0.008]	-0.026** [0.012]
Mix (computer + interpersonal)	-0.008 [0.006]	-0.012** [0.006]	-0.014*** [0.005]	-0.012 [0.009]
Mix (routine + analytical)	-0.050*** [0.008]	-0.056*** [0.009]	-0.050*** [0.008]	-0.058*** [0.012]
Mix (routine + interpersonal)	0.023*** [0.008]	0.029*** [0.009]	0.019** [0.008]	0.023* [0.012]
<i>Worker Skills</i>				
Afqt (analytical)		0.065*** [0.012]		-0.038 [0.023]
Computer		0.045*** [0.006]		0.017 [0.023]
Social (interpersonal)		0.015*** [0.005]		-0.003 [0.029]
ASVAB (routine)		-0.008 [0.016]		-0.012 [0.022]
Mix (afqt + computer)		0.044* [0.023]		0.017 [0.013]
Mix (afqt + social)		0.028* [0.015]		-0.075*** [0.020]
Mix (computer + asvab mech)		0.013 [0.025]		-0.070*** [0.026]
Mix (computer + social)		0.008 [0.013]		0.061*** [0.019]
Mix (asvab mech + afqt)		0.001 [0.009]		0.096** [0.039]
Mix (asvab mech + social)		-0.040*** [0.011]		-0.045 [0.042]
Ethnicity*Gender, Age/Year, Region, Edu FE	X	X	X	X
Occupation FE	X	X	X	X
Worker FE			X	X
Observations	87,655	78,719	87,655	50,580
R-squared	0.426	0.439	0.758	0.761

# Robustness Checks of Return to Skill Mixing [back](#)

Dependent: ln(hourly wage)	(1)	(2)	(3)	(4)
<i>Occupation Skills</i>				
Analytical	-0.014* [0.008]	-0.008 [0.033]	-0.009 [0.008]	-0.013 [0.008]
Computer	-0.002 [0.009]	0.069** [0.027]	0.002 [0.009]	-0.038*** [0.010]
Interpersonal	-0.019** [0.008]	-0.118*** [0.030]	-0.018** [0.008]	-0.014* [0.008]
Routine	0.026*** [0.009]	0.091*** [0.017]	0.005 [0.008]	0.010 [0.008]
Mix (analytical + computer)	0.007 [0.005]	-0.040 [0.036]	0.008* [0.005]	0.020*** [0.007]
Mix (analytical + interpersonal)	0.010** [0.004]	0.156*** [0.042]	0.006 [0.004]	0.025*** [0.005]
Mix (computer + routine)	-0.028*** [0.007]	-0.045*** [0.015]	-0.021** [0.008]	-0.087*** [0.013]
Mix (computer + interpersonal)	-0.011** [0.005]	-0.019 [0.033]	-0.013*** [0.005]	-0.021*** [0.008]
Mix (routine + analytical)	-0.033*** [0.007]	-0.080*** [0.015]	-0.041*** [0.008]	-0.041** [0.018]
Mix (routine + interpersonal)	0.010 [0.007]	0.033** [0.016]	0.033*** [0.006]	0.026** [0.012]
Ethnicity × Gender, Age, Region, Edu FE	X	X	X	X
Occupation FE	X	X	X	X
Worker FE	X	X	X	X
Observations	87,655	87,655	87,655	87,655
R-squared	0.757	0.757	0.757	0.758