

Sources of Biased Technological Change: Occupations, Sectors, and the Organization of Production

(tentative; was *Managing a Polarized Structural Change*)

Sang Yoon (Tim) Lee¹ Yongseok Shin²

¹University of Mannheim

²Washington University in St. Louis and FRB St. Louis

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What We Do, Theoretically

Task-based Macro Model

- Tractable model in which **sectoral output** is produced as a **composite of tasks** organized by a **manager**
- Individuals with heterogeneous skill choose to become a manager or worker by comparative advantage
- Workers positively sort into tasks (occupations) with differing skill requirements
- Technological changes at the task level, esp. **routinization**, cause
 1. **job and wage polarization**
 2. **vertical polarization**TM: rise in managers' employment and wages relative to workers
 3. **structural change**

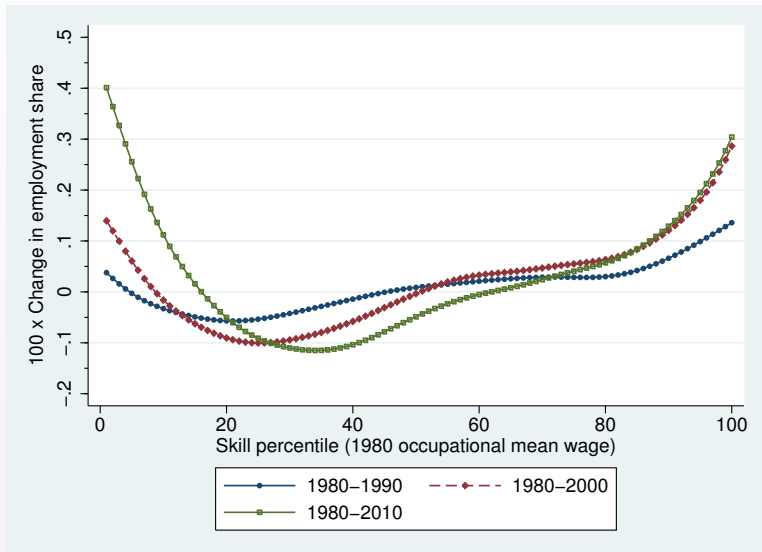
Quantitative Results

- Task-level technological change is dominant: can explain more than half of structural change since 1980
- Sector-specific TC or college measures cannot explain the task-level shifts
- **Routinization** can explain more than half of task-level TC, but **interpersonal skills** are also important

Employment Polarization

1980-2010, extends Autor and Dorn (2013)

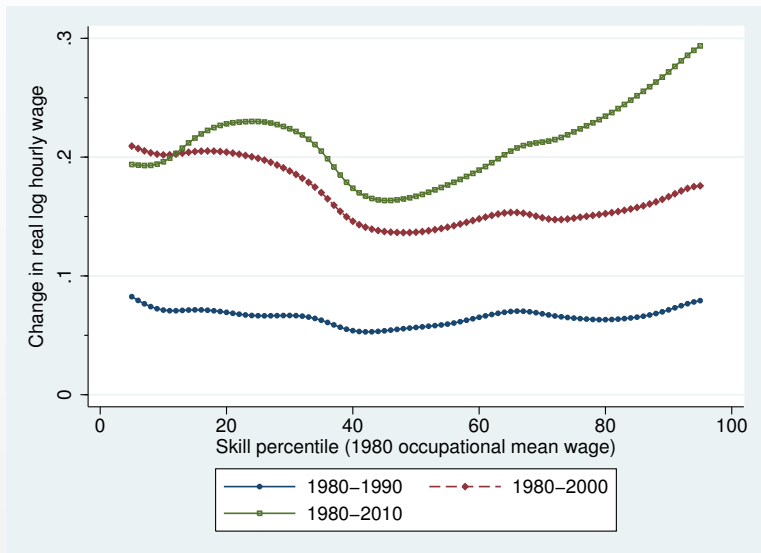
▶ by decade



Wage Polarization

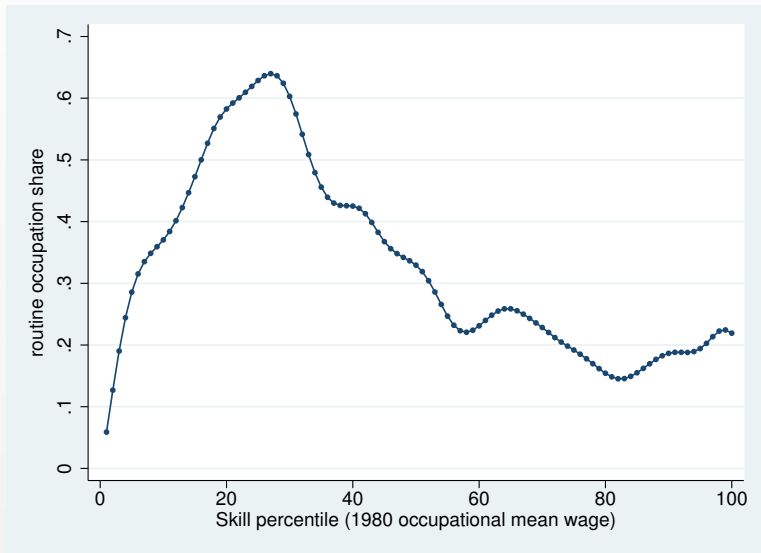
1980-2010, extends Autor and Dorn (2013)

▶ by decade



Routinization Hypothesis

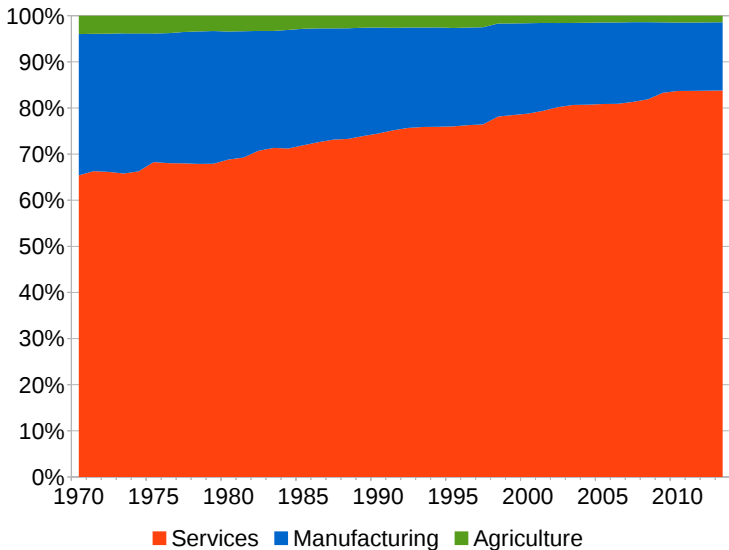
Replicated following Autor and Dorn (2013)



Structural Change: Employment

BEA NIPA Accounts (similar in Census)

▶ GDP (Nominal)



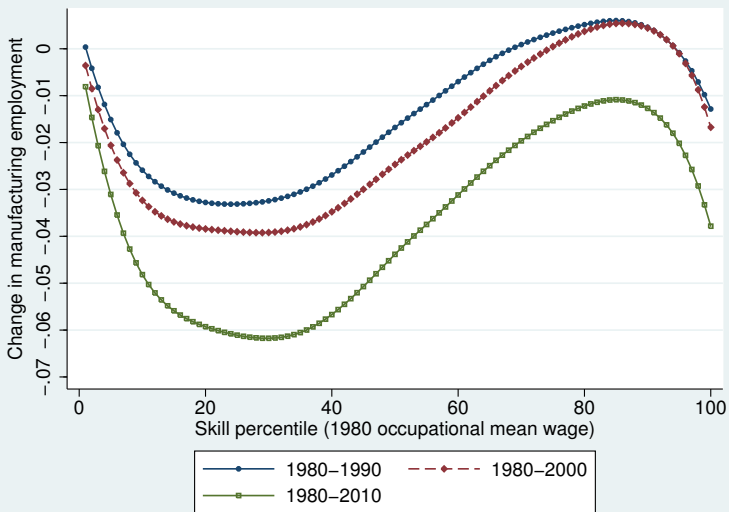
Change in Manufacturing Employment

1980-2010

▶ by decade

▶ by levels

▶ by sector



Vertical Polarization

- Employment share of management and their compensation have been rising relative to wage-workers'
- Less well-known that this has been faster in manufacturing
- We explain this by routinization replacing wage-workers, who at the margin instead become managers
- We dub this **vertical polarization**

Managers vs Workers, Aggregate

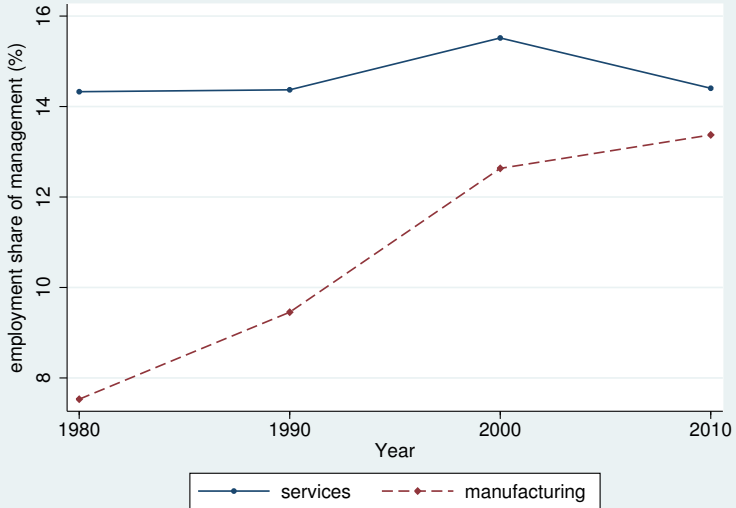
▸ occupation coding

▸ before crisis

▸ firm-individual census

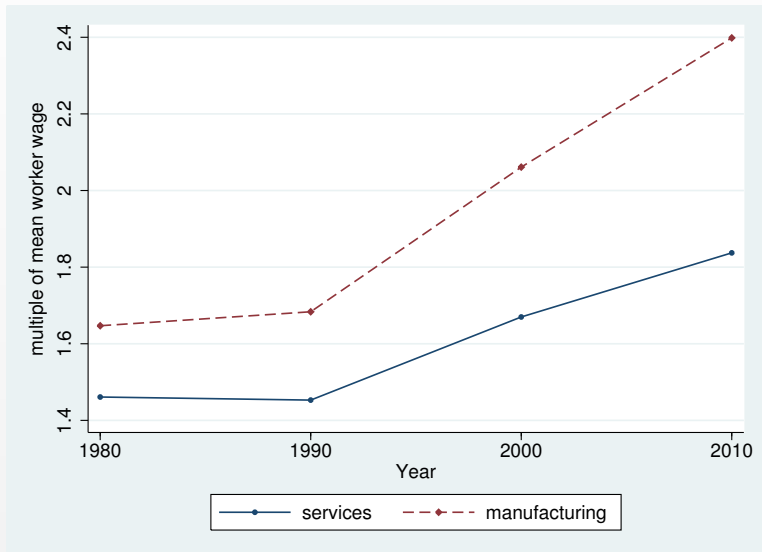


Manager Employment by Sector



Manager Wages by Sector

▶ more



Related Literature

1. Job Polarization:

Autor et al. (2006); Autor and Dorn (2013); Acemoglu and Autor (2011); Goos et al. (2014)

2. Structural Change:

Ngai and Pissarides (2007); Acemoglu and Guerrieri (2008); Buera and Kaboski (2012); Herrendorf et al. (2013, 2014); Buera et al. (2015)

3. Assignment Models:

Costinot and Vogel (2010); Lee (2015); Burstein et al. (2015); Grossman et al. (2015)

Roadmap

Analytical Model:

1. Static equilibrium with 1 sector (within)
2. Comparative statics within sector
3. Static equilibrium with 2 sectors (between)
4. Comparative statics between sectors, long-run BGP

Quantitative Analysis:

1. Calibration to 1980-2010 censuses
2. Polarization and structural change
3. Long-run dynamics

Model Elements: Individuals

1. Mass L of individuals differ in terms of **2 skills**
 $s = (z, h) \in \mathcal{S} \subset \mathbb{R}_+^2$ with distribution μ
 - z : managerial talent
 - h : efficiency units of labor
 - **neither sector- nor task-specific**
2. Occupation choice: Individuals can work as a span-of-control **manager**, or as a **worker in 1 of 3 tasks**:
 - Managers organize tasks, using z
 - Tasks $j \in \{0, 1, 2\}$ (e.g., manual, routine, abstract) use h

Model Elements: Sectors

3. Two types of sectoral output $i \in \{m, s\}$ (i.e., manufacturing and services) form final good:

$$Y = \left[\gamma_m^\epsilon Y_m^{\frac{\epsilon-1}{\epsilon}} + \gamma_s^\epsilon Y_s^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}.$$

where $\gamma_m + \gamma_s = 1$ and $\epsilon < 1$.

4. Sectors differ **only** in how tasks are combined in production
- Easily generalizable to I -sectors, J -tasks
 - Endogenous allocation of skills to occupations and sectors lead to endogenous sectoral and aggregate TFPs

Occupation Choice

1. Manager vs worker: comparative advantage (z vs h)
 2. Among worker occupations:
 - Task 0 (manual) : $h \rightarrow \bar{h}$ when producing task output
(actual h becomes irrelevant)
 - Task 1 (routine) : $h \rightarrow h$
 - Task 2 (abstract): $h \rightarrow h - \chi$ “un-utilized” skill
- Ensures positive sorting of h -skills into worker tasks

Task-Specific Technologies

- Production unit: a manager in sector i combines tasks τ_{ij} :

$$y_i(z) = \left[\eta_i^{\frac{1}{\omega}} x_{iz}^{\frac{\omega-1}{\omega}} + (1 - \eta_i)^{\frac{1}{\omega}} x_{ih}^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}}$$
$$x_{iz} = M_z k^\alpha z^{1-\alpha}, \quad x_{ih} = \left(\sum_{j=0}^2 \nu_{ij}^{\frac{1}{\sigma}} \tau_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- Simple form of log-supermodularity in skills and tasks:

$$\tau_{i0} = M_0 k^\alpha [\bar{h} \mu_i(h)]^{1-\alpha}$$

$$\tau_{i1} = M_1 k^\alpha \left[\int_h h d\mu_i \right]^{1-\alpha}$$

$$\tau_{i2} = M_2 k^\alpha \left[\int_h (h - \chi) d\mu_i \right]^{1-\alpha}$$

where M_j : task-specific TFP, h : set of workers hired

Within-Sector Planner's Problem

- Thanks to homogeneity, (PP) is to maximize

$$Y_i = \left[\eta_i^{\frac{1}{\omega}} X_{iz}^{\frac{\omega-1}{\omega}} + (1 - \eta_i)^{\frac{1}{\omega}} X_{ih}^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}}, \quad X_{ih} = \left(\sum_j \nu_{ij}^{\frac{1}{\sigma}} T_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

given $(K_i, \mathcal{S}, \mu_i)$, where

$$\begin{aligned} X_{iz} &= M_z K_{iz}^\alpha Z_i^{1-\alpha}, & T_{i0} &= M_0 K_{i0}^\alpha [\bar{h}\mu_i(\mathcal{H}_0)]^{1-\alpha}, \\ T_{i1} &= M_1 K_{i1}^\alpha H_{i1}^{1-\alpha}, & T_{i2} &= M_2 K_{i2}^\alpha [H_{i2} - \chi\mu_i(\mathcal{H}_2)]^{1-\alpha} \end{aligned}$$

- Resource constraints are

$$\begin{aligned} Z_i &= \int_{\mathcal{Z}} z d\mu_i, & K_i &= \int_{\mathcal{Z}} \sum_j k_{ij}(z) d\mu_i, \\ H_{ij} &= \int_{\mathcal{H}_j} h d\mu_i = \int_{\mathcal{Z}} \sum_j h_{ij}(z) d\mu_i, \\ \mathcal{S} &= \mathcal{Z} \cup \mathcal{H}_0 \cup \mathcal{H}_1 \cup \mathcal{H}_2 \end{aligned}$$

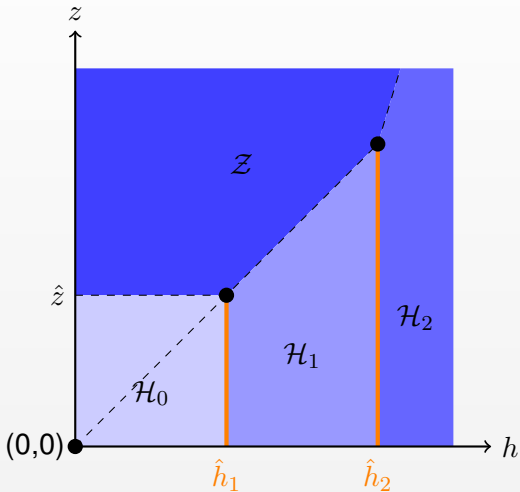
Within-Sector Solution

- Technical assumptions:
 1. μ_i non-degenerate and $\mu_i(h > \chi) > 0$
(necessary for existence)
 2. μ_i is continuous over a connected support
(necessary for uniqueness)
- Solution to (PP) given $(K_i, \mathcal{S}, \mu_i)$ is unique and characterized by a **fixed point in** $(\hat{h}_1, \hat{h}_2, \hat{z})$ that equates MRTS at these three thresholds
- Thresholds endogenously determine sectoral TFP

One Sector Equilibrium

Equal to Optimal Assignment

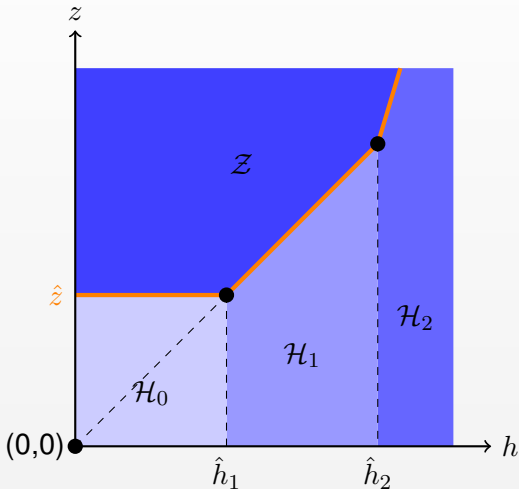
Positive Sorting:



One Sector Equilibrium

Equal to Optimal Assignment

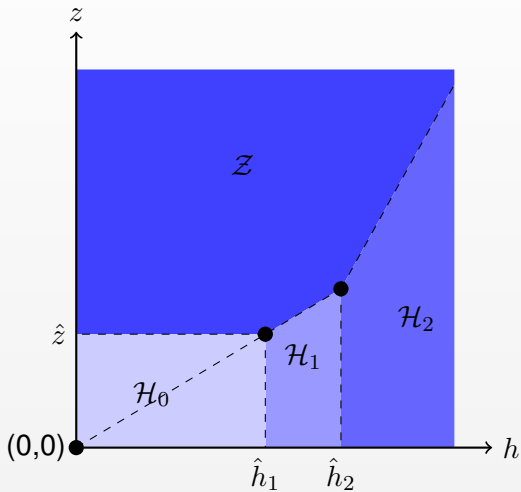
Comparative Advantage:



Routinization and Job Polarization

Within-Sector: Relative Increase in M_1

Assume $\omega < \sigma < 1$:



Equilibrium Wage Polarization

- Indifference at the thresholds across tasks:

$$w_0 \bar{h} = w_1 \hat{h}_1, \quad w_1 \hat{h}_2 = w_2 (\hat{h}_2 - \chi)$$
$$\Rightarrow w_1/w_0 = \bar{h}/\hat{h}_1, \quad w_1/w_2 = 1 - \chi/\hat{h}_2.$$

so task 1's relative wage falls as $\hat{h}_1 \uparrow$ and/or $\hat{h}_2 \downarrow$

- Between managers/workers:

$$w_z \hat{z} = w_0 \bar{h} \quad \Rightarrow \quad w_z/w_0 = \bar{h}/\hat{z}.$$

so managers' relative wages rise as $\hat{z} \downarrow$

\Rightarrow Job polarization \rightarrow Wage polarization¹

¹among managers and workers who don't switch tasks

Two Sectors

- Thresholds (\hat{z}, \hat{h}_j) must be sector invariant
- Assume a selection criteria s.t. average skills of occupations are also sector invariant:²

$$\bar{h}_j = H_{ij}/L_{ij}, \quad \bar{z} = Z_i/L_{iz}.$$

- Sectoral employment shares determined by

$$\kappa \equiv \frac{K_s}{K_m} = \frac{L_s}{L_m} = \left(\frac{\gamma_s}{\gamma_m} \right)^{\frac{1}{\epsilon}} \left(\frac{Y_s}{Y_m} \right)^{\frac{\epsilon-1}{\epsilon}}$$

so $L_m = 1/(1 + \kappa)$, $L_s = \kappa/(1 + \kappa)$

²This can be motivated by assuming vanishing log-supermodularity within occupations.

Two Sector Solution

- Sectoral productions can be written as

$$Y_i = \Phi_i K_i^\alpha L_i^{1-\alpha}$$

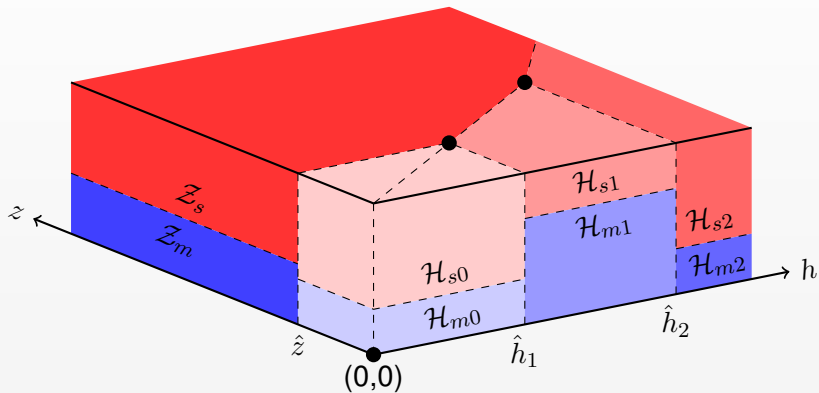
where Φ_i is endogenous TFP determined by (\hat{h}_j, \hat{z})

- So $\kappa = (\gamma_s/\gamma_m) \cdot (\Phi_s/\Phi_m)^{\epsilon-1}$ also function of (\hat{h}_j, \hat{z})
- Aggregate employment share of task j :

$$L_j = \sum_{i \in \{m, s\}} (L_{ij}/L_i) \cdot L_i$$

- L_{ij}/L_i : known from within-sector equilibrium
- L_i : known from κ
- More tedious, but equilibrium exists and unique

Two Sector Equilibrium



Routinization and Structural Change

- Within-sector polarization faster in manufacturing if
 - $\nu_{m1} > \nu_{s1}$: manufacturing more routine-intense
 - $\eta_m < \eta_s$: manufacturing less manager-intense
- Manufacturing TFP grows faster than services

⇒ **Structural change if $\epsilon < 1$**

(Ngai and Pissarides, 2007; Goos et al., 2014)

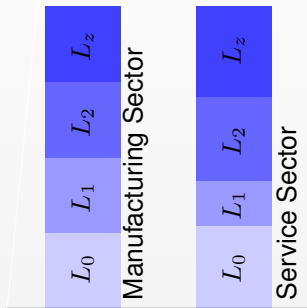
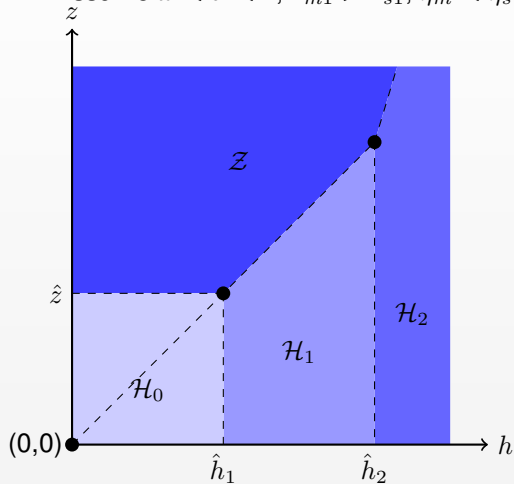
- Feedback into polarization since manufacturing has more routine jobs and fewer managers

**Routinization ⇒ Polarization ⇒ Structural Change
⇒ Polarization**

Routinization and Polarization, Two Sectors

Two Sectors: Relative Increase in M_1

Assume $\omega < \sigma < 1$, $\nu_{m1} > \nu_{s1}$, $\eta_m < \eta_s$:

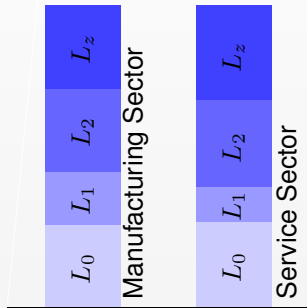
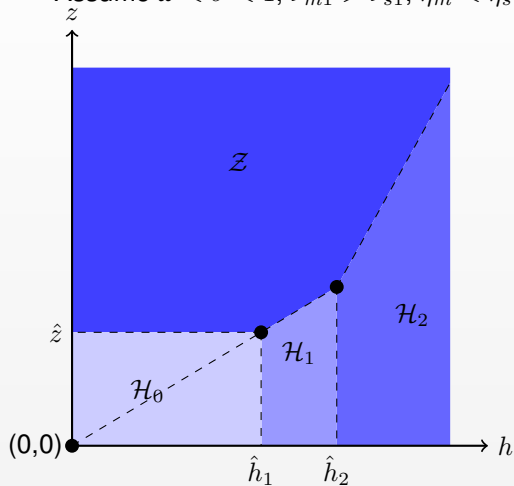


Manufacturing more reliant on routine task

Routinization and Polarization, Two Sectors

Two Sectors: Relative Increase in M_1

Assume $\omega < \sigma < 1$, $\nu_{m1} > \nu_{s1}$, $\eta_m < \eta_s$:

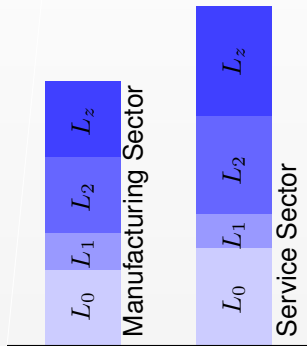
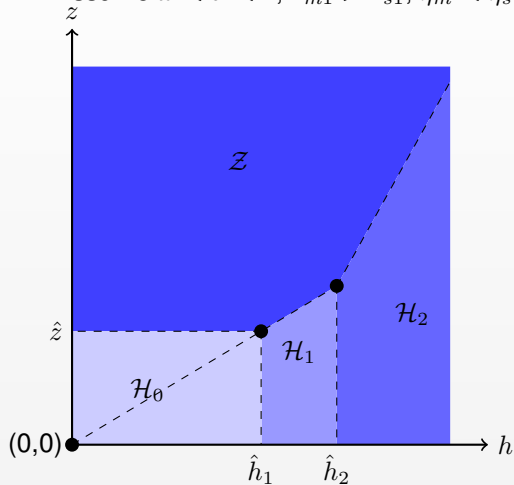


Polarization faster in manufacturing,
ignoring sectoral reallocation (structural change)

Routinization and Structural Change

Two Sectors: Relative Increase in M_1

Assume $\omega < \sigma < 1$, $\nu_{m1} > \nu_{s1}$, $\eta_m < \eta_s$:

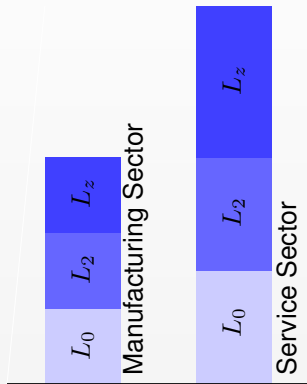
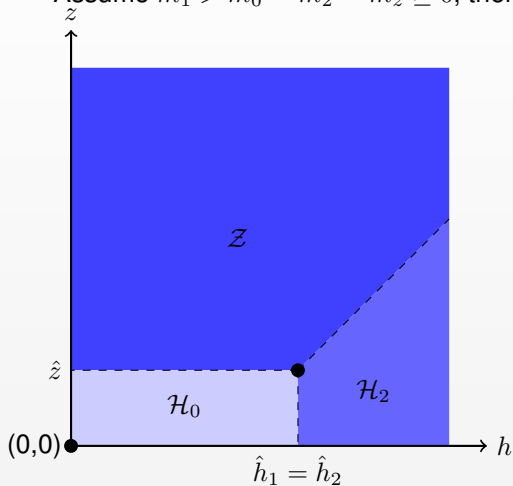


TFP growth higher in manufacturing
SC toward services if $\epsilon < 1$

BGP Equilibrium

Two Sectors: Constant Growth in M_j 's

Assume $m_1 > m_0 = m_2 = m_z \geq 0$, then as $t \rightarrow \infty$:



Task 1 vanishes; Manufacturing does not

Motivational Poster



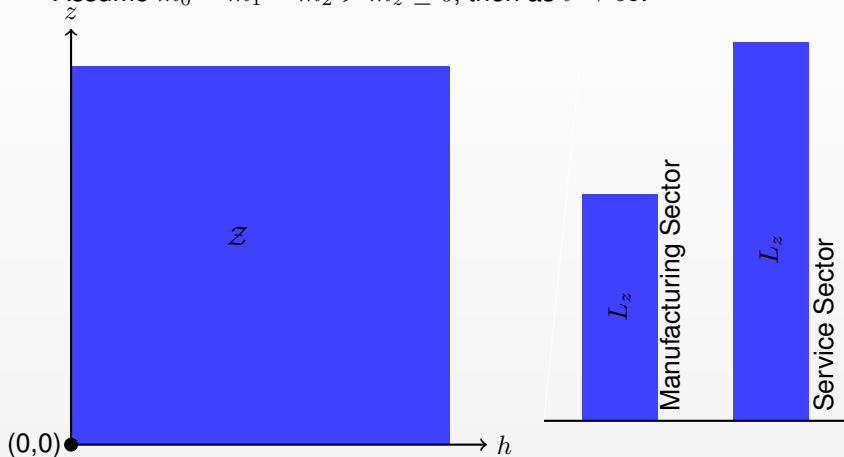
ADAPTATION

THE BAD NEWS IS ROBOTS CAN DO YOUR JOB NOW. THE GOOD NEWS IS WE'RE NOW HIRING ROBOT REPAIR TECHNICIANS. THE WORSE NEWS IS WE'RE WORKING ON ROBOT-FIXING ROBOTS- AND WE DO NOT ANTICIPATE ANY FURTHER GOOD NEWS.

Motivational BGP Equilibrium

Two Sectors: Constant Growth in M_j 's

Assume $m_0 = m_1 = m_2 > m_z \geq 0$, then as $t \rightarrow \infty$:



We all become managers!

Quantitative Analysis

- Divide 1980 OCC's into 1+1+7+2 tasks: broadly, management (11%), manual (10%), routine (59%), abstract (20%)
- Bivariate Pareto type IV distribution (γ_h, γ_z, a) fit to 1980 data on observed wage shares: ▶ graph

$$1 - \mu(z, h) = \left[1 + z^{1/\gamma_z} + h^{1/\gamma_h} \right]^{-a}$$

- Constant growth rates m_j for all 11 task productivities
- Exogenous productivity growth a_m in manufacturing
- Feed k_t into model for each decade 1980-2010, target trends to calibrate parameters

Calibration Targets

► Wage shares

Ranked by mean wage (except management)	SOC Code	Employment Shares (%)			
		1980	2010	Manufacturing	
Low Skill Services	400	10.44	13.92	0.59	0.23
Middle Skill		59.09	46.48	25.86	12.93
Administrative Support	300	16.57	14.13	3.47	1.53
Machine Operators	700	9.81	3.75	8.79	3.02
Transportation	800	8.73	6.64	3.80	2.28
Sales	240	7.87	9.37	0.79	0.62
Technicians	200	3.23	3.86	1.00	0.57
Mechanics & Construction	500	7.91	6.02	4.44	3.19
Miners & Precision Workers	600	4.97	2.71	3.58	1.73
High Skill		19.22	26.16	3.87	3.64
Professionals	40	11.02	16.51	1.73	1.45
Management Support	20	8.20	9.65	2.14	2.20
Management	1	11.26	13.44	2.47	2.59

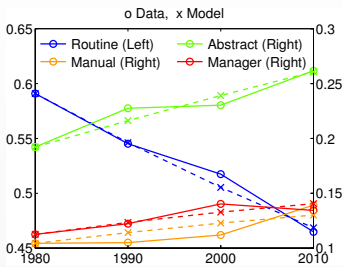
Calibrated Parameters

► OCC params

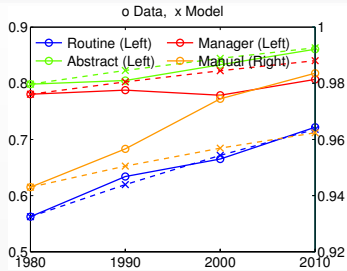
Parameter	Value	Target
γ	0.348	Estimated following
ϵ	0.004	Herrendorf et al. (2013)
<hr/>		
Fit to 1980		
<hr/>		
$M_j \equiv M$	1.054	Output per worker, normalization
A_m	1.015	Manufacturing employment share
$a, \gamma_h, \gamma_z, \chi_j$ (8)		Wage shares by task/sector ► Pareto
η_i (2), ν_{ij} (20)		Employment shares by task/sector
<hr/>		
Fit to 2010		
<hr/>		
σ	0.261	Output per worker growth,
ω	0.150	wage/employment shares
a_m	0.011	by task and by sector
m_j (11)		(method of moments)

Model Fit: Employment Shares

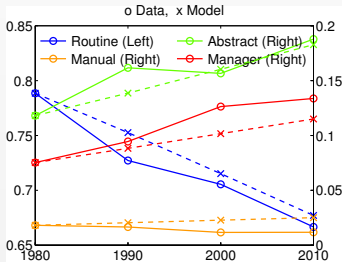
► Wage shares



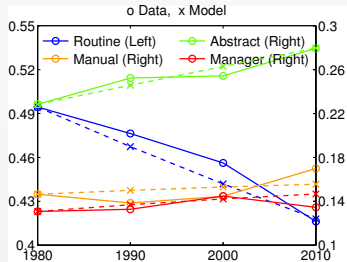
Aggregate



Service Share by Task

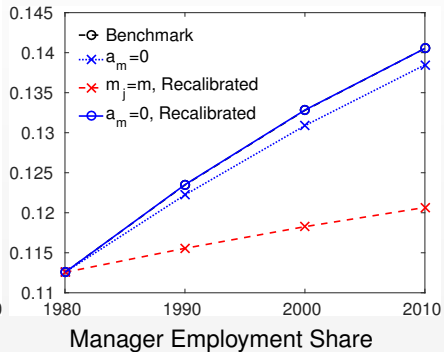
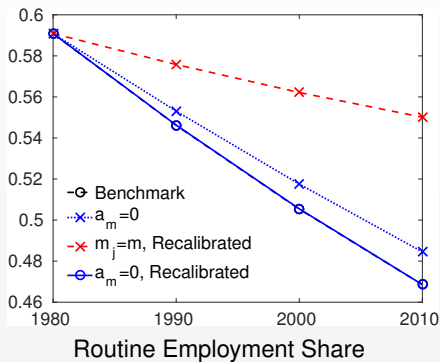


Manufacturing

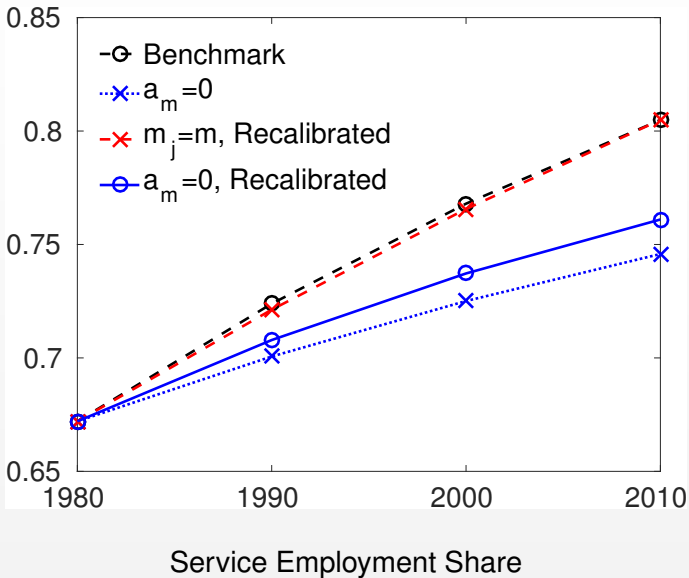


Services

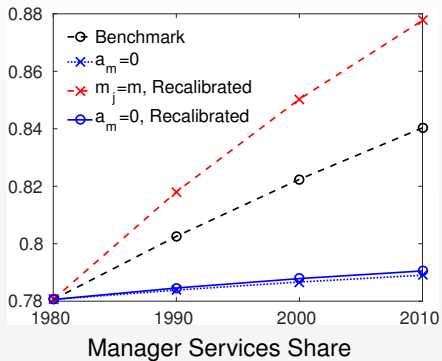
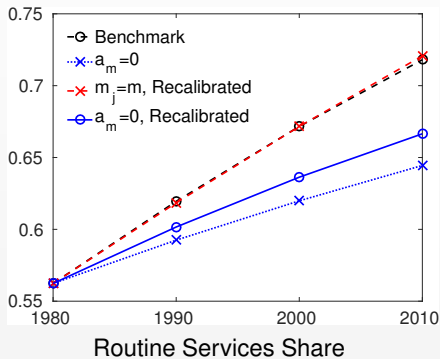
Polarization



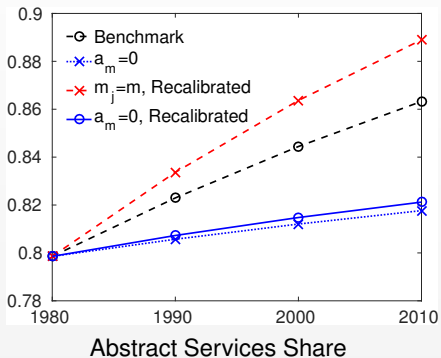
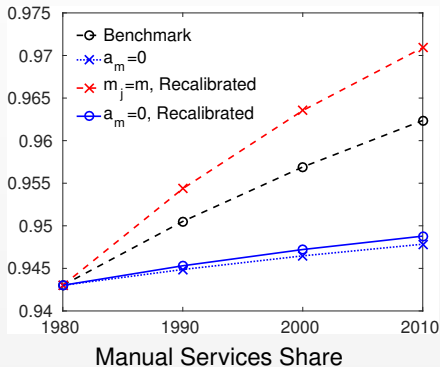
Structural Change



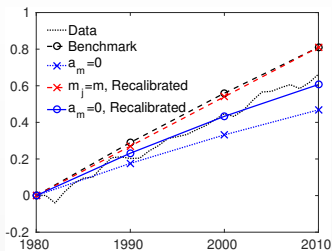
Structural Change, Within-Task



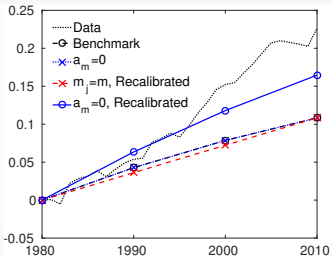
Structural Change, Within-Task



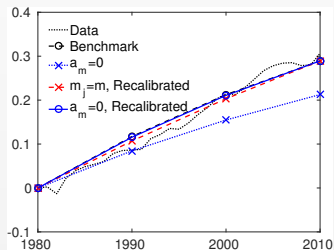
Log Measured TFP



Manufacturing



Services



Aggregate

Summary

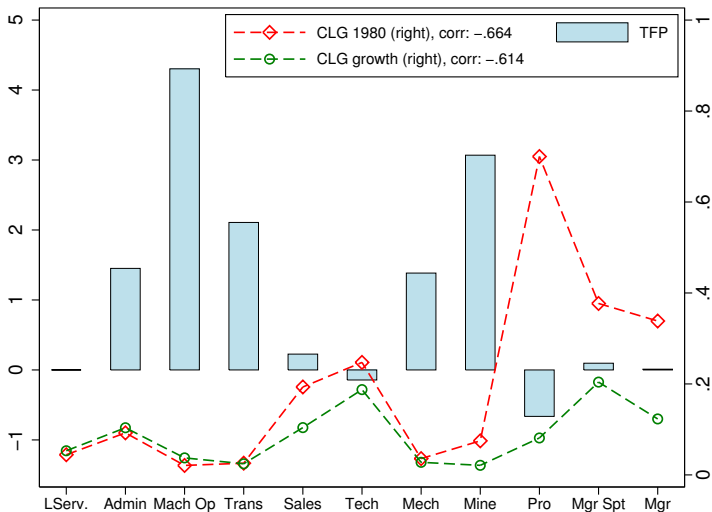
1. Task-level TC growth explains a lot
 - $1/2 \sim 2/3$ of structural change, in aggregate and among routine jobs
 - $1/4$ among managerial jobs
2. Sector-BTC explains less than $1/3$ of polarization
 - However, does not cause any within-sector polarization
 - But useful for matching employment shifts by disaggregated jobs within sectors, especially management
3. TFP growth can be almost entirely explained at task-level

Sources of Task-Level TC

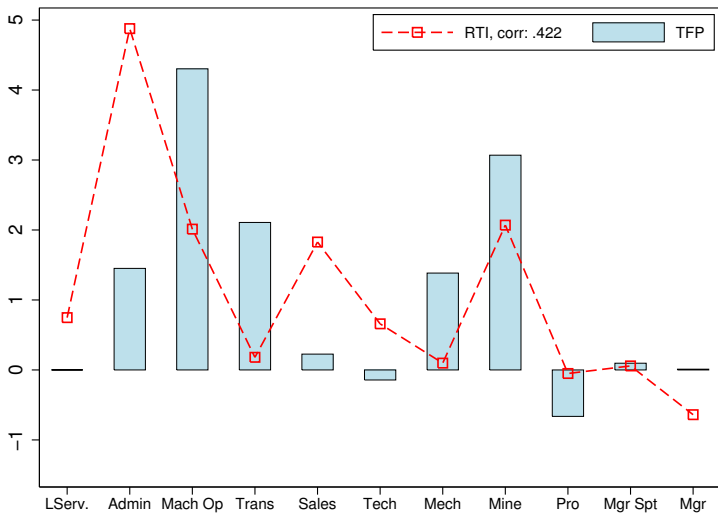
Correlate college shares and empirical measures of OCC task content with our calibrated task productivities

1. College measures explain little (Acemoglu and Autor, 2011; Autor and Dorn, 2013)
2. Aggregated measures such as RTI miss too much information
3. Among disaggregated O*NET measures, [routine-manual](#) and [manual-interpersonal](#) explain more than half of task-TFP differences

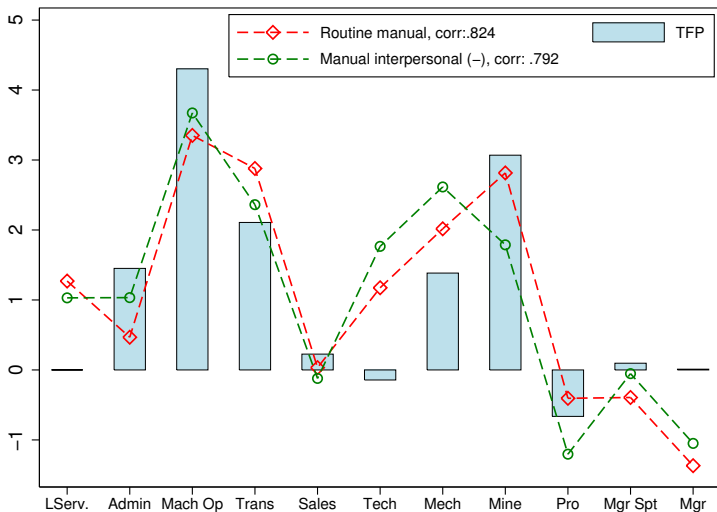
College and Task-Level TC



RTI and Task-Level TC



O*NET and Task-Level TC

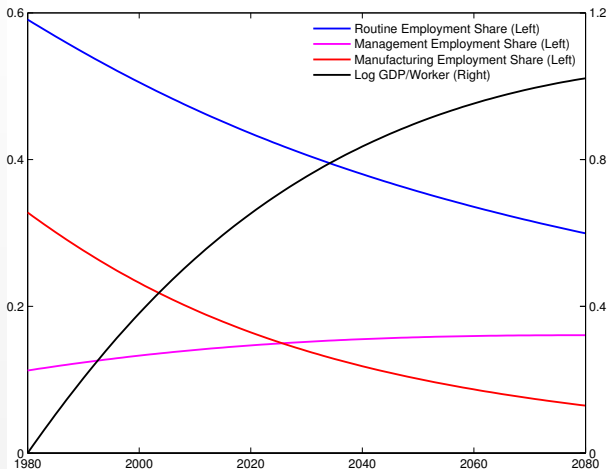


Implications for Long-run Growth

- In the data, manufacturing jobs fell by ~ 13 ppt
- If only change in A_m causes structural change, can analytically compute exactly that routine jobs would have fell only by ~ 4 ppt
- Manufacturing would disappear before routine jobs do
- But routine jobs also fell by ~ 13 ppt, i.e, almost in parallel to manufacturing

Long-Run Dynamics

Secular Stagnation?



Other Implications

- Managers have increased, but establishment sizes have not shrunk
- ⇒ Rise of mid-level managers, which in our model comes from individuals with lower z 's
- May not make much sense to treat services as a monolithic sector
- ⇒ Cleaning companies rely more on manual, financial services on managers, etc.

Conclusion

- A tractable task-based macro model of horizontal/vertical polarization and structural change
- Polarization leads to structural change, which further reinforces polarization
- Task-level TC accounts for $>50\%$ of structural change
- Routinization and interpersonal skills account for more than half of Task-level TC

Further Thoughts

- Endogenous skill distribution dynamics?
- Heterogeneous capital-skill complementarity across jobs?
- Trade and off-shoring among heterogeneous countries?
- Industrial input-output structure?

Long-Run Agenda

- Build a framework that integrates an economy's
 1. Skill distribution across workers
 2. Occupation and industry structure
 3. Productivity distribution across firms (not in current project)
- Today: Application to job polarization and structural change in the U.S.

Span of Control in the Data

- According to the model, sectors are a collection of production units
- A production unit is a manager with a bunch of workers
- Span of control models imply that manager compensation proportional to establishment output
- **Lack of evidence** in macro: previous work either focus on managers and ignore firms, or just assume managers are firms and ignore managers³

³Gabaix and Landier (2008); Gabaix et al. (2014) show evidence that CEO compensation of firms in Execucomp correlate with firm size, but Compustat only includes large, publicly traded firms (less than a percent of the universe). There are ongoing works using firm-employee matched data from other countries such as Denmark, but as far as we know with no official results yet.

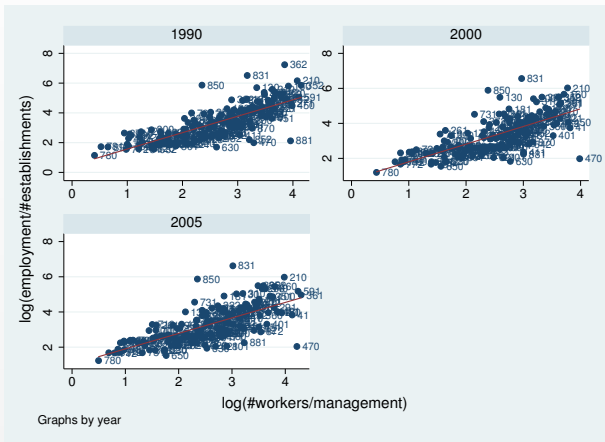
Connecting Managers to Establishments

- Unfortunately, census does not ask questions like "do you lead a firm/establishment?"
- Check whether a narrowly defined OCC code + self-employed similar to establishments by industry
- Even more unfortunately, IND codes change over time and are discordant across datasets
- However, a narrow manager occupation definition fits cross-industry patterns quite well

Establishment Size and Span of Control

▶ back to data

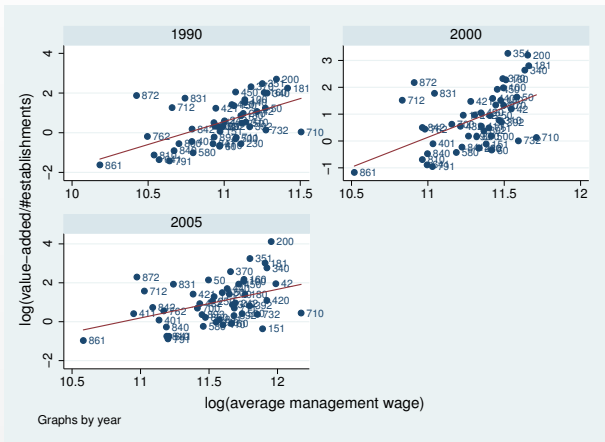
▶ back to model



x-axis: Census, *y*-axis: SUSB, 170 industries.

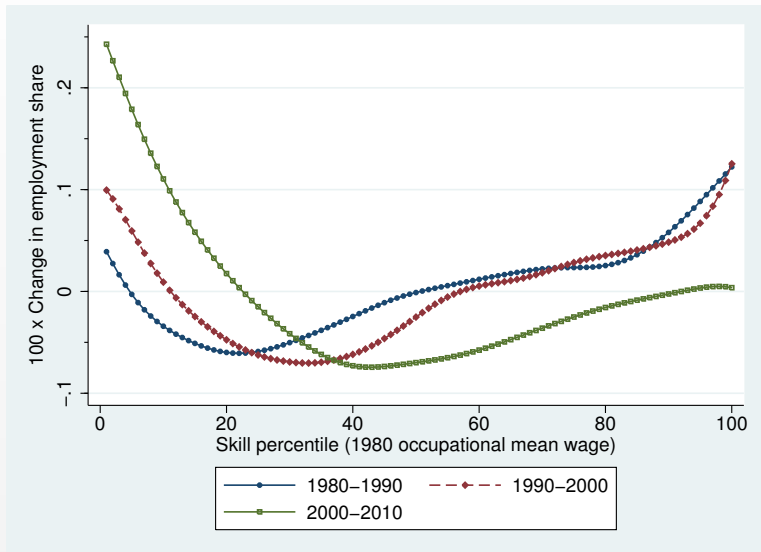
Establishment Output and Manager Compensation

► Wage Comparison



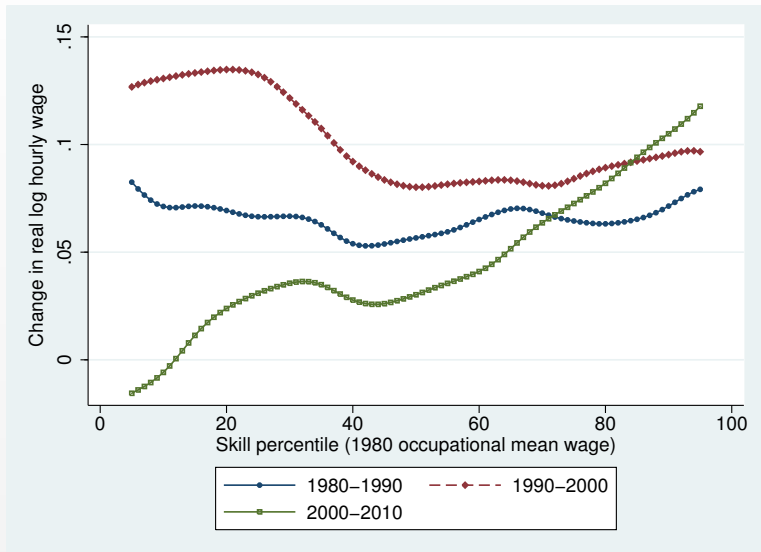
x-axis: Census, *y*-axis: BEA, 48 industries.

Employment Polarization



1980-2005, replicated following Autor and Dorn (2013)

Wage Polarization

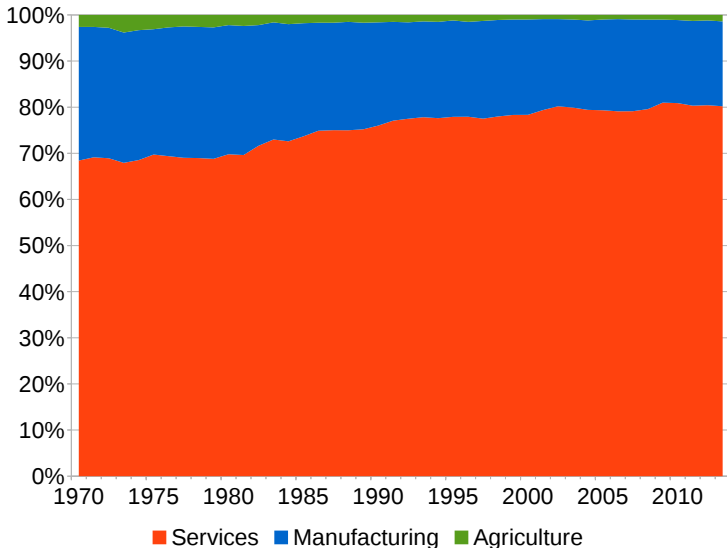


1980-2005, replicated following Autor and Dorn (2013)

Structural Change: GDP (Nominal)

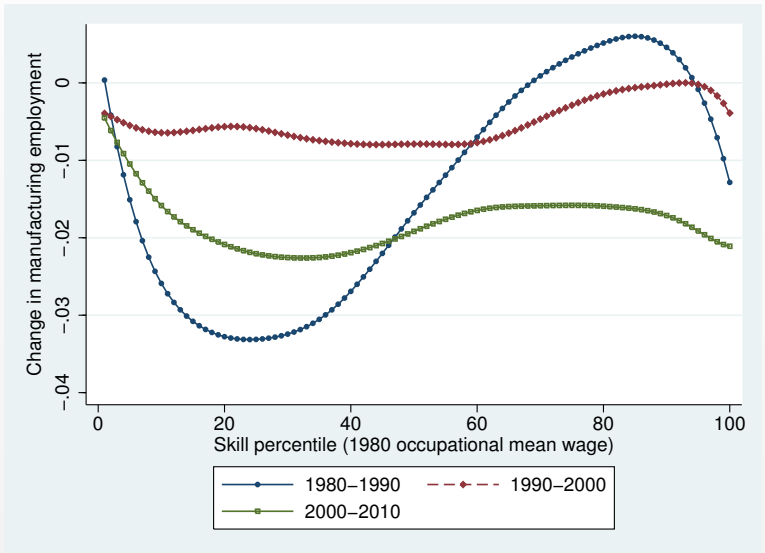
BEA NIPA Accounts

▶ Employment



Change in Manufacturing Employment

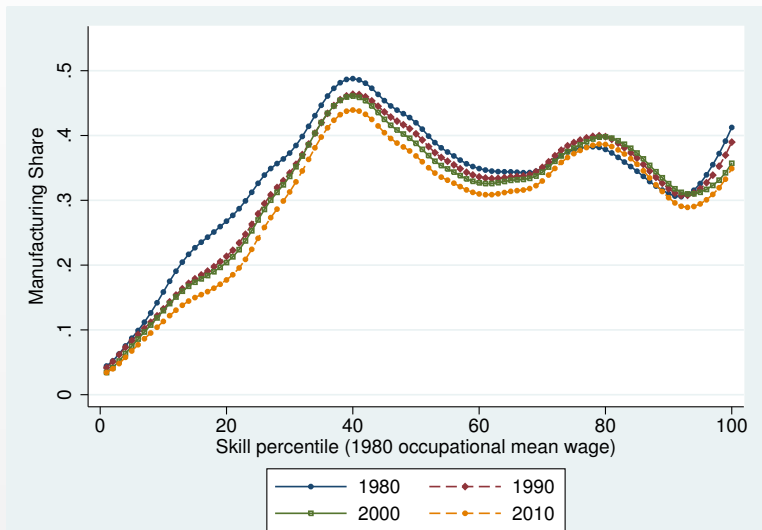
▶ back



Manufacturing Employment Shares

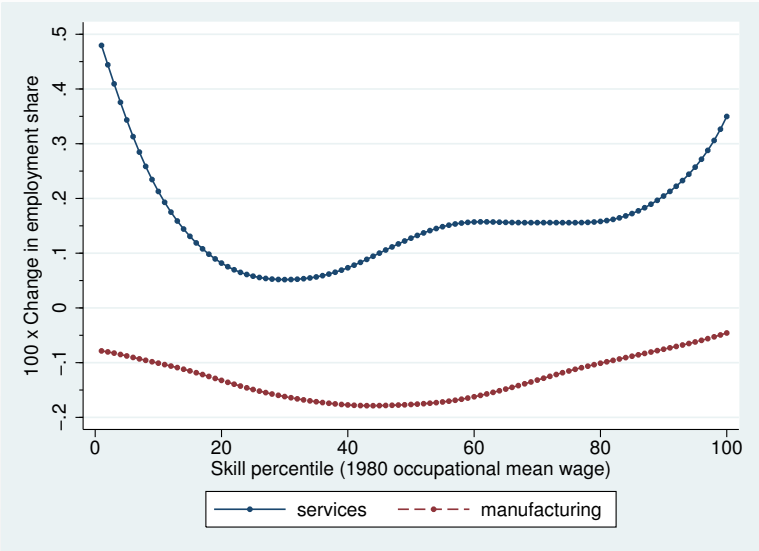
$$\nu_{m1} > \nu_{s1}$$

▶ back



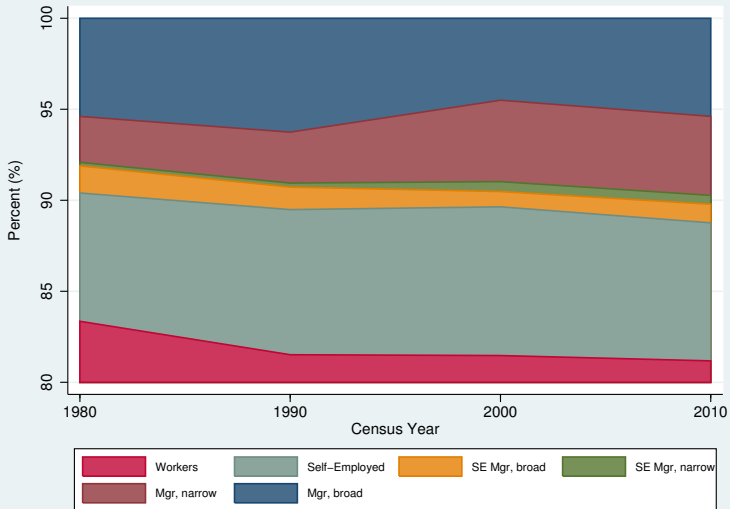
Employment Polarization by Sector

▶ back



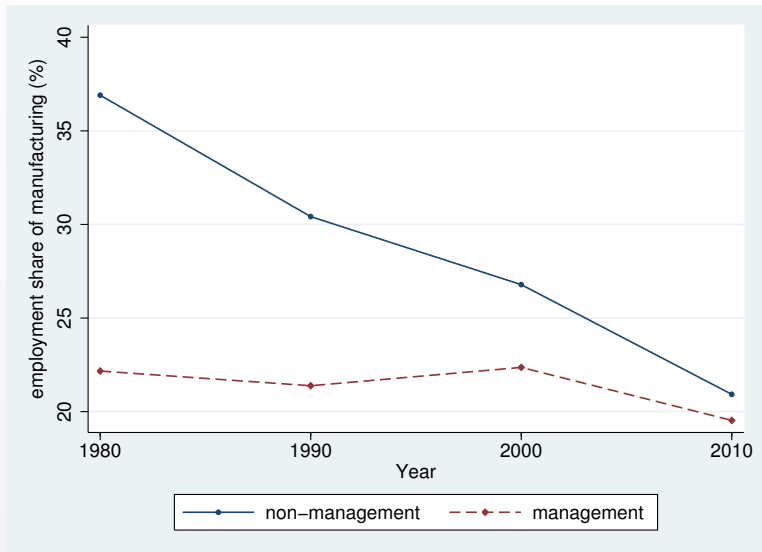
Manager OCC and Self-employment

▶ back



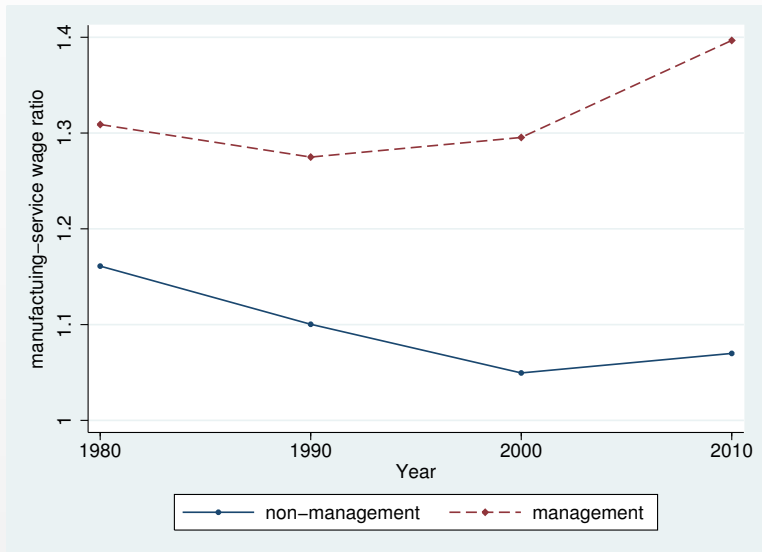
Sectoral Employment Shares by Occupation

▶ back



Sectoral Wage Ratios by Occupation

▶ back



Managers vs Workers, Before Crisis

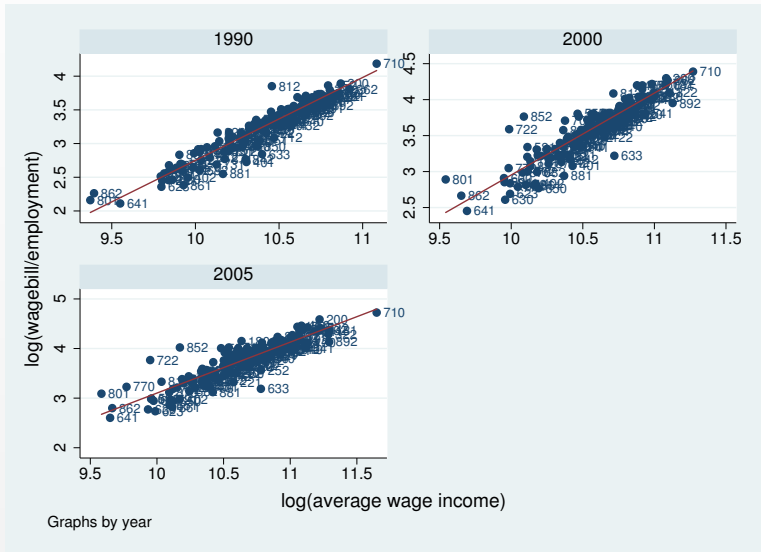
▶ back



Average Wage in Firm and Individual Census

170 Industries, Correlation: 0.95

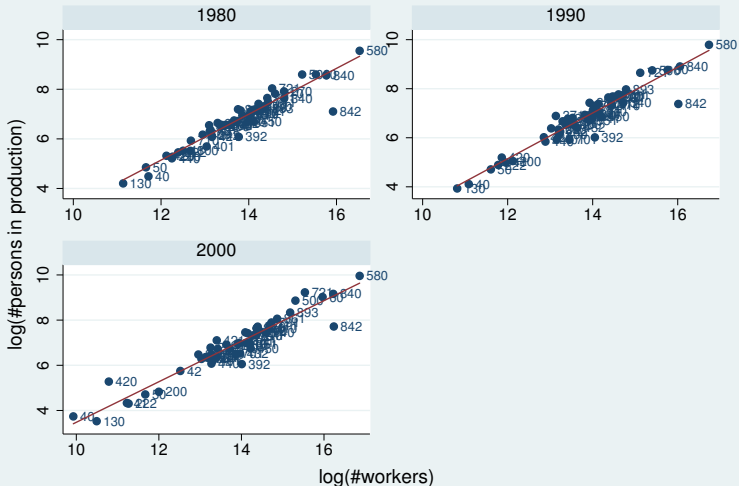
[▶ back](#)



Employment in NIPA and Individual Census, SIC

53 Industries, Correlation: 0.95

[▶ back](#)

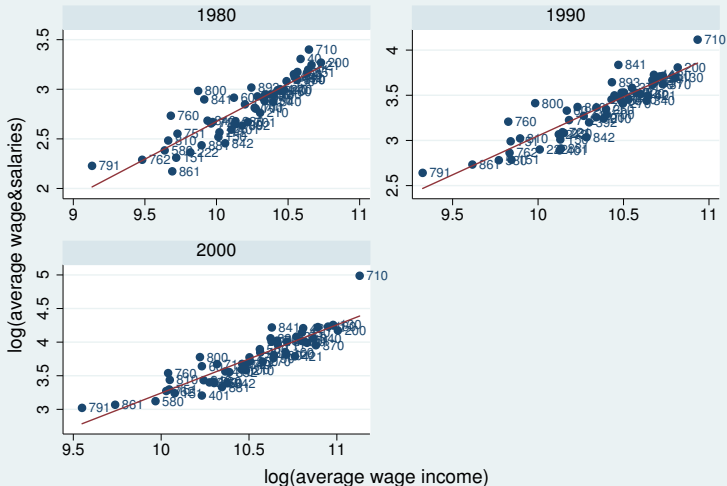


Graphs by Census year

Average Wage in NIPA and Individual Census, SIC

53 Industries, Correlation: 0.90

[▶ back](#)

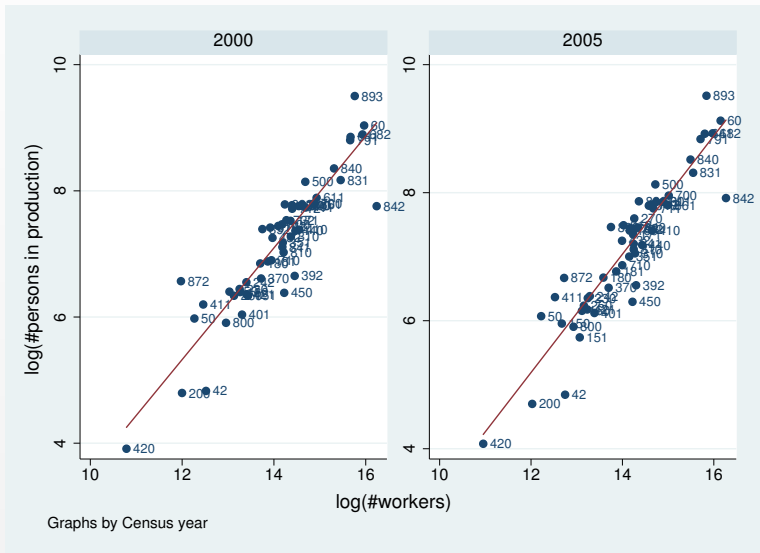


Graphs by Census year

Employment in NIPA and Individual Census, NAICS

53 Industries, Correlation: 0.92

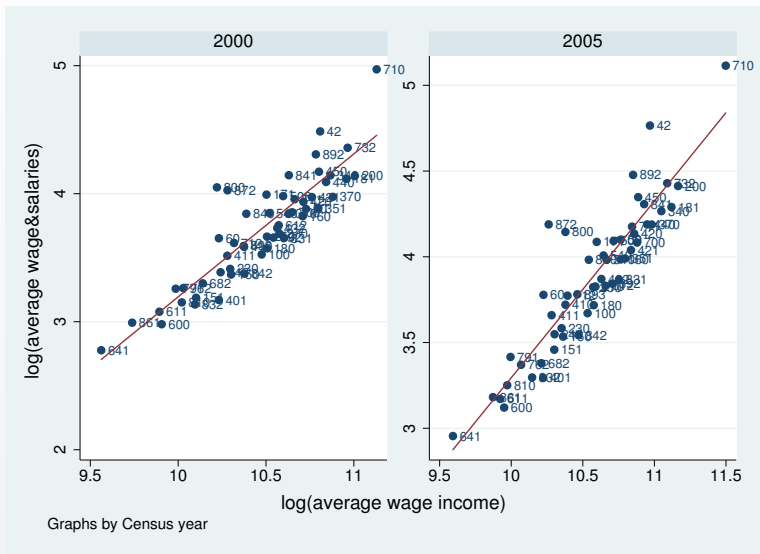
[▶ back](#)



Average Wage in NIPA and Individual Census, NAICS

53 Industries, Correlation: 0.90

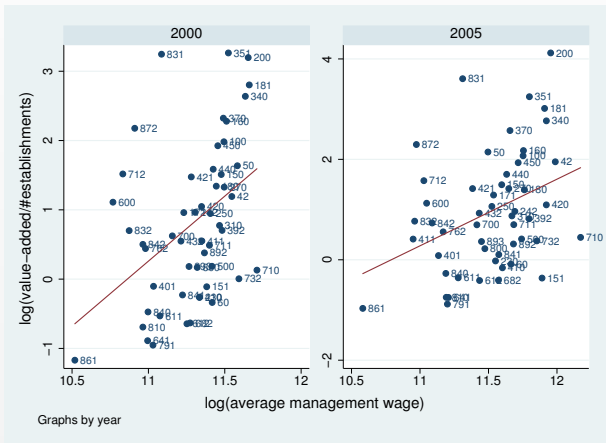
[▶ back](#)



Establishment Output and Manager Compensation, NAICS

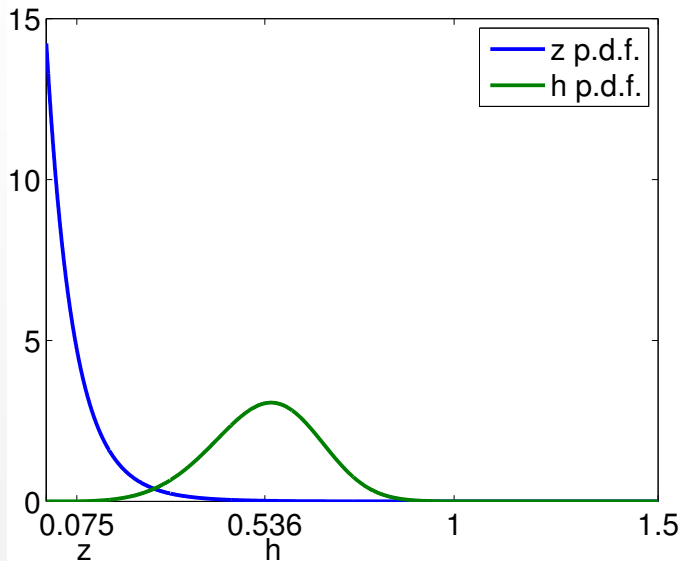
52 Industries

[▶ back](#)



Bivariate Pareto Skill Distribution

▶ back



Calibration Targets

▶ Emp. shares

Ranked by mean wage (except management)	SOC Code	Total Wage Shares (%)			
		1980	2010	Manufacturing	
Low Skill Services	400	6.75	7.60	0.52	0.16
Middle Skill		53.43	35.90	24.76	10.02
Administrative Support	300	12.90	9.60	2.90	1.15
Machine Operators	700	8.21	2.39	7.37	1.91
Transportation	800	7.73	4.15	3.37	1.46
Sales	240	7.40	8.45	1.06	0.85
Technicians	200	3.35	4.33	1.13	0.66
Mechanics & Construction	500	8.40	4.88	4.91	2.61
Miners & Precision Workers	600	5.43	2.10	4.03	1.38
High Skill		24.20	33.98	6.07	5.51
Professionals	40	13.36	20.78	2.59	2.12
Management Support	20	10.84	13.20	3.48	3.39
Management	1	15.62	22.52	4.22	5.81

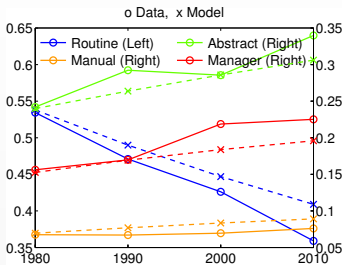
More Calibrated Parameters

▶ back

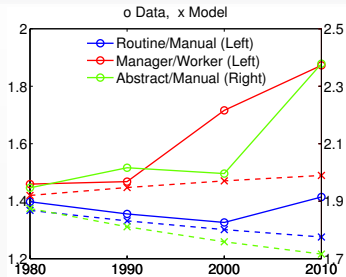
Ranked by mean wage (except management)	χ_j	Emp Wgts (ν_{ij}, η_i)		m_j
		Manu.	Serv.	
Low Skill Services	-	0.021	0.177	0.000
Middle Skill		0.817	0.508	
Administrative Support	-	0.090	0.171	0.015
Machine Operators	0.005	0.259	0.015	0.043
Transportation	0.012	0.119	0.078	0.021
Sales	0.018	0.026	0.119	0.002
Technicians	0.024	0.034	0.038	-0.001
Mechanics & Construction	0.031	0.157	0.061	0.014
Miners & Precision Workers	0.037	0.131	0.026	0.031
High Skill		0.162	0.317	
Professionals	0.044	0.068	0.182	-0.007
Management Support	0.050	0.095	0.135	0.001
Management	-	0.058	0.098	0.000

Model Fit: Total Wage Shares

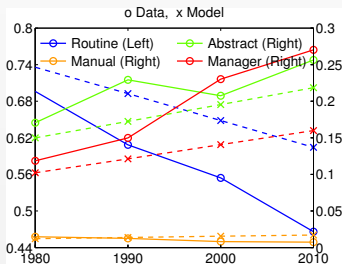
Emp. shares



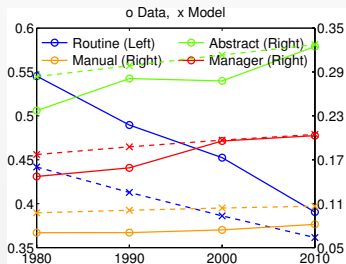
Aggregate Shares



Ratios



Manufacturing



Services

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