A Tale of Two Workers: The Macroeconomics of Automation

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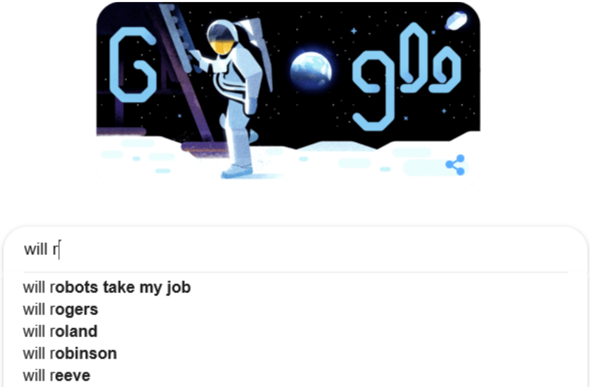
Motivation: why are we here?

- The "technological" advances over the last few decades have left an indelible mark on the way work is done.
- Automation, computing, robotics ("automation technology")... words that become part of our everyday lexicon as the processes behind them have transformed the nature of work.
- These advances have made us more productive
- ... and also fundamentally changed the types of jobs we do, and the way that we do them.
    - A growing literature (e.g. Autor, Katz, and Kearney (2006) Acemoglu and Autor (2011), Autor and Dorn (2013)) demonstrates that "automation technologies" induce large-scale shifts in the types of jobs performed in the economy.
    - The U.S. economy has seen a sharp drop in the fraction of the population employed in Routine occupations.
    - Routine occupations tend to represent middle-class jobs → Increasing polarization of the labor market.

This is not just an academic discussion...



Empirics: So what is new?

- Identify what happens to those with "**Routine characteristics**"
  - Have they become engineers?
  - Have the become janitors?
  - Have they simply stopped working?
- But... what are routine characteristics?!
  - Use "agnostic" machine learning techniques
- We find that decline in Routine can be accounted for by:
  - Decrease in the labor force participation (2/3)
  - Increase in non-routine manual employment (1/3)

Model: So what is new?

- Once key facts are established...
- Guidance for an **empirically relevant** heterogeneous agents GE quantitative model.
  - "Lab" to evaluate welfare & allocation impact of policies
  - Important for policy evaluation: Degree of adoption of automation is endogenous in a GE model: Responds to shocks and policy $\rightarrow$ affects R
- We find:
  - Price decline of ICT since 1989 explains over 50% of the decline in routine employment
  - Aggregate increase in welfare masks massive heterogeneity
  - Re-training as well as re-distribution programs: analyze effects on output, LF, welfare

Data

How to classify the routine workers?

Question: Why can't we just follow those who were routine workers in the 1980s and check where they end up today?

- This is only telling us the story of a few single (now getting older) cohorts
- Difficult to disentangle macro effects from life-cycle patterns

We are actually interested in: Counterfactual occupation choices under pre-automation conditions.

For example: What would have been the 1980 occupation choice of a 30 year old men in 2017?

A machine learning approach

- Use machine learning to the "likely routine" workers, by identifying "routine characteristics".
- Study the evolution of people with these characteristics.

The details:

- Use pre-shock data of employed (CPS 1984-1989)
- Apply a Random Forest algorithm flexibly to age, education, gender, race.
- With an eye on the theoretical model, classify into: **Non-routine-cognitive (NRC), Other occupations (Non-NRC)**

▸ Precision and Recall ▸ Extraction of clean series ▸ Example

Men: Lost R are found in NLF (2/3) and NRM (1/3)

Table: Labor market and occupation composition men, 1989-2017

	non-NRC		NRC	
	(1)	(2)	(3)	(4)
	1989	2017	1989	2017
Fraction in R	0.67	0.57	0.02	0.06
Fraction in NRM	0.11	0.15	~0	0.01
Fraction in NRC	0.01	~0	0.99	0.90
Fraction in NLF	0.17	0.24	~0	0.03
Fraction in Unemployment	0.05	0.04	~0	0.01
Unemployment rate	0.06	0.06	~0	0.01
Population Weight	0.65	0.52	0.35	0.48

R by cell NLF by cell NRM by cell Women

Summary of Empirics

1. NLF accounts for 2/3 of the fall in ER, and ENRM for 1/3.
2. Employment at NRC and unemployment are stable.
3. Changes in NLF and NRM are NOT observed for NRC

Model

Setup: Participation, Occupational Choices, Frictions

- GE Heterogeneous agents with labor force participation and occupational choice
- Motivated by the empirical sharp distinction between two broad groups
  - **Non-NRC, Low-skill**: Heterogeneous, draw ε_R and ε_{NRM} from known idiosyncratic productivity level $\Gamma(\varepsilon_R, \varepsilon_{NRM})$.
    - Choose whether to participate in the labor market
    - Choose whether to seek employment in either the R or NRM
    - Subject to search and matching friction (DMP)
    - Full info on worker abilities, fully segmented matching markets
  - **NRC, High-skill**: identical and decide on optimal labor supply in a frictionless market
- Labor inputs produce three intermediate goods (R, NRM, NRC)

Setup: Capital and Ownership

- Capital input in the forms of ICT capital and non-ICT capital are used in final good production.
- Both capital stocks are owned by perfectly competitive final good producers who make investment decisions.

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- Capital input in the forms of ICT capital and non-ICT capital are used in final good production.
- Both capital stocks are owned by perfectly competitive final good producers who make investment decisions.
- Ownership: high-skilled are "capitalists" and own all firm equity in the economy: As such, advances in automation due to ICT benefit them.

Head's Education	$\frac{\text{Med Net Worth}}{\text{LHS Med Net Worth}}$
Low skilled: Less than high school	1
Low skilled: High school	2.85
Low skilled: Some college	3.35
High skilled: College plus	11.97

Source: Survey of consumer finances

Setup: Taxes and Transfers

- linear/proportional tax on firms' profits
- progressive proportional tax on labor income
- unemployment benefits
- out of the labor force transfers
- (potentially) unconditional lump sum transfers

Putting the ingredients together

- Given equilibrium prices, outside options, taxes, sorting across:
  - Occupation (R,NRM)
  - Labor status (E,U,NLF)
- Given sorting and state variables: optimal decision by firm
- In General Equilibrium: Everything is consistent....
- For a simple description, can use a PE Roy model of "Occupational Sorting"

Full Model

Final good production and optimal capital accumulation

- Use two types of capital and three intermediate goods to produce

$$Y_t = Z_t K_t^{\gamma} \left((1-\eta)\left[(1-\alpha) Y_{NRC,t}^{EOS1} + \alpha \left[X_A^{\nu} + Y_{R,t}^{\nu} \right]^{\frac{EOS1}{\nu}} \right]^{\frac{EOS2}{EOS1}} + \eta Y_{NRM,t}^{EOS2} \right)^{\frac{1-\gamma}{EOS2}}$$

- Optimal investment in physical and ICT capital in accordance with standard Euler equations:

$$\phi_K = \mathbb{E}\left[\Theta \times \left(MPK' + (1-\delta)\phi_K'\right)\right]$$

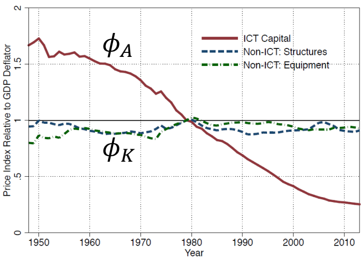
$$\phi_A = \mathbb{E}\left[\Theta \times \left(MPA' + (1-\delta)\phi_A'\right)\right]$$

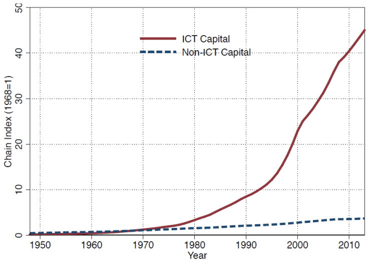
  - MPK and MPA denote the marginal products of the two types of capital.
  - ϕ_K and ϕ_A denote relative prices

- **Important:** degree of adoption of ICT is **endogenous** in a GE model

- Responds to shocks and policy → affects low skilled workers

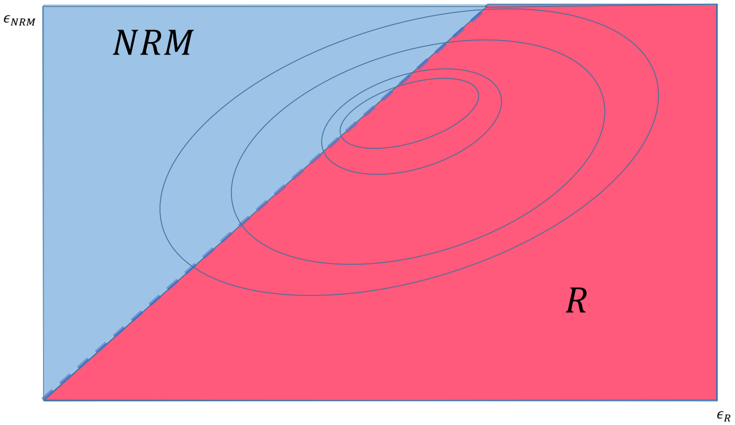
ϕ_A





Data: Eden and Gaggl (2018) from BEA detailed fixed asset accounts (quality adjusted *prices* and *stocks* of ICT)

The Basic Story



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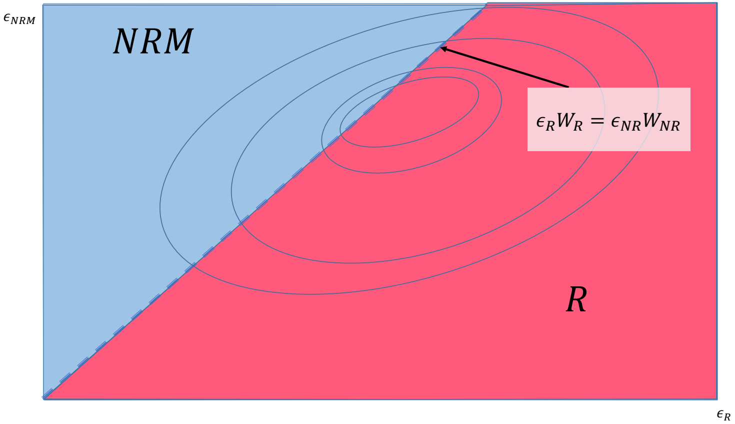

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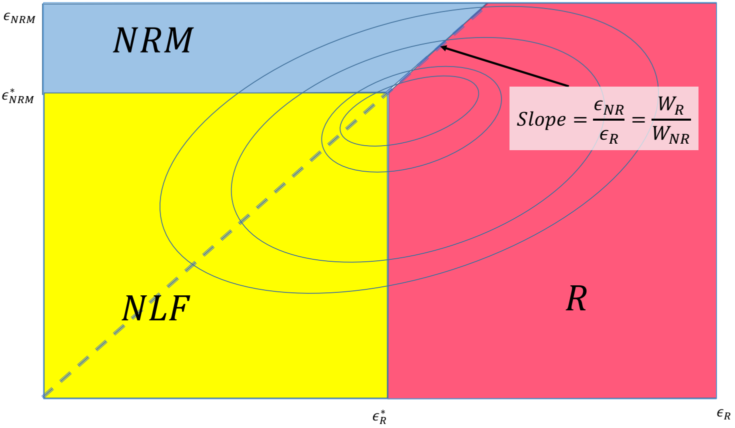
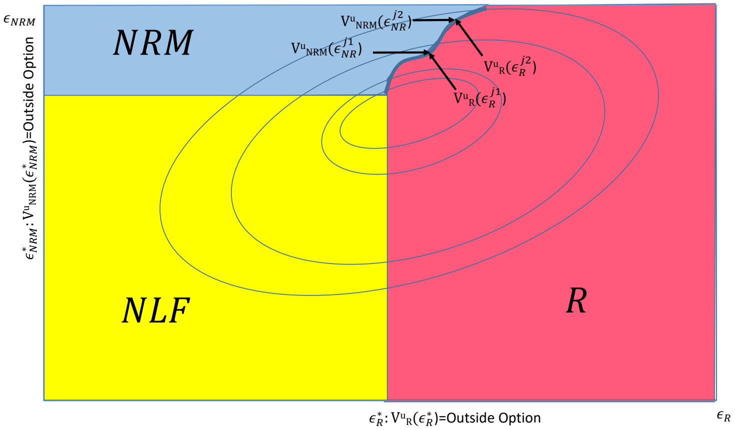
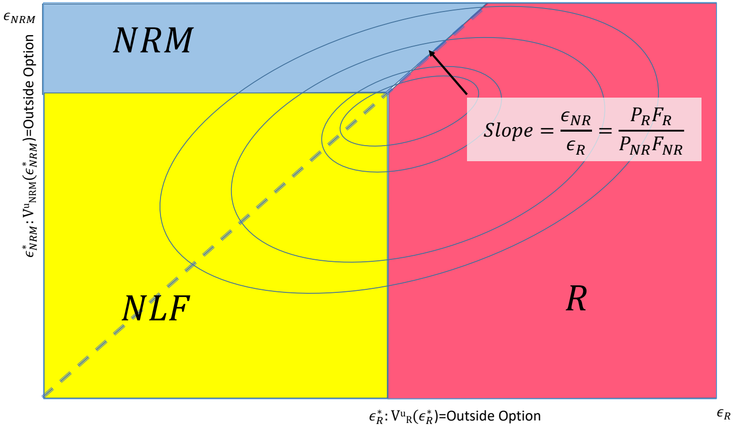


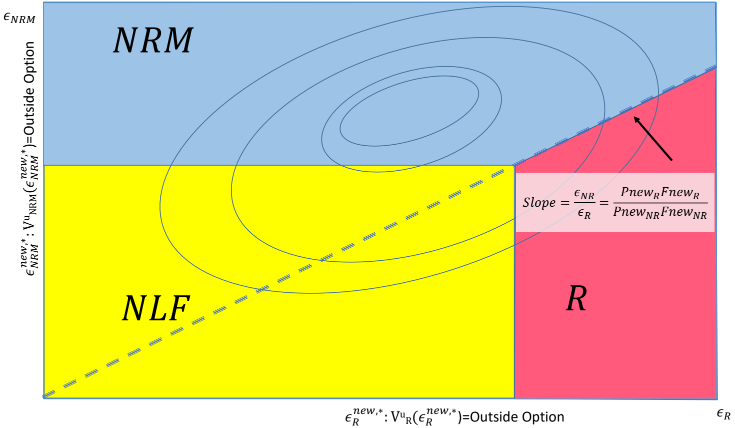
The Basic Story... with curvature, frictions etc.



The Basic Story... with clever (?) assumptions



The Basic Story... a fall in $\phi_A \rightarrow$ a fall in Routine price $\frac{P_R}{P_{NR}}$



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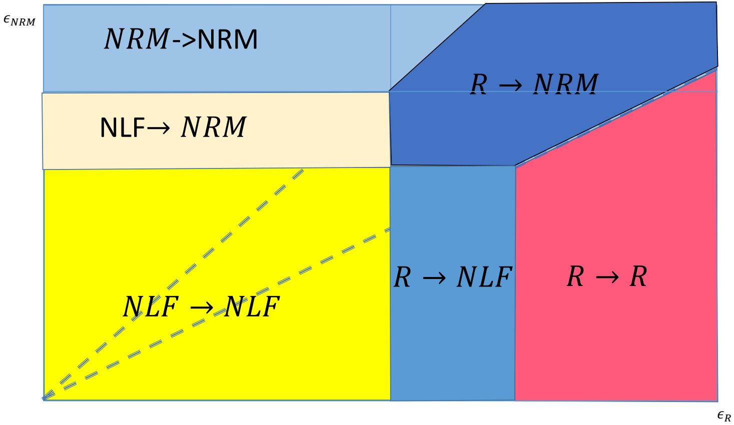

Construction of Steady State Equilibrium

- We analyze steady state equilibrium of the model Eqm Definition
- Consider the change in ϕ_A between 1989 and 2017
- Maintain three sufficient condition that deliver, as in the data, stationary unemployment rates even in the presence of productivity changes.
    1. CRRA utility function
    2. Vacancy costs that are proportional to productivity
    3. Income proportional to the wage (i.e., unemployment benefit modelled as a replacement rate and no capital income).

Derivation

Solution, Calibration and Identification

- Parameters belong to the following categories:
  - Preference parameters
  - Matching function parameters
  - Labor seperation rates
  - Taxes values
  - Replacement ratios
  - NLF "benefits"
  - **Ability distribution parameters**
  - **Production function parameters**
- Jointly determined

Solution, Calibration and Identification

Ability distribution parameters parameters: No need to solve the economic model!

- As is common in the literature we assume the ability distribution is distributed jointly log normal
- Five parameters: 2 std, 2 mean, 1 correlation
- 2 mean: Simple rescaling $\rightarrow$ wlog set to 1
- 1 correlation: cannot be identified so solve the model for various values: no effect on the results.
- 2 std:
  - Can show that map to the variance of observed wages for R and NRM (truncated)
  - Mapping is independent of GE solution. Derivation

Solution, Calibration and Identification

Production function parameters

$$Y_t = Z_t K_t^{\gamma} \left((1-\eta) \left[(1-\alpha) Y_{NRC,t}^{EOS1} + \alpha \left[X_A^{\nu} + Y_{R,t}^{\nu} \right]^{\frac{EOS1}{\nu}} \right]^{\frac{EOS2}{EOS1}} + \eta Y_{NRM,t}^{EOS2} \right)^{\frac{1-\gamma}{EOS2}}$$

- γ: Income share of K (Non-ICT capital)
- $EOS2$: Income share of NRM workers (constant in Eden and Gaggl's data)

Solution, Calibration and Identification

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- γ: Income share of K (Non-ICT capital)
- $EOS2$: Income share of NRM workers (constant in Eden and Gaggl's data)
- $\nu, EOS1$:
  - Feed $\Delta\phi_A$ to the model
  - Match two moments that characterize the response to automation: $\Delta\frac{X_A}{E_R}$ and fraction of ΔR accounted for by NLF.
  - Note: ΔR not targeted

Targeted moments

Model Results

Non-targeted Moments

Table: % change: Model vs. Data

	Data	Model
Employment		
% Routine (out of N-NRC)	-15	-7.85

Non-targeted Moments

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Income Shares		
% of GDP: Aggregate labor	-4.3	-2.39

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% Routine (out of N-NRC)	-15	-7.85
Income Shares		
% of GDP: Aggregate labor	-4.3	-2.39
% of GDP: Routine	-9.51	-6
% of GDP Non-Routine Cognitive	4.17	3.5
% of GDP Non Routine Manual	0.67	0

Non-targeted Moments

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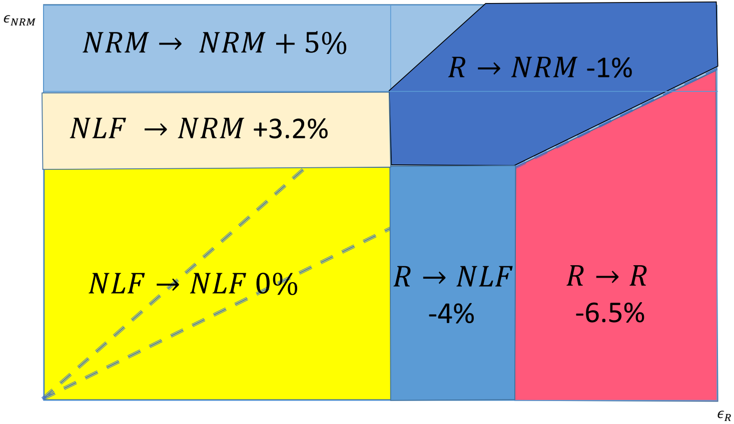
% of GDP: Routine	-9.51	-6
% of GDP Non-Routine Cognitive	4.17	3.5
% of GDP Non Routine Manual	0.67	0
Wages		
$\frac{\omega_R}{\omega_{NRM}}$: Efficiency Wages	NA	-11
$\frac{Avg\omega_R}{Avg\omega_{NRM}}$: Average Wages	-10	-3.6
Elasticity K-ICT to ϕ_A		
	0.4	0.41
GDP		
	40	11

notes: Income shares and wages from Eden and Gaggl (2018).

More moments

Welfare Results



- Aggregate welfare gain 3.6%
- NRC welfare gain 22.6%

Policy Experiments

Policy Experiments: Two Sets of Policies

1. Study the effects of policies aimed at counteracting the negative effects of ICT

    - "Training": the GE consequences of changing workers' abilities **– from MGF to personal care worker (the skills of tomorrow)**

2. Policies discussed in the contexts of employment disappearance

    - Reform the unemployment insurance system
    - Universal Basic Income
    - Change transfers to non-participants in the labor force (Welfare)
    - Labor tax reform

Δ G: financed with changes ($+-$) in labor taxation on the NRC

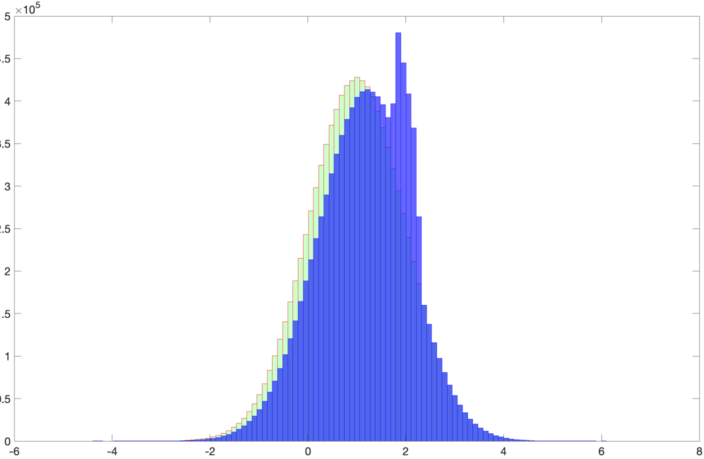
Experiments: From MFG to Personal Care Worker

Increase NRM ability

- "Retrain" a segment of the population:
  - Those who are NLF after the ICT change
- Target: bring labor force participation back to it 1989 (pre-automation) value
- Solve for the GE allocation
- Required magnitude: roughly a quarter of the standard deviation of NRM ability
- See, for instance, the review of active labor market programs by Card et al (2018): training programs generally exhibit small employment effects in the short-run that turn positive only in the long-run, with larger effect for the long-term unemployed, e.g. those with low labor force attachment.

Experiments: From MFG to Personal Care Worker

Increase NRM ability



Experiments: From MFG to Personal Care Worker

Retraining effect on allocations and wages

	ICT Change	Retraining
Cutoffs		
$\Delta\varepsilon^*_R$	6.704	-0.222
$\Delta\varepsilon^*_{NRM}$	-4.838	3.998
Labor states		
ΦNLF	2.185	-2.213
ΦR	-3.821	0.274
ΦNRM	1.635	1.939
ΔY_{NRC}	1.227	0.366
ΔY_R	-3.721	0.596
ΔY_{NRM}	7.141	5.016
GDP		
ΔGDP	11.979	1.018
Wages		
$\Delta\omega_R$	-6.704	0.222
$\Delta\omega_{NRM}$	4.838	-3.998
$\Delta\omega_{NRC}$	23.236	0.825

Experiments: From MFG to Personal Care Worker

Retraining effect on welfare

	ICT Change	Retraining
Welfare		
Aggregate:	1.036	1.008
ΔR^{Old} -> ΔR^{New}	0.935	1.012
ΔR^{Old} -> ΔNRM^{New}	0.990	NA
ΔR^{Old} -> ΔNLF^{New}	0.960	NA
ΔNRM^{Old} -> ΔR^{New}	NA	0.988
ΔNRM^{Old} -> ΔNRM^{New}	1.050	0.968
ΔNRM^{Old} -> ΔNLF^{New}	NA	0.980
ΔNLF^{Old} -> ΔR^{New}	NA	1.000
ΔNLF^{Old} -> ΔNRM^{New}	1.032	1.092
ΔNLF^{Old} -> ΔNLF^{New}	1.000	1.000
ΔNRC^{Old} -> ΔNRC^{New}	1.226	1.020

Experiments: From MFG to Personal Care Worker

Benchmarking the Cost

- To achieve the target, need to "treat" 10% of those outside the labor force
- Gains in GDP 1%
- As long as program cost per participant is less than 30% of GDP per capita it pays off

Experiments: Transfers

- We consider four types of tax and transfer schemes:
  - UI
  - UBI
  - Transfers NLF
  - Labor tax reform

- To discipline the experiments:
  - Increase unemployment benefits to bring back labor force participation to pre-automation levels (ex-post: 25.7% of average UI transfers in the economy)
  - Increase all other transfers by the same per-capita transfer amount used in the UI experiment

Experiments: UI & UBI

- UI: Budget constraint of an unemployed becomes
  $C_{u,\varepsilon_R} = b_{\varepsilon_R}\omega_{\varepsilon_R}(1 - T_{u,\varepsilon_R}) + UI$

- UBI: Budget constraint becomes (for all individuals: employed, unemployed and out of the labor force)
  $C_{e,\varepsilon_R} = \omega_{\varepsilon_R}(1 - T_{e,\varepsilon_R}) + UBI$

- Introduction of an additive term to the individual's budget constraint $\rightarrow$ linearity of the solution approach is no longer applicable.

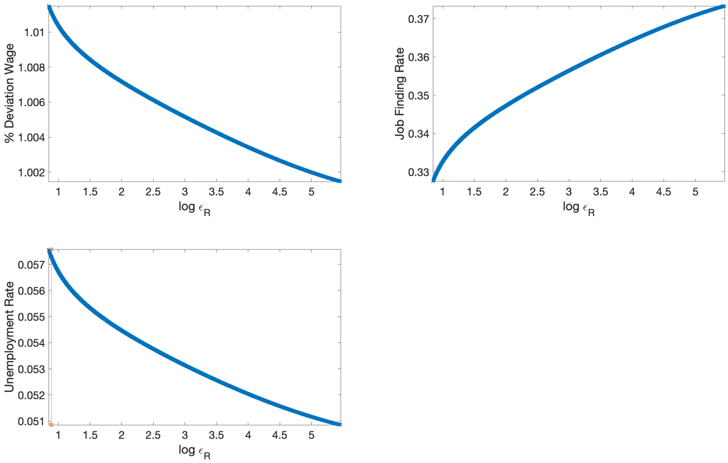
- Each ε market has a different tightness ratio

- Occupation cutoffs are no longer linear functions of ability.

- Discretize support plus splines

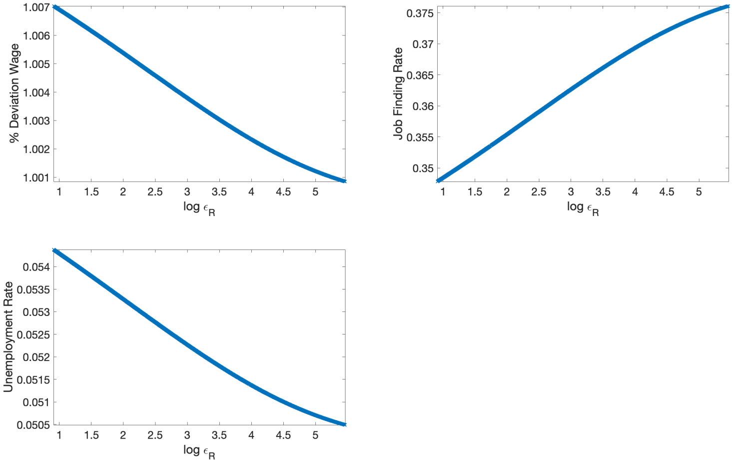
Experiments: UI

Figure: UI policy



Experiments: UBI

Figure: UBI policy



Implications of Transfers for Allocations

	ICT Change	UI	UBI	NLF Benefits
Cutoffs				
$\Delta\varepsilon^*_R$	6.704	-3.953	10.773	26.371
$\Delta\varepsilon^*_{NRM}$	-4.838	-4.508	9.453	26.660
Labor states				
ΦNLF	2.185	-2.203	5.843	15.118
ΦR	-3.821	1.566	-4.691	-11.517
ΦNRM	1.635	0.637	-1.152	-3.602
Emp Rate: R	0.950	0.945	0.946	0.950
Emp Rate: NRM	0.950	0.945	0.946	0.950
ΔY_{NRC}	1.227	0.131	-13.869	-8.033
ΔY_R	-3.721	-0.114	-5.031	-12.368
ΔY_{NRM}	7.141	-0.751	-4.015	-13.175
GDP				
ΔGDP	11.979	-0.056	-9.916	-10.040
NRC Labor Tax				
ΦLabor NRC Tax	0.000	-0.505	35.190	25.005

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NRC Labor Tax				
ΦLabor NRC Tax	0.000	-0.505	35.190	25.005

Implications of Transfers for Welfare

	ICT Change	UI	UBI	NLF Benefits
Wages				
$\Delta\omega_R$	-6.704	0.140	-7.222	3.424
$\Delta\omega_{NRM}$	4.838	0.695	-5.902	3.135
$\Delta\omega_{NRC}$	23.236	-0.298	7.498	-3.789
$\Delta\omega_{NRC}$: After Tax	23.236	0.113	-12.797	-10.644
Welfare				
Aggregate:	1.036	1.010	1.073	1.063
ΔR^{Old} -> ΔR^{New}	0.935	1.019	1.062	1.035
ΔR^{Old} -> ΔNRM^{New}	0.990	1.027	1.117	NA
ΔR^{Old} -> ΔNLF^{New}	0.960	NA	1.263	1.167
ΔNRM^{Old} -> ΔR^{New}	NA	NA	NA	1.033
ΔNRM^{Old} -> ΔNRM^{New}	1.050	1.024	1.074	1.032
ΔNRM^{Old} -> ΔNLF^{New}	NA	NA	1.271	1.166
ΔNLF^{Old} -> ΔR^{New}	NA	1.022	NA	NA
ΔNLF^{Old} -> ΔNRM^{New}	1.032	1.025	NA	NA
ΔNLF^{Old} -> ΔNLF^{New}	1.000	1.000	1.341	1.347
ΔNRC^{Old} -> ΔNRC^{New}	1.226	1.001	0.781	0.770

Is There a Better Way to Redistribute?

- Transfers experiment demonstrate massive incentives to redistribute
- But, induce major losses in employment, output and welfare of high-skilled
- Can alternative tax schemes on labor do better?
  - Decrease taxes on low skilled workers (essentially to zeros)
  - Increase taxes on the high-skilled to balance the budget

Is There a Better Way to Redistribute?

More progressive taxation is less distortive than UBI and Welfare

	UI	UBI	NLF Benefits	Taxation
Cutoffs				
$\Delta\varepsilon^*_R$	-3.953	10.773	26.371	-9.660
$\Delta\varepsilon^*_{NRM}$	-4.508	9.453	26.660	-10.244
Labor states				
ΦNLF	-2.203	5.843	15.118	-5.182
ΦR	1.566	-4.691	-11.517	3.814
ΦNRM	0.637	-1.152	-3.602	1.368
Emp Rate: R	0.945	0.946	0.950	0.950
Emp Rate: NRM	0.945	0.946	0.950	0.950
ΔY_{NRC}	0.131	-13.869	-8.033	-2.059
ΔY_R	-0.114	-5.031	-12.368	3.129
ΔY_{NRM}	-0.751	-4.015	-13.175	3.901
GDP				
ΔGDP	-0.056	-9.916	-10.040	0.292
NRC Labor Tax				
ΦLabor NRC Tax	-0.505	35.190	25.005	9.978

Is There a Better Way to Redistribute?

Yet, quite effectively redistributes

	UI	UBI	NLF Benefits	Taxation
Welfare				
Aggregate:	1.010	1.073	1.063	1.041
ΔR^{Old} -> ΔR^{New}	1.019	1.062	1.035	1.101
ΔR^{Old} -> ΔNRM^{New}	1.027	1.117	NA	1.105
ΔR^{Old} -> ΔNLF^{New}	NA	1.263	1.167	NA
ΔNRM^{Old} -> ΔR^{New}	NA	NA	1.033	NA
ΔNRM^{Old} -> ΔNRM^{New}	1.024	1.074	1.032	1.108
ΔNRM^{Old} -> ΔNLF^{New}	NA	1.271	1.166	NA
ΔNLF^{Old} -> ΔR^{New}	1.022	NA	NA	1.058
ΔNLF^{Old} -> ΔNRM^{New}	1.025	NA	NA	1.061
ΔNLF^{Old} -> ΔNLF^{New}	1.000	1.341	1.347	1.000
ΔNRC^{Old} -> ΔNRC^{New}	1.001	0.781	0.770	0.950

Conclusions

- NLF accounts for 2/3 of the fall in ER, and ENRM for 1/3
- Quantitative GE model of Automation
  - Significant winners and losers
- Policy experiments
  - Consider a variety of policy experiments
- Exciting (at least to us) framework to analyze the consequence of a variety of policies that are currently being discussed

Appendix

Precision and Recall

		Observed		
		NRC	non-NRC	**Precision**
	NRC	848,364	444,759	**65.61%**
Predicted	non-NRC	483,632	2,380,753	**83.12%**
	Recall	**63.69%**	**84.26%**	

- **Precision**: Share of correctly classified within a predicted category.
- **Recall**: The share of true that were picked up by the prediction within a category.

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Precision and Recall by Gender

Men

		Observed		
		NRC	non-NRC	**Precision**
	NRC	506,002	294,252	**63.23%**
Predicted	non-NRC	242,256	1,213,131	**83.35%**
	Recall	**67.62%**	**80.48%**	

Women

		Observed		
		NRC	non-NRC	**Precision**
	NRC	342,362	150,507	**69.46%**
Predicted	non-NRC	241,376	1,167,622	**82.87%**
	Recall	**58.65%**	**88.58%**	

Back

Recover clean series for NRC and non-NRC

- Had there been no errors → recover dynamics of the NNRC characteristics.
- With classification errors, use the following two equations to recover clean series:

$$
\begin{aligned}
\hat{x}_{NRC} &= S_{NRC|NRC} X_{NRC} + S_{NNRC|NRC} X_{NNRC} \\
\hat{x}_{NNRC} &= S_{NRC|NNRC} X_{NRC} + S_{NNRC|NNRC} x_{NNRC}
\end{aligned}
$$

where:

		Classified	
		NRC	NNRC
True	NRC	$S_{NRC\|NRC}$	$S_{NRC\|NNRC}$
	NNRC	$S_{NNRC\|NRC}$	$S_{NNRC\|NNRC}$

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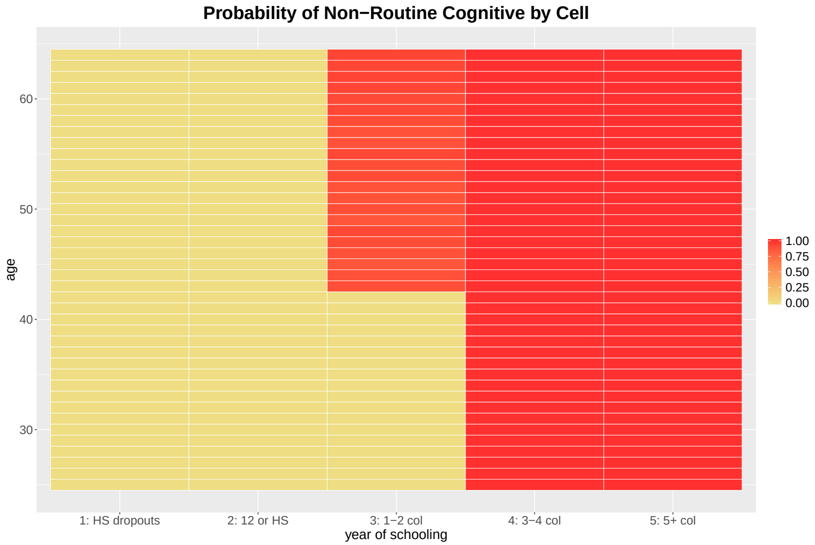
Example for predictions by education and age: Men 1989



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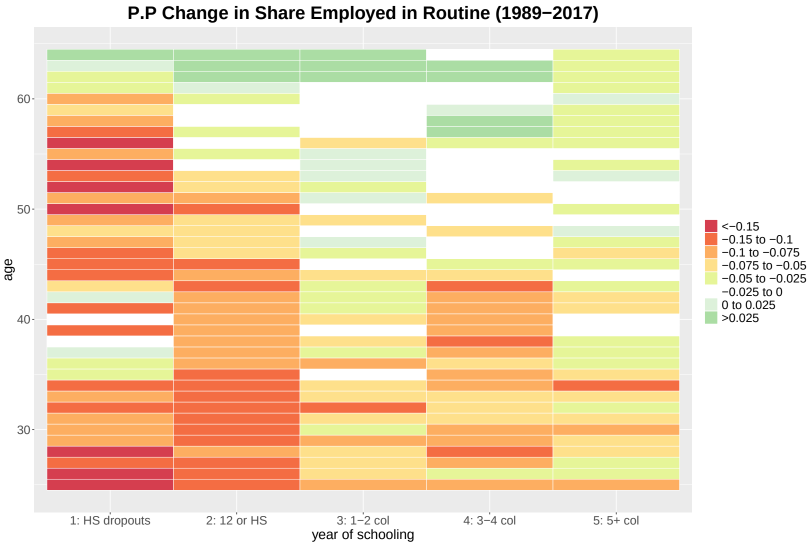
Changes in R by education and age: Men



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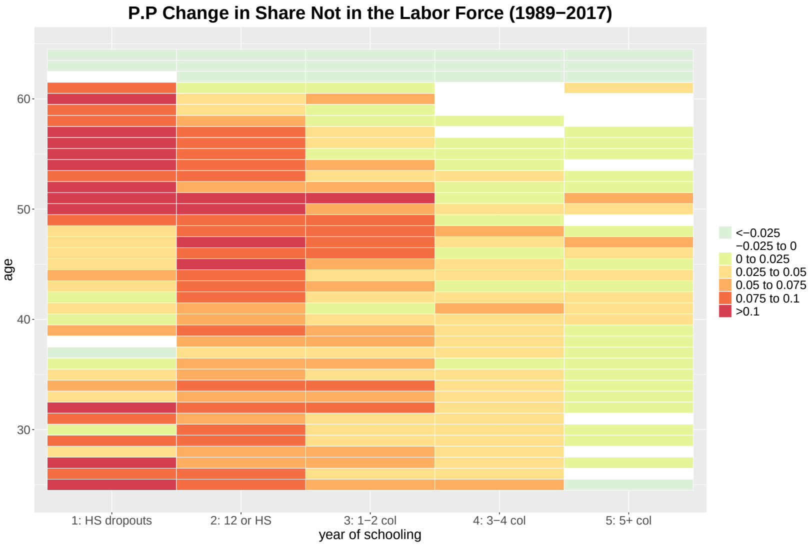
Changes in NLF by education and age: Men



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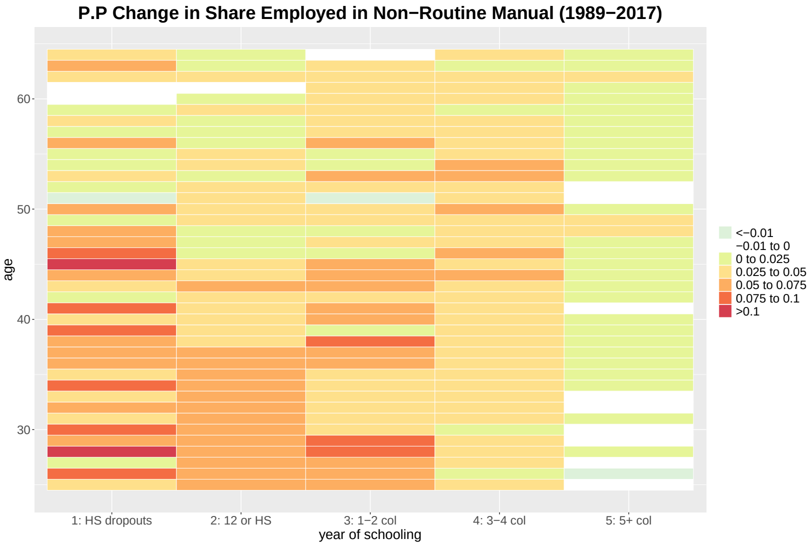
Changes in NRM by education and age: Men



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What about the patterns for women?

- Similar patterns can be observed for non-NRC women but over a different time period.
- As is well known, the last 40 years of the twentieth century was characterized by a pronounced increase in labor force participation among women.
- Since the turn of the twenty-first century, female labor force participation has plateaued and begun to fall, even among the prime-aged.
- As such, our view is that the period since the turn of the twenty-fist century is more indicative of the female occupation dynamics.

Lost R are found in NLF (2/3) and NRM (1/3)

Table: Labor market status and occupation composition changes for non-NRC types

	female		male	
	(1)	(2)	(3)	(4)
	2001	2017	2001	2017
Fraction in R	0.39	0.30	0.64	0.57
Fraction in NRM	0.17	0.21	0.12	0.15
Fraction in NRC	0.07	0.06	0.01	~0
Fraction in NLF	0.34	0.40	0.19	0.24
Fraction in Unemployment	0.03	0.03	0.04	0.04
Unemployment rate	0.05	0.06	0.05	0.06
Population Weight	0.68	0.55	0.58	0.52

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Test case 2: NLSY79 cohort of workers in routine occupations

- Results so far informative with respect to what happens to people with identified "Routine characteristics"
- Complementary analysis:
  - Follow a **specific cohort**: what happens to them over time?

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NLSY

- Construct weekly employment and job histories
- Count the # of weeks a worker was working in R/NRM/NRC occupation during a baseline period (1985-1989)
- Define a worker of type R (for example) if worked in R occupation for the majority of weeks during the baseline period
- For each year after the baseline calculate the fraction of weeks a person was...
  - working in R/NRM/NRC
  - unemployed
  - not in the labor force

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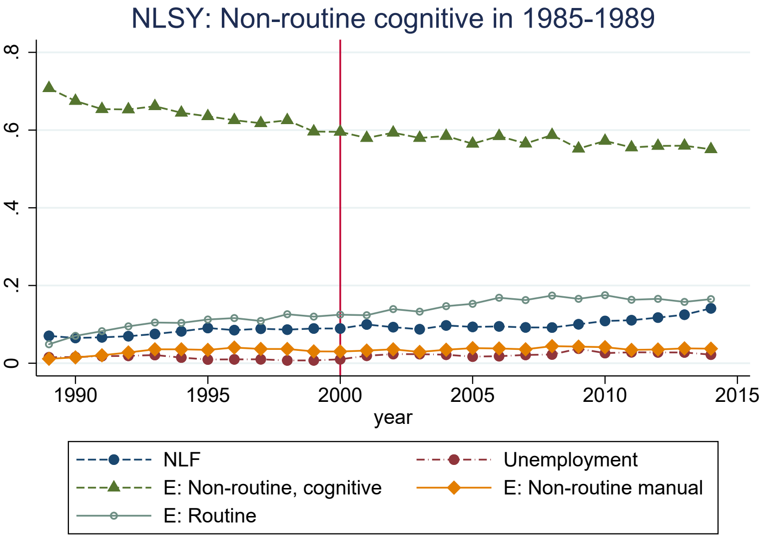
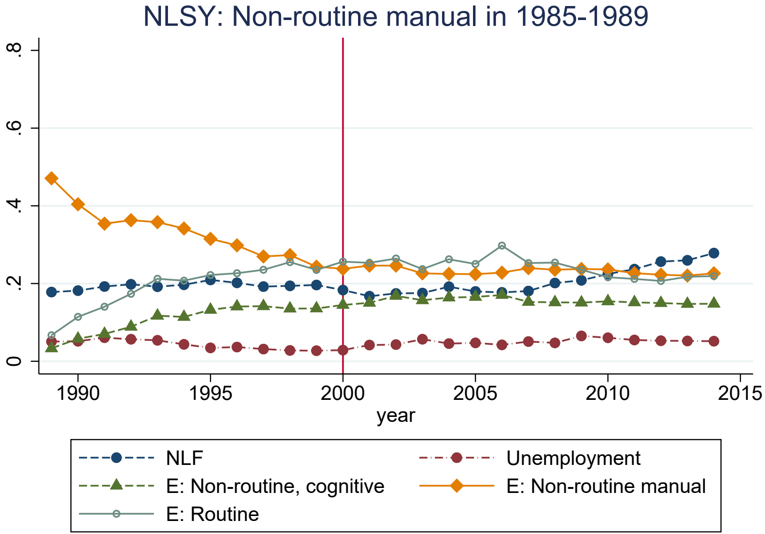
The Evolution of Employment Choices



The Evolution of Employment Choices



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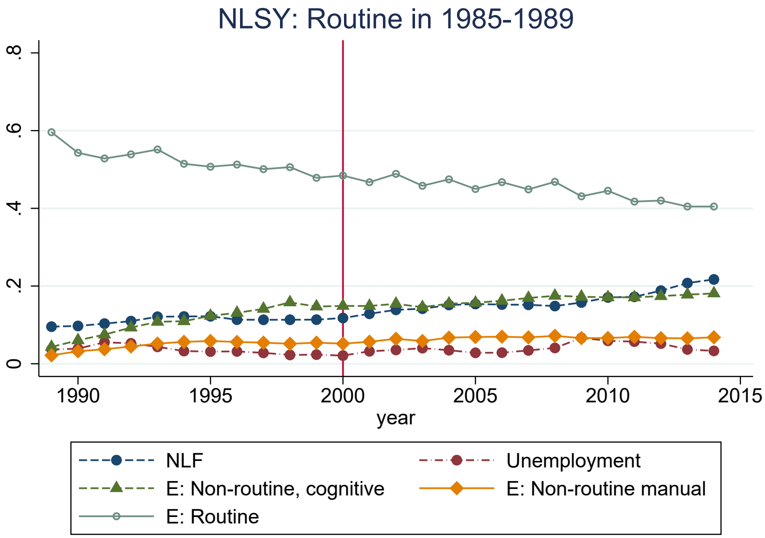
The Evolution of Employment Choices



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The Evolution of Employment Choices

- In NRM and NRC:
  - Starting age 40 (year 2000): occupation life cycle "stabilizes" and converges
- In R:
  - R to R continues to fall.
  - Fall in R is mainly observed in rise in NLF.
  - For this specific cohort: not so much rise NRM

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The Evolution of Employment Choices

	To starting occ 1989 → 2000	To starting occ 2000 → 2015
NRM	-49.5%	-4.9%
NRC	-15.9%	-7.5%
R	-18.7%	-16.4%
	To NLF 1989 → 2000	**To NLF 2000 → 2015**
NRM	2.7%	51.9%
NRC	26.9%	58.1%
R	23.3%	84.4%
	To NRM 1989 → 2000	**To NRM 2000 → 2015**
NRM	-49.5%	-4.9%
NRC	163%	24.3%
R	137%	31.5%

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The Evolution of Employment Choices (levels)

	To starting occ 1989 → 2000	To starting occ 2000 → 2015
NRM	-23.3%	-1.1%
NRC	-11.2%	-4.5%
R	-11.1%	-8.0%
	To NLF 1989 → 2000	To NLF 2000 → 2015
NRM	0.5%	9.5%
NRC	1.9%	5.1%
R	2.2%	9.9%
	To NRM 1989 → 2000	To NRM 2000 → 2015
NRM	-23.3%	-1.1%
NRC	1.9%	0.7%
R	3%	1.6%

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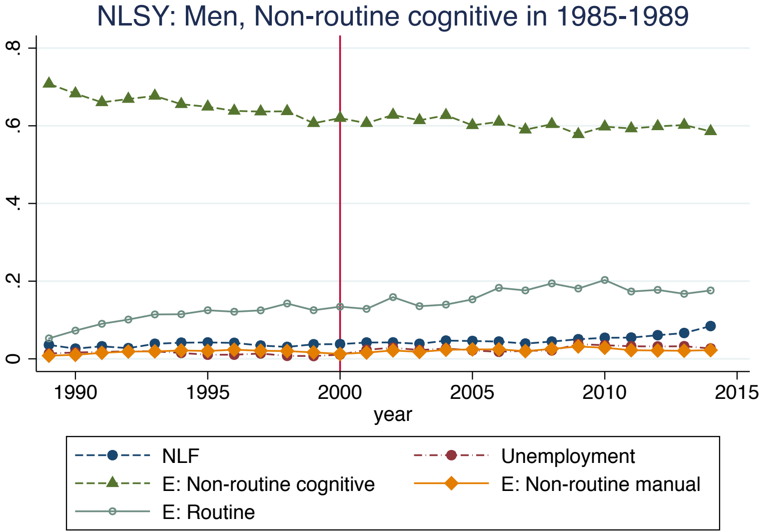
The Evolution of Employment Choices: Men



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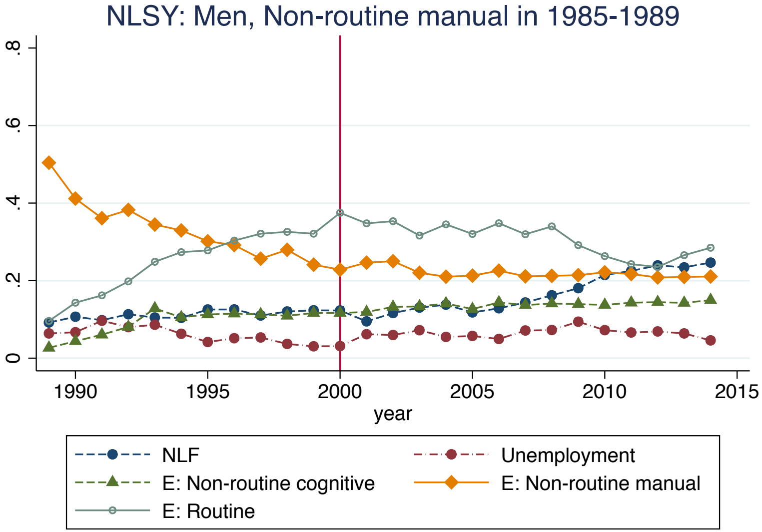
The Evolution of Employment Choices: Men



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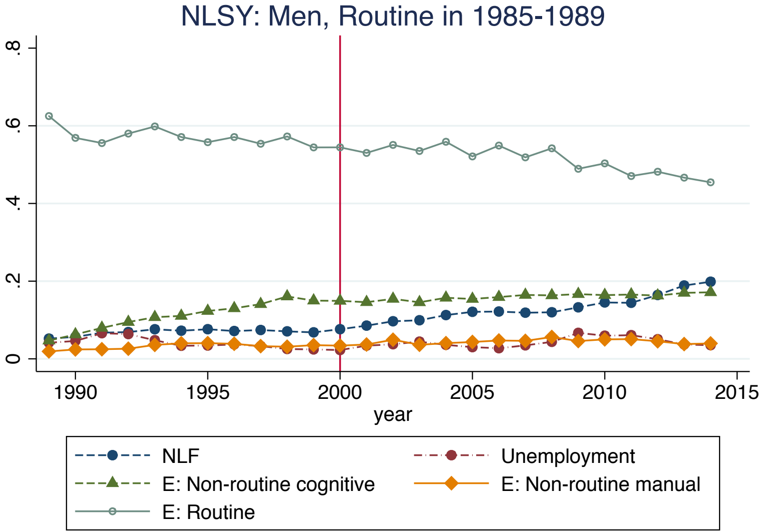
The Evolution of Employment Choices: Men



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The Evolution of Employment Choices: Men

	To starting occ	To starting occ
	1989 → 2000	2000 → 2015
NRM	-54.7%	-7.7%
NRC	-12.5%	-5.5%
R	-12.9%	-16.5%
	To NLF	To NLF
	1989 → 2000	2000 → 2015
NRM	33.8%	100%
NRC	5.6%	122%
R	46.4%	160%
	To NRM	To NRM
	1989 → 2000	2000 → 2015
NRM	-54.7%	-7.7%
NRC	55.6%	77.0%
R	77.4%	16.7%

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The Evolution of Employment Choices (levels): Men

	To starting occ 1989 → 2000	To starting occ 2000 → 2015
NRM	-27.6%	-1.8%
NRC	-8.8%	-3.4%
R	-8.1%	-9.0%
	To NLF 1989 → 2000	**To NLF 2000 → 2015**
NRM	3.1%	12.4%
NRC	0.2%	4.6%
R	2.4%	12.2%
	To NRM 1989 → 2000	**To NRM 2000 → 2015**
NRM	-27.6%	-1.8%
NRC	0.4%	1.0%
R	1.5%	0.6%

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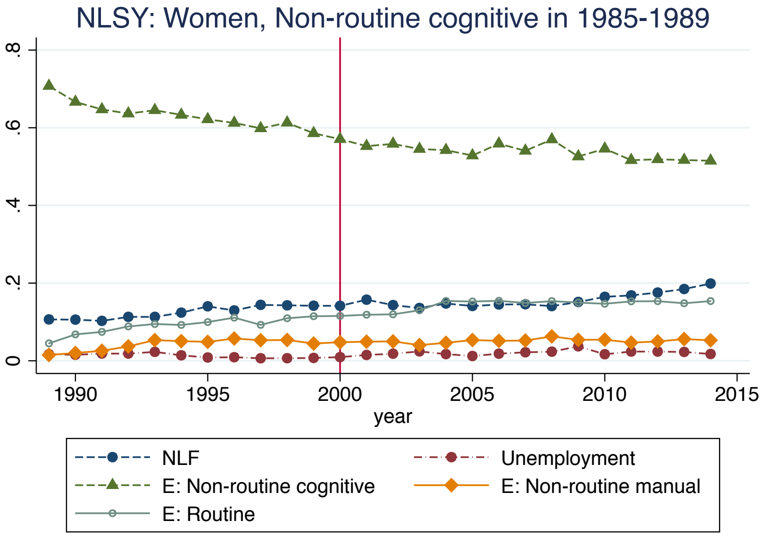
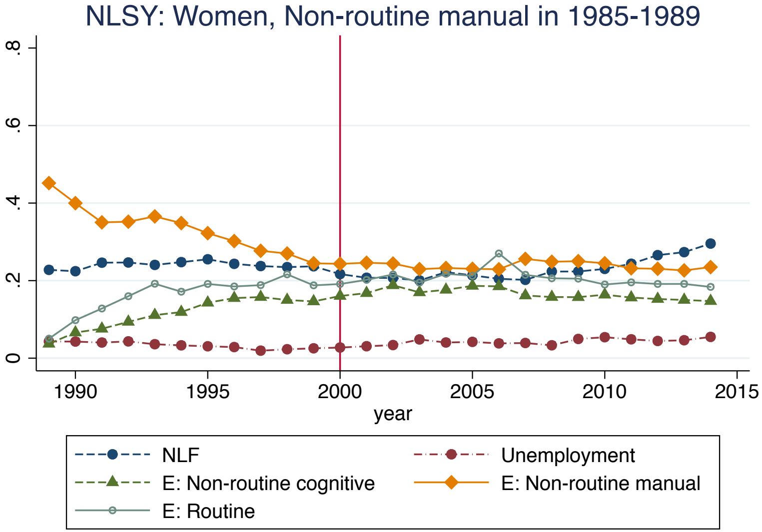
The Evolution of Employment Choices: Women



The Evolution of Employment Choices: Women



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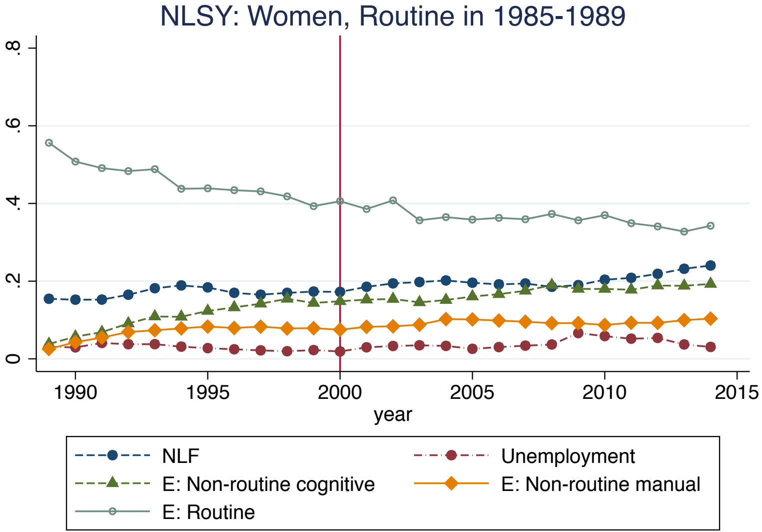
The Evolution of Employment Choices: Women



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The Evolution of Employment Choices: Women

	To starting occ 1989 → 2000	To starting occ 2000 → 2015
NRM	-46.1%	-3.4%
NRC	-19.3%	-9.7%
R	-27.0%	-15.6%
	To NLF 1989 → 2000	**To NLF 2000 → 2015**
NRM	-4.8%	36.3%
NRC	32.9%	40.1%
R	11.4%	39.4%
	To NRM 1989 → 2000	**To NRM 2000 → 2015**
NRM	-46.1%	-3.4%
NRC	219%	10.1%
R	195%	38.1%

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The Evolution of Employment Choices (levels): Women

	To starting occ	To starting occ
	1989 → 2000	2000 → 2015
NRM	-20.8%	-0.8%
NRC	-13.7%	-5.6%
R	-15.0%	-6.3%
	To NLF	To NLF
	1989 → 2000	2000 → 2015
NRM	-1.1%	7.9%
NRC	3.5%	5.7%
R	1.8%	6.8%
	To NRM	To NRM
	1989 → 2000	2000 → 2015
NRM	-20.8%	-0.8%
NRC	3.3%	0.5%
R	5.0%	2.9%

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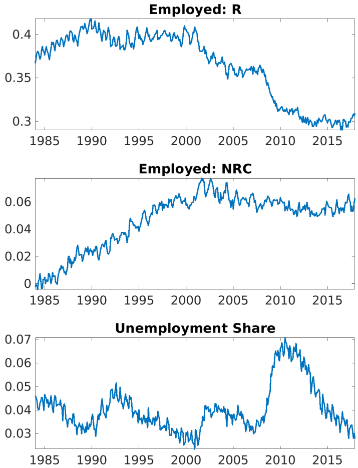
Non-NRC type Women



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Construction of Steady State Equilibrium

Productivity cutoffs

$$V_{u,\varepsilon_R} = \frac{(f_R \times P_R \times \varepsilon_R)^{1-\sigma}}{1-\beta} \times \daleth_R$$

$$V_{u,\varepsilon_{NRM}} = \frac{(f_{NRM} \times P_{NRM} \times \varepsilon_{NRM})^{1-\sigma}}{1-\beta} \times \daleth_{NRM}$$

Imply a linear relation of the cutoff everywhere in the domain:

$$\hat{\varepsilon}_{NRM}(\varepsilon_R) = \underbrace{\left(\frac{\daleth_R}{\daleth_{NRM}}\right)^{\frac{1}{1-\sigma}} \frac{f_R P_R}{f_{NRM} P_{NRM}}}_{\text{The "slope" of the diagonal}} \times \varepsilon_R$$

Construction of Steady State Equilibrium

Productivity cutoffs

$$V_{u,\varepsilon_R} = \frac{(f_R \times P_R \times \varepsilon_R)^{1-\sigma}}{1-\beta} \times \daleth_R$$

$$V_{u,\varepsilon_{NRM}} = \frac{(f_{NRM} \times P_{NRM} \times \varepsilon_{NRM})^{1-\sigma}}{1-\beta} \times \daleth_{NRM}$$

Imply a linear relation of the cutoff everywhere in the domain:

$$\hat{\varepsilon}_{NRM}(\varepsilon_R) = \underbrace{\left(\frac{\daleth_R}{\daleth_{NRM}}\right)^{\frac{1}{1-\sigma}} \frac{f_R P_R}{f_{NRM} P_{NRM}}}_{\text{The "slope" of the diagonal}} \times \varepsilon_R$$

Technically important: to solve for the GE, required to integrate over the probability distribution of ability.

Given that (i) the integral bounds are linear and that (ii) the tightness ratios are stationary: solve for the GE allocations and welfare in closed form even with curvature in utility, curvature in production function, and frictions in the labor market

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Symmetric stationary equilibrium

Given the various productivities, relative prices of ICT and NICT capital, the different parameters values, replacement ratios, income taxes, distributions of workers productivities, and measures of population, a symmetric stationary equilibrium with Nash bargaining is a collection of:

1. Prices of intermediate goods: P_{NRC}, P_R, P_{NRM}
2. Wages: ω_{NRC}, $\omega_{R,\varepsilon}$, $\omega_{NRM,\varepsilon}$
3. Tightness ratios: $\theta_{R,\varepsilon}$, $\theta_{NRM,\varepsilon}$
4. Price for claims on equity p
5. Consumption of workers
6. Demand for claims on equity
7. Employment of workers by sector and type
8. Quantities produced by intermediate goods producers
9. Quantities of intermediate goods demanded by the final good producer
10. Investment in Physical capital and ICT Capital

Symmetric stationary equilibrium cont.

s.t.:

1. Vacancy choices solve the intermediate producers dynamic problem
2. The demand for intermediate goods and the accumulation of K and X_A solve the final good producer dynamic problem
3. The demand for consumption and claims on equity solve the workers' dynamic problem
4. The value of entry is zero in all markets (free entry)
5. The market for each intermediate good clears
6. The market for final good clears (i.e. demands for consumption and investment equal supply)
7. Wages solve the Nash bargaining problem
8. The government's budget is balanced
9. Equity is held entirely by NRC workers
10. Workers optimally choose occupation and LF

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Solution, Calibration and Identification

Ability distribution parameters parameters: No need to solve the economic model!

- 2 std
  - Given std guesses, target within NNRC initial allocation of R,NRM,NLF
  - Given cutoffs match the std of log wages of the truncated distribution
- $f(x,y) = \frac{1}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}} \exp\left(-\frac{1}{2(1-\rho^2)}\left[\frac{(x-\mu_X)^2}{\sigma_X^2} + \frac{(y-\mu_Y)^2}{\sigma_Y^2} - \frac{2\rho(x-\mu_X)(y-\mu_Y)}{\sigma_X\sigma_Y}\right]\right)$
- $NLF = mvncdf\left(\begin{array}{c} x^* \\ y^* \end{array}, \begin{array}{c} \mu_X \\ \mu_Y \end{array}, \Sigma\right), x^* = \varepsilon^*_{R(i)}, y^* = \varepsilon^*_{NR(i)}$
- $R = (1 - Pop_{NRC}) \int_{\varepsilon^*_R}^{\infty} \int_{-\infty}^{\varepsilon_{NRM}(\varepsilon_R)} \frac{EMP_{\varepsilon_R}}{EMP_{\varepsilon_R} + UN_{\varepsilon_R}} \times \varepsilon_R \times f(\varepsilon_R, \varepsilon_{NRM}) d\varepsilon_{NRM} d\varepsilon_R$
- $NRM = (1 - Pop_{NRC}) \int_{\varepsilon^*_{NRM}}^{\infty} \int_{-\infty}^{\varepsilon_R(\varepsilon_{NRM})} \frac{UN_{\varepsilon_{NRM}}}{EMP_{\varepsilon_{NRM}} + UN_{\varepsilon_{NRM}}} \times \varepsilon_{NRM} \times f(\varepsilon_R, \varepsilon_{NRM}) d\varepsilon_R d\varepsilon_{NRM}$

Solution, Calibration and Identification

Ability distribution parameters parameters: No need to solve the economic model!

- We know that

$$W = D\varepsilon$$
$$\log W = \log D + \log \varepsilon$$
$$\log W \sim N(\mu + \log D, \sigma)$$

and note that we can express now W^* as follows:

$$W^* = D\varepsilon^*$$
$$\log W^* = \log D + \log \varepsilon^*$$

- Therefore

$$\begin{aligned} \text{Var}(\log W | \log \varepsilon > \log \varepsilon^*) &= \text{Var}(\log D + \log \varepsilon | \log \varepsilon > \log \varepsilon^*) \\ &= \text{Var}(\log \varepsilon | \log \varepsilon > \log \varepsilon^*) \end{aligned}$$

- Simple truncated variance in a bivariate log normal - solve outside of the model.

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Welfare

$$V_{\varepsilon_R} = \left[\frac{UN_{\varepsilon_R}}{EMP_{\varepsilon_R} + UN_{\varepsilon_R}} \frac{\daleth_R}{1-\beta} + \frac{EMP_{\varepsilon_R}}{EMP_{\varepsilon_R} + UN_{\varepsilon_R}} \left(\frac{\frac{\left(1-\beta(1-\mu(\theta_{\varepsilon_R}))\right)}{1-\beta} \daleth_R - \frac{b_{\varepsilon_R}^{1-\sigma}\left(1-T_{u,\varepsilon_R}\right)^{1-\sigma}}{1-\sigma}}{\beta \mu(\theta_{\varepsilon,R})} \right) \right] (f_R P_R \varepsilon_R)^{1-\sigma}$$

$$NLF^{NEW} = I\left(\varepsilon_R \leq \varepsilon_R^{*,NEW}\right) \times I\left(\varepsilon_{NRM} \leq \varepsilon_{NRM}^{*,NEW}\right)$$

$$NRM^{NEW} = I\left(log(m^{new}) + log(\varepsilon_R) \leq log(\varepsilon_2)\right) \times I\left(\varepsilon_{NRM}^{*,NEW} \leq \varepsilon_{NRM}\right)$$

$$R^{NEW} = I\left(log(m^{new}) + log(\varepsilon_R) > log(\varepsilon_2)\right) \times I\left(\varepsilon_R^{*,NEW} \leq \varepsilon_R\right)$$

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Welfare

$$\Delta_{R^{OLD} \rightarrow R^{NEW}} = \frac{P_R^{NEW}}{P_R^{OLD}}$$

$$\Delta_{R^{OLD} \rightarrow NRM^{NEW}} = F(parameters) \times \frac{P_{NRM}^{NEW} E\left(\varepsilon_{NRm}\right)^{R^{OLD} \rightarrow NRM^{NEW}}}{P_R^{OLD} E\left(\varepsilon_R\right)^{R^{OLD} \rightarrow NRM^{NEW}}}$$

$$\Delta_{R^{OLD} \rightarrow NRLF^{NEW}} = \frac{G(parameters)}{P_R^{OLD} E(\varepsilon_R)^{R^{OLD} \rightarrow NLF^{NEW}}}$$

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The Effects of Automation

Labor states and Shares	
ΔNLF (ΦNLF)	7.75 (2.57)
ΔR (ΦR)	-7.85 (-4.14)
ΔNRM (ΦNRM)	11.17 (1.57)
Emp Rate (R)	0.95
Emp Rate (NRM)	0.95
ΦLabor Share: Agg	-2.39
ΦLabor Share: R	-6.00
ΦLabor Share: NRC	3.62
ICT per R worker	
$\Delta X_A / \left(\frac{EMP_R}{EMP_R + UN_R} \times R \right)$	198
GDP and Profit Tax	
ΔGDP	11.18
ΦT_π	-2.42
Relative Wages	
$\Delta \omega_R$	-7.45
$\Delta \omega_{NRM}$	4.22

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Final Goods Production

GDP is given by

$$Y_t = Z_t K_t^{\gamma} \underbrace{\left((1-\eta) \underbrace{\left[(1-\alpha) Y_{NRC,t}^{EOS1} + \alpha \left[X_A^{\nu} + Y_{R,t}^{\nu} \right]^{\frac{EOS1}{\nu}} \right]^{\frac{EOS2}{EOS1}}}_{\Phi^{\frac{EOS2}{EOS1}}} + \eta Y_{NRM,t}^{EOS2} \right)^{\frac{1-\gamma}{EOS2}}}_{\Omega^{\frac{1-\gamma}{EOS2}}}$$

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Final good production

$$\pi = \left\{ \begin{array}{c} Y - P_R Y_R - P_{NRM} Y_{NRM} - P_{NRC} Y_{NRC} \\ \\ -\left[\phi_A \left(X_A' - (1-\delta_A) X_A\right) + \phi_K \left(K' - (1-\delta_K) K\right)\right] \\ \\ \end{array} \right\}$$

$$V(K, X_A, \Lambda) = \max_{K', X_A', Y_R, Y_{NRM}, Y_{NRC}} \left\{ (1 - T_\pi)\pi + \mathbb{E}\left[\Theta V\left(K', X_A', \Lambda'\right)\right] \right\}$$

where:

- T_π is a tax rate on firms' profits
- Θ is the stochastic discount factor
- $\Lambda =$ Agg. variables that determine in GE the return $= \{\phi_K, \phi_A, Z, T_\pi, Y_R, Y_{NRM}, Y_{NRC}\}$

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Final good production: Investment

- The firm chooses the optimal accumulation of physical and ICT capital in accordance with two (standard) Euler equations that equalize current cost and future returns:

$$\phi_K = \mathbb{E}\left[\Theta \times \left(MPK' + (1-\delta)\phi_K'\right)\right]$$

$$\phi_A = \mathbb{E}\left[\Theta \times \left(MPA' + (1-\delta)\phi_A'\right)\right]$$

  where MPK and MPA denote the marginal products of the two types of capital.
- **Important:** degree of adoption of ICT is **endogenous** in a GE model
- Responds to shocks and policy $\rightarrow$ affects R

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Economists (NRC) are boring

- An exogenously determined fraction of workers are NRC, who participate in a frictionless labor market and receive a market wage that is equal to their marginal revenue product.
- Separable utility with Frisch labor supply of estimated education group (0.5).

Intermediate producers

- Free entry into the production of intermediate goods with each of the two labor production inputs.
- Each potential intermediate good producer maximizes its profits by deciding:
  1. Whether to enter
  2. Where to enter
- Equilibrium is achieved such that in all distinct "intermediate goods" markets values of entry are zero.

Intermediate producers: Routine (NRM is Similar)

- Recall: on workers side, there is heterogeneity in the productivity of those who become R workers.
- Assume markets are segmented by productivities.
  - In each "sub-market" ε_R: free entry of intermediate producers
- Search-and-matching model for each ε_R labor market:
  - Firms post type specific vacancies v_{ε_R}
  - Cost κ_{ε_R} per vacancy
  - $\theta_{\varepsilon_R} = \frac{v_{\varepsilon_R}}{u_{\varepsilon_R}}$: determines matching probabilities as is common in the Diamond-Mortensen-Pissarides framework.
  - Matches separate with exogenous prob. δ_R
- Once matched produce $f_R \times \varepsilon_R$ units; sell to final good producer at price P_R
- Pay a bargained wage ω_{R,ε_R}

Routine Intermediate producers: Optimality Condition

- Intermediate R producer solves

$$J(x_{R,\varepsilon_R},\Lambda) = \max_{x'_{R,\varepsilon_R}} \left\{ \begin{array}{c} (1-T_\pi)\left[x_{R,\varepsilon_R}\left(f_R \times \varepsilon_R \times P_R - \omega_{R,\varepsilon_R}\right) - \kappa_{R,\varepsilon_R} v_{R\varepsilon_R}\right] \\ +E\left[\Theta \times J\left(x'_{R,\varepsilon_R},\Lambda'\right)\right] \end{array} \right\}$$

$$\text{s.t.: } x'_{R,\varepsilon_R} = (1-\delta_R)\, x_{R,\varepsilon_R} + v_{R,\varepsilon_R}\, q\left(\theta_{R,\varepsilon_R}\right)$$

- Resulting with the optimality condition

$$\frac{\kappa_{R,\varepsilon_R}}{q\left(\theta_{R,\varepsilon_R}\right)} = E\left[\Theta\left[f_R \times \varepsilon_R \times P_R - \omega_{R,\varepsilon_R} + (1-\delta_R)\frac{\kappa_{R,\varepsilon_R}}{q\left(\theta'_{R,\varepsilon_R}\right)}\right]\right]$$

Value Functions: a worker with $\varepsilon_R, \varepsilon_{NR}$

$$V_{e,R,\varepsilon}(\Lambda) =$$

$$\max_{C_{e,R,\varepsilon}} \left\{ \begin{array}{l} U(C_{e,R,\varepsilon}) + \beta(1-\delta_R) \times \\ E\left[\max\left\{V_{e,R,\varepsilon}(\Lambda'), V_{u,R,\varepsilon}(,\Lambda'), V_{u,NRM,\varepsilon}(\Lambda'), V_{o,\varepsilon}(\Lambda')\right\}\right] + \\ \beta\delta_R \times E\left[\max\left\{V_{u,R,\varepsilon}(\Lambda'), V_{u,NRM,\varepsilon}(\Lambda'), V_{o,\varepsilon}(\Lambda')\right\}\right] \end{array} \right\}$$

$$\text{s.t.}: \; C_{e,R,\varepsilon} = \omega_{R,\varepsilon}(1 - T_{e,R,\varepsilon})$$

$$V_{u,R,\varepsilon}(\Lambda) =$$

$$\max_{C_{u,R,\varepsilon},} \left\{ \begin{array}{l} U(C_{u,R,\varepsilon}) + \beta\mu(\theta_{R,\varepsilon}) \times \\ E\left[\max\left\{V_{e,R,\varepsilon}(,\Lambda'), V_{u,R,\varepsilon}(\Lambda'), V_{u,NRM,\varepsilon}(\Lambda'), V_{o,\varepsilon}(\Lambda')\right\}\right] \qquad + \\ \beta(1-\mu(\theta_{R,\varepsilon}))\, E\left[\max\left\{V_{u,R,\varepsilon}(\Lambda'), V_{u,NRM,\varepsilon}(,\Lambda'), V_{o,\varepsilon}(,\Lambda')\right\}\right] \end{array} \right\}$$

$$\text{s.t.}: \; C_{u,R,\varepsilon} = b_{R,\varepsilon} \times \omega_{R,\varepsilon} \times (1 - T_{u,R,\varepsilon})$$

$$V_{o,\varepsilon}(\Lambda) = \max_{C_{o,\varepsilon}} \left\{ U(C_{o,\varepsilon}) + \beta E\left[\max\left\{V_{u,\varepsilon,R}(\Lambda'), V_{u,\varepsilon,NRM}(\Lambda'), V_{o,\varepsilon}(\Lambda')\right\}\right]\right\}$$

$$\text{s.t.}: \; C_{o,\varepsilon} = b_{o,\varepsilon}$$

Wage Bargaining

Wages split match surplus according to Nash bargaining ($\tau =$ worker's bargaining power):

$$\max_{\omega_{R,\varepsilon_R}} \left(\tilde{V}_{R,\varepsilon}(\Lambda)\right)^{\tau} \left(\frac{\partial J\left(x_{R,\varepsilon_R},\Lambda\right)}{\partial x_{R,\varepsilon_R}}\right)^{1-\tau}$$

where

$$\tilde{V}_{R,\varepsilon}(\Lambda) = V_{e,R,\varepsilon}(\Lambda) - V_{u,R,\varepsilon}(\Lambda)$$

$$V_{u,R,\varepsilon}(\Lambda) = \max\left\{V_{u,R,\varepsilon}(\Lambda), V_{u,NRM,\varepsilon}(\Lambda), V_{o,\varepsilon}(\Lambda)\right\}$$

$\rightarrow$ the wage function:

$$\begin{aligned} \omega_{R,\varepsilon_R} &= f_R \times \varepsilon_R \times P_R \\ &- \frac{1-\tau}{\tau} \frac{U\left(C_{e,R,\varepsilon}\right) - U\left(C_{u,R,\varepsilon}\right)}{U'\left(C_{e,R,\varepsilon}\right)\left(1-T_{e,R,\varepsilon}\right) - U'\left(C_{u,R,\varepsilon}\right)\left(1-T_{u,R,\varepsilon}\right) b_{R,\varepsilon}} + \theta_{R,\varepsilon_R}\kappa_{R,\varepsilon_R} \end{aligned}$$

Government Budget Constraint

$$NLF \times b_o + UI_{NRM} + UI_R$$
$$= Rev_R + Rev_{NRM} + Rev_{NRC} + Rev_{\pi} + Rev_{\pi_R} + Rev_{\pi_{NRM}}$$

Where, for example:

$$UI_R = (1 - Pop_{NRC}) \times$$
$$\int_{\varepsilon_R^*}^{\infty} \int_{-\infty}^{\varepsilon_{NRM}(\varepsilon_R)} \frac{UN_{\varepsilon_R}}{EMP_{\varepsilon_R} + UN_{\varepsilon_R}} \times b \times \omega(\varepsilon_R) \times f(\varepsilon_R, \varepsilon_{NRM}) d\varepsilon_{NRM} d\varepsilon_R$$

$$Rev_R = (1 - Pop_{NRC}) \times$$
$$\int_{\varepsilon_R^*}^{\infty} \int_{-\infty}^{\varepsilon_{NRM}(\varepsilon_R)} \frac{EMP_{\varepsilon_R}}{EMP_{\varepsilon_R} + UN_{\varepsilon_R}} \times T_{\varepsilon_R} \times \omega(\varepsilon_R) \times f(\varepsilon_R, \varepsilon_{NRM}) d\varepsilon_{NRM} d\varepsilon_R$$

and similarly for UI_{NRM} etc...

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Moments to Remember

	Data	Model	Relevant Parameters
First Moments : Targeted			
Aggregate Labor Share	0.629	0.629	$\alpha, \eta, F_R, \tau_R$
Routine Labor Share	0.30	0.30	$\alpha, \eta, F_R, \tau_R$
ICT Share	0.029	0.029	$\alpha, \eta, F_R, \tau_R$
Indifference Condition	Consistency		$\alpha, \eta, F_R, \tau_R$
Second Moments : Targeted			
Change in ratio of $\frac{X_A}{E_R}$	7.14	7.14	$v, EOS_1, \Delta\phi_A$
Fraction of ΔR: NLF	0.63	0.63	$v, EOS_1, \Delta\phi_A$
$\frac{\phi_A^{\mathbf{2017}}}{\phi_A^{\mathbf{1989}}}$	0.324	0.324	$v, EOS_1, \Delta\phi_A$

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