Skills, Tasks and Technologies

Beyond the Canonical Model

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Skills, Tasks and Technologies:

Beyond the Canonical Model

- *Canonical model* — Elegantly, powerfully operationalizes supply and demand for skills
  - A formalization of Tinbergen's "Education Race" analogy
  - Two distinct skill groups that perform two different and imperfectly substitutable tasks.
  - Technology is *factor-augmenting*—Always raises productivity/wages
- Model is a theoretical and empirical success
  - Katz and Murphy (1992), Card and Lemieux (2001), Autor, Acemoglu and Lyle (2004), Goldin and Katz (2008), Carneiro and Lee (2009).

Beyond the Canonical Model of Skills and Wages

- But model largely silent on some *central empirical facts* of last three decades:
  1. Falling real wages of low-skill workers (at least in U.S.)
  2. Non-monotone shifts in inequality, despite rising 'return to skill'
  3. Widespread 'polarization' of employment across advanced economies
  4. Directly skill-*replacing* (not augmenting) technologies

- *Needed:* Model with richer interplay btwn skills, tasks, technologies
  1. Distinguish between 'skills' and 'tasks'
  2. Endogenize assignment of skills to tasks: Comparative advantage
  3. Direct competition btwn skills, techs, trade in performing tasks
  4. Nest canonical model as one possible case

Beyond the Canonical Model of Skills and Wages

Outline

1. The canonical model: Implications and empirical successes
2. Where the canonical model falls short
3. What should an amended model offer?
4. A Ricardian model of skills, tasks and technologies
5. Some potential empirical directions
6. Conclusions

The Canonical Model

- Basic assumptions
  1. Two skills, high and low: H, L. Typically college v. high school
  2. No distinction between skills and 'tasks'—Skill is direct input into production
  3. H and L are imperfect productive substitutes: $\sigma > 0$.
  4. Wages are set on the demand curve
- Canonical representation

$$Y = \left[(A_L L)^{\frac{\sigma-1}{\sigma}} + (A_H H)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

  where A_L and A_H are factor-augmenting technology terms.
- Elasticity of substitution plays key role
  - $\sigma > 1$: H and L are gross substitutes. Rise in A_H/A_L is SBTC
  - $\sigma < 1$: H and L are gross complements. *Fall* in A_H/A_L is SBTC

The Canonical Model

- Skill premium

$$\ln\left(\frac{W_H}{W_L}\right) = \frac{\sigma-1}{\sigma}\ln\left(\frac{A_H}{A_L}\right) - \frac{1}{\sigma}\ln\left(\frac{H}{L}\right).$$

- Supply and demand visible
  1. $\ln(H/L)$ represents position of supply curve
  2. $\frac{\sigma-1}{\sigma}\ln\left(\frac{A_H}{A_L}\right)$ represents position of demand curve
  3. Impact of supply on wage inequality

$$\frac{\partial \ln(W_H/W_L)}{\partial \ln(H/L)} = -\frac{1}{\sigma}$$

  4. Impact of factor tech Δ on wage inequality

$$\frac{\partial \ln(W_H/W_L)}{\partial \ln(A_H/A_L)} = \frac{\sigma-1}{\sigma} > 0 \text{ iff } \sigma > 1$$

Consensus is that $\sigma \in (1.4, 2.5)$, so technology that raises relative output of H also raises its relative wage.

The Canonical Model

Some key testable predictions

1. Rise in supply of H/L reduces skilled wage differential
   - $\partial \ln (w_H / w_L) / \partial \ln (H/L) = -1/\sigma < 0$
2. Rise in supply of H/L also *raises* real wage of L: $\partial w_L / \partial H/L > 0$
   - This follows from imperfect substitutability between H and L.
3. Factor augmenting tech Δ always raises wages of L workers: $\partial W_L / \partial A_L > 0$ and $\partial W_L / \partial A_H > 0$.
   - This also follows from imperfect substitutability.
4. *Predictions of this model are always monotone in skill*
   - A bit tautological since there are only two skills/wages
   - But assume a continuum of efficiencies in ea. skill group: still true
   - *Loosely:* Wage inequality is either rising or falling in this model, *not both*

The Canonical Model: Implementation

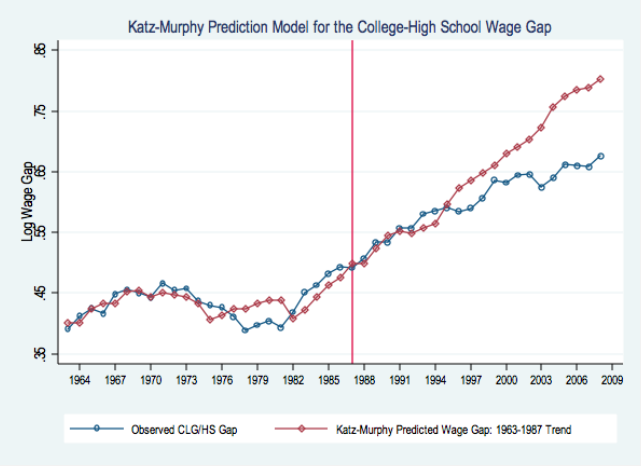
- The two-factor model famously applied by Katz and Murphy (1992):
  - Used data from 1963 through 1987, fit by OLS

$$\ln\left(\frac{W_H}{W_L}\right) = \frac{\sigma-1}{\sigma}\gamma_0 + \frac{\sigma-1}{\sigma}\gamma_1 t - \gamma_2 \ln\left(\frac{H_t}{L_t}\right)$$

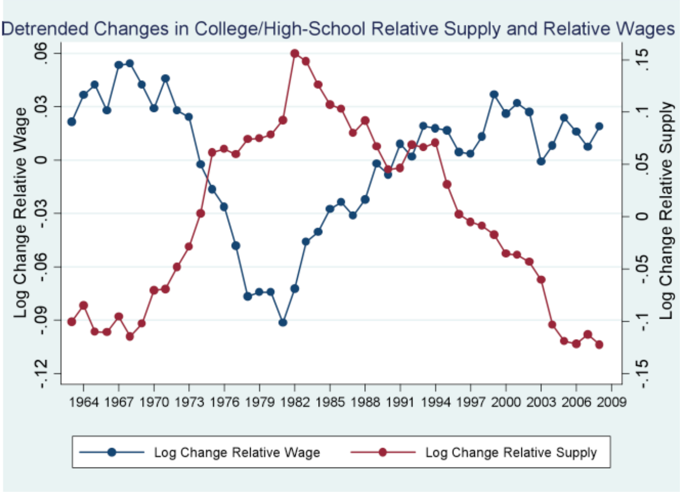
  - Replicating their approach, we get

$$\ln\left(\frac{W_H}{W_L}\right) = \underset{(0.005)}{0.027 \times t} \quad \underset{(0.128)}{-0.612} \cdot \ln\left(\frac{H_t}{L_t}\right)$$

- This estimate implies
  1. Log relative demand for College/Non-College rising at 2.7 log points annually
  2. Elasticity of substitution $\hat{\sigma} = 1/\hat{\gamma}_2 \approx 1.6$
- You can see how well this works in the next figure...


Katz-Murphy Prediction Model for the College-High School Wage Gap
Log Wage Gap
.35
.45
.55
.65
.75
.85
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
Observed CLG/HS Gap
Katz-Murphy Predicted Wage Gap: 1963-1987 Trend

The Canonical Model: Easy to See Why K-M Model Fits!

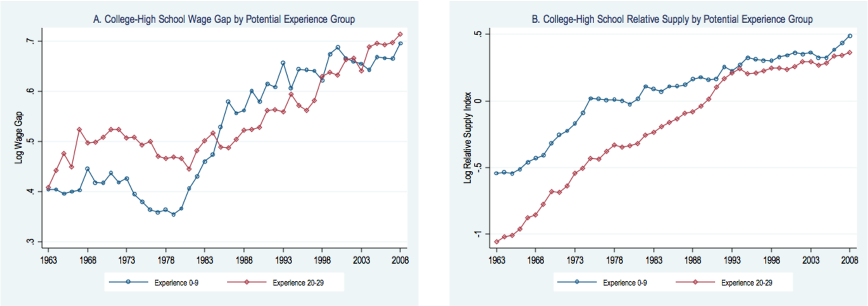


The Canonical Model: Many more Successes

1. Katz and Goldin (2008): Fit to data for 1915 – 2006
2. Carneiro and Lee (2009): Fit to data for U.S. regions
3. Card and Lemieux (2001):
    - Fit to data for three countries: U.S., U.K., Canada
    - Allow for imperfect substitutability among age cohorts
    - Explain cross-country variation in timing of rise of college premium *and* within-country variation in magnitude of rise in premium by age groups within countries.
    - See also Fitzenberger and Kohn (2006) for German application.

The Canonical Model

Explaining the College Premium by Experience Group



Beyond the ‘Canonical Model’ of Skills and Wages

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2. *Where the canonical model falls short*
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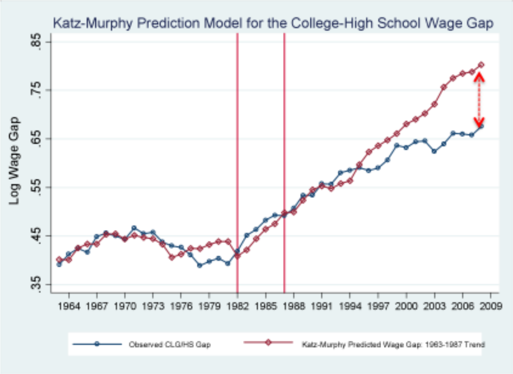
Where the Canonical Model is Silent (or Mis-speaks)

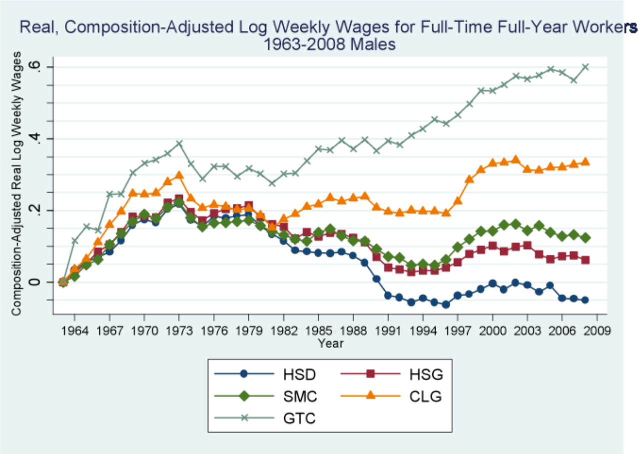
1. Wage inequality rises less than predicted
2. *Real wage levels fall* for some groups
3. Wage changes non-monotone in skill
4. Polarization of employment growth across high/low-skill occupations (also non-monotone)
5. Rising importance of *occupation* as a predictor of earnings
6. Casual empiricism only
   - Directly skill-replacing technologies commonplace
   - Offshoring may function like a skill-replacing technology

Wage Inequality Rises by Much Less than Predicted



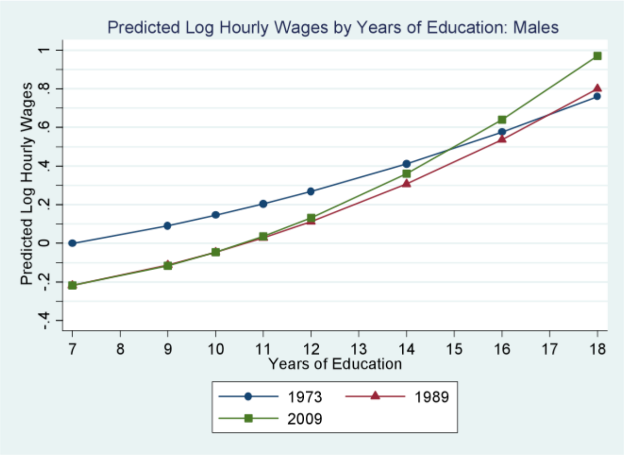
- College premium rose by 12 points between 1992 and 2008. Model predicts a *rise* of 25 log points!
- Model implies demand *decelerated* after 1992 or elasticity (σ) rose

Real wage levels fall for low-education males

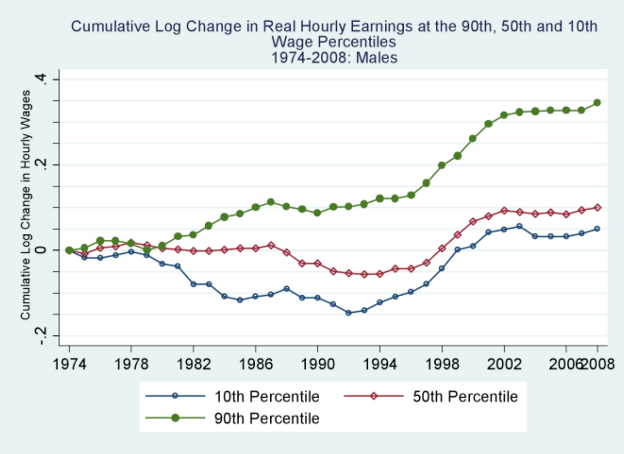


Generates a 'Convexification' of Return to Education

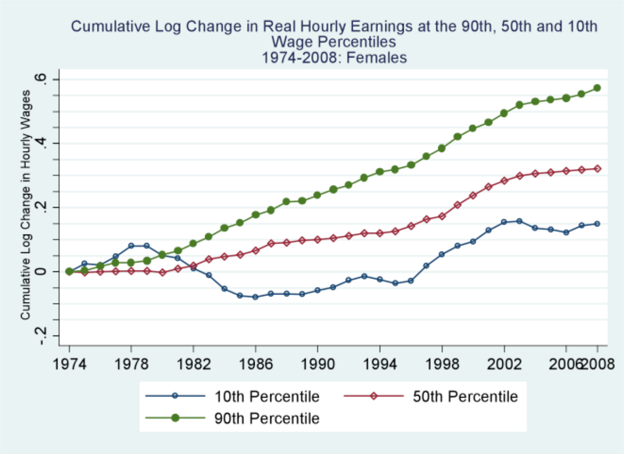
See Lemieux (2006)



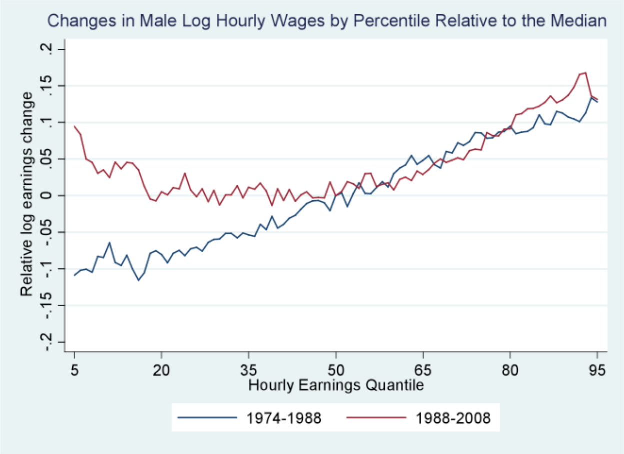
Wage changes non-monotone: Male indexed 90/50/10



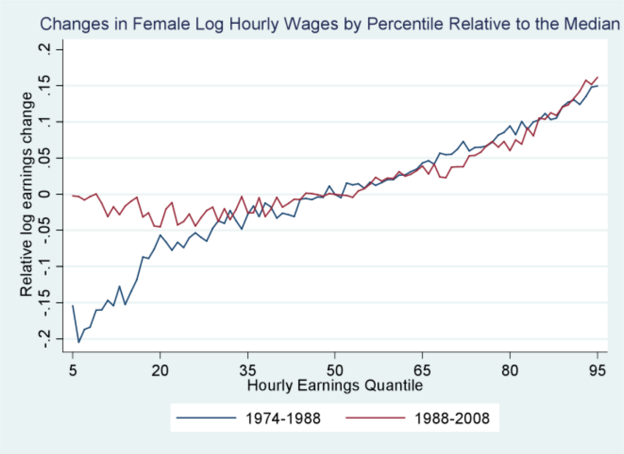
Wage changes non-monotone: Female indexed 90/50/10



Non-monotone wage changes: Males full distribution

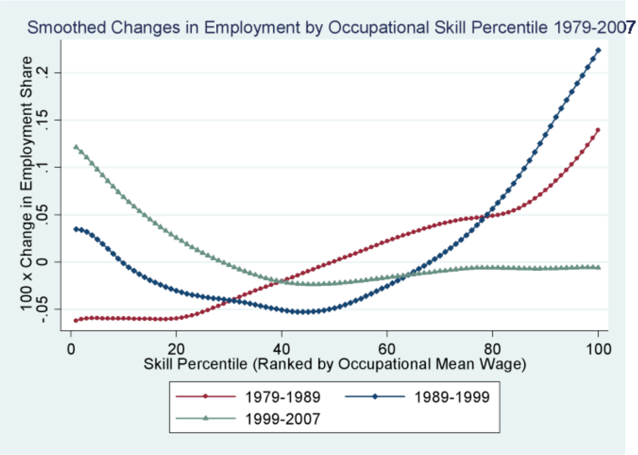


Non-monotone wage changes: Females full distribution

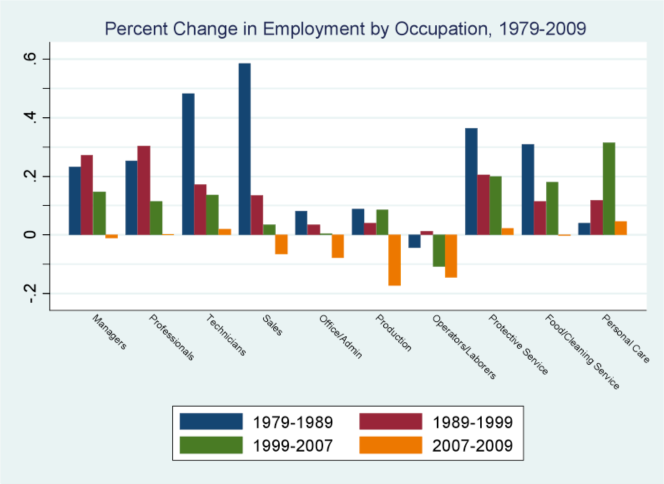


Polarization of Emp. Growth by Occupational Skill

Monotone in 1980s, Concentrated in Tails in 1990s and 2000s

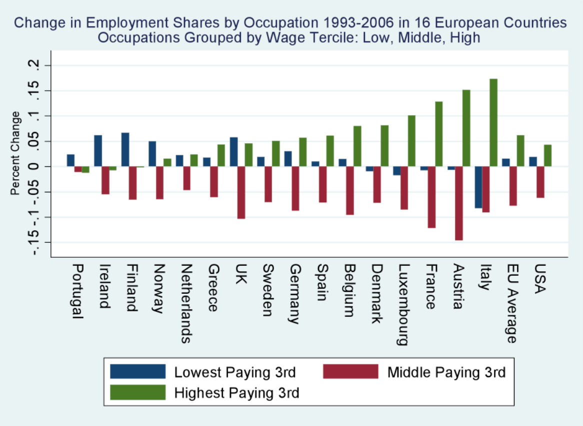


Polarization of Emp Growth by Occupational Skill



Polarization of Emp Growth by Occupational Skill

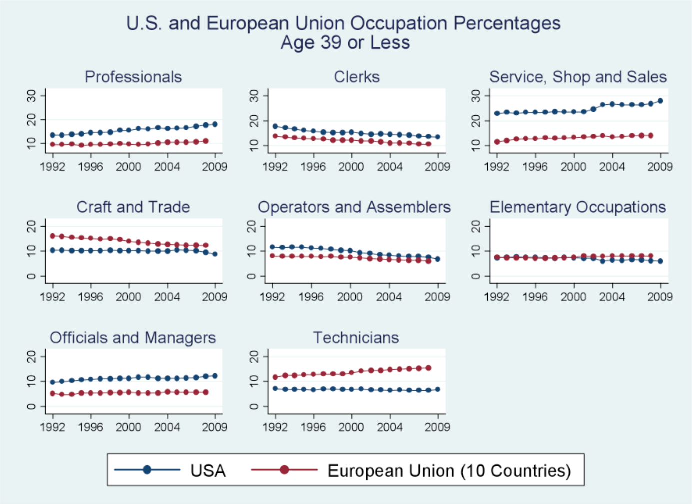
Harmonized European LFS Data from Goos, Manning and Salomons (2009)



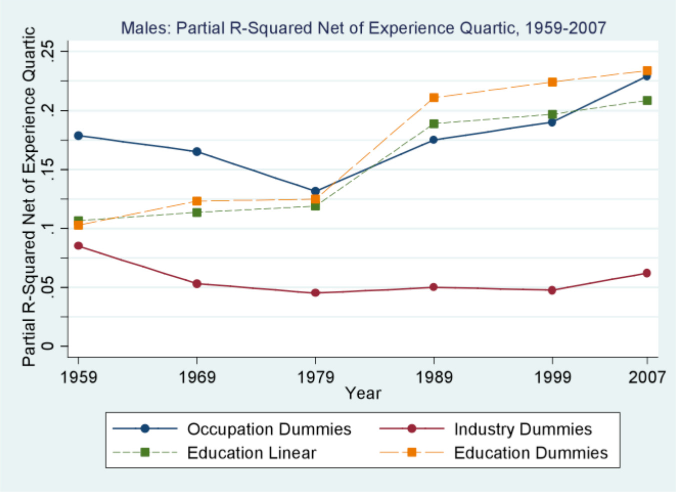
- See also Dustmann, Ludsteck and Schonberg (2009), *QJE*

Polarization of Emp Growth by Occupational Skill

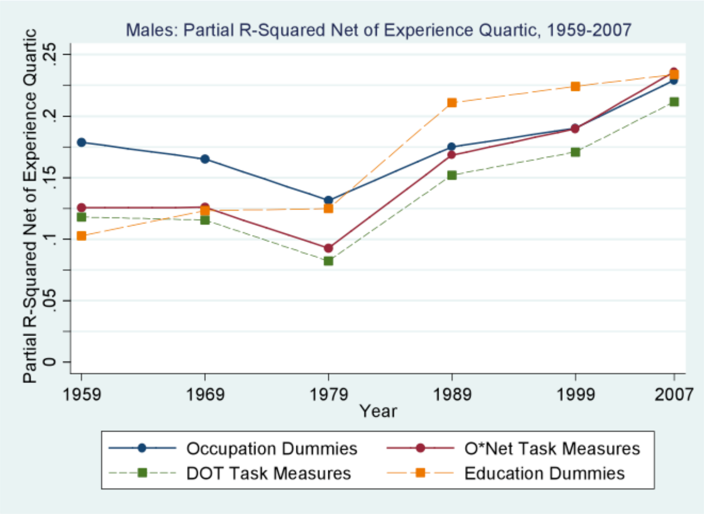
U.S. + Eurostat Data: 10 Countries, 1992-2008. Correlation(US, EU) = 0.67



Rising importance of *occupation* as a predictor of earnings



Rising importance of *job tasks* as a predictor of earnings



Where the Canonical Model is Silent (or Mis-speaks)

1. Wage inequality rises less than predicted
2. *Real wage levels fall* for some groups
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What should an amended model offer?

Objectives

1. Explicit distinction between *skills* and *tasks*
    - Tasks—Unit of work activity that produces output
    - Skill—Worker's endowment of capabilities for performing various tasks
2. Allow for *comparative advantage* among workers in different tasks
    - Assignment of skills to tasks is *endogenous* (as in Roy, 1951)
3. Allow for multiple sources of competing task 'supplies'
    - Workers of different skill levels
    - Machines—Task can be routinized/automated
    - Offshoring—As per Grossman, Rossi-Hansberg (2008)
4. Incorporate at least three skill groups—To study polarization
5. Goal: well-defined set of skill demands, as in canonical model
6. Ability to endogenize task-biased technological change

A Ricardian Model of Skills, Tasks and Technologies

- Related models
  - Heckman and Scheinkman (1987)
  - Acemoglu and Zilibotti (2001)
  - Autor, Levy and Murnane (2003)
  - Gibbons, Katz, Lemieux, Parent (2005)
  - Grossman and Rossi-Hansberg (2008)
  - Autor and Dorn (2009)
  - Goos, Manning and Salomons (2009)
  - Costinot and Vogel (2010)
- Our model is *less* general than Costinot and Vogel, but quite broadly applicable (we think)

A Ricardian Model of Skills, Tasks and Technologies

Production technology: Tasks into goods

- Static environment with a unique final good, Y
- Y produced with continuum of *tasks* on the unit interval, $[0, 1]$
- Cobb-Douglas technology mapping tasks the final good:

$$\ln Y = \int_0^1 \ln y(i) di,$$

  where $y(i)$ is the "service" or production level of task i.
- Price of the final good, Y, is numeraire.

A Ricardian Model of Skills, Tasks and Technologies

Supply of skills to tasks

Three types of labor: High, Medium and Low

- Fixed, inelastic supply of the three types. Supplies are L, M and H
- We later introduce capital or technology (embedded in machines)

Each task on continuum has production function

$$y(i) = A_L \alpha_L(i)\, l(i) + A_M \alpha_M(i)\, m(i) + A_H \alpha_H(i)\, h(i) + A_K \alpha_K(i)\, k(i),$$

- A terms are factor-augmenting technologies
- $\alpha_L(i)$, $\alpha_M(i)$ and $\alpha_H(i)$ are *task productivity schedules*
- For example, $A_L \alpha_L(i)$ is the productivity of low skill workers in task i, and $l(i)$ is the number of low skill workers allocated task i.

A Ricardian Model of Skills, Tasks and Technologies

Role of comparative advantage

- All tasks can be performed by low, medium or high skill workers

$$y(i) = A_L \alpha_L(i)\, l(i) + A_M \alpha_M(i)\, m(i) + A_H \alpha_H(i)\, h(i) + A_K \alpha_K(i)\, k(i)$$

- *But comparative advantage by skill differs thru* $\alpha_L(i)$, $\alpha_M(i)$, $\alpha_H(i)$

Comparative advantage schedule

- **Assumption:** $\alpha_L(i)/\alpha_M(i)$ *and* $\alpha_M(i)/\alpha_H(i)$ *are continuously differentiable and strictly decreasing*
- Higher indices correspond to "more complex" tasks
- In all tasks, H has absolute advantage relative to M, M has abs. adv. relative to L
- But *comparative advantage* determines task allocations

A Ricardian Model of Skills, Tasks and Technologies

Equilibrium objects: Task thresholds, I_L, I_H

- In any equilibrium there exist I_L and I_H such that $0 < I_L < I_H < 1$ and for any $i < I_L$, $m(i) = h(i) = 0$, for any $i \in (I_L, I_H)$, $l(i) = h(i) = 0$, and for any $i > I_H$, $l(i) = m(i) = 0$

Allocation of tasks to skill groups determined by I_H, I_L

- Tasks $i > I_H$ will be performed by high skill workers (Abstract)
- Tasks $i < I_L$ will be performed by low skill workers (Manual)
- Middle tasks $I_L \leq i \leq I_H$ will be performed by medium skill workers (Routine)

Boundaries of these sets are endogenous

- Given skill supplies, firms (equivalently workers) decide which skills perform which tasks $\longrightarrow$ *Substitution of skills across tasks*.

A Ricardian Model of Skills, Tasks and Technologies

A ton of algebra happens... then, these wage equations pop out!

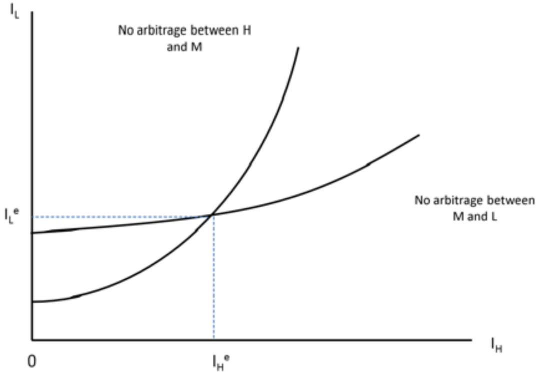
- Relative wages solely a function of labor supplies and task thresholds

$$\frac{w_H}{w_M} = \left(\frac{1-I_H}{I_H-I_L}\right)\left(\frac{H}{M}\right)^{-1},$$
$$\frac{w_M}{w_L} = \left(\frac{I_H-I_L}{I_L}\right)\left(\frac{M}{L}\right)^{-1}$$

- So, labor supplies L, M, H plus compare adv. $\alpha(L)$, $\alpha(M)$, $\alpha(L)$ determine task allocation, I_L and I_H, and hence wages.
- It's that simple!

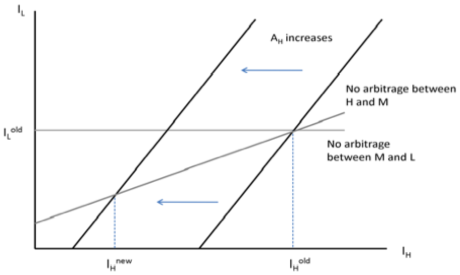
Equilibrium Task Thresholds: No Arbitrage Across Skill Groups

Figure 22. Determination of Equilibrium Threshold Tasks



Skill-Biased Technical Change: A Rise in A_H

Figure 25. Comparative Statics



- Rise in productivity of H workers broadens their task set, lowers I_H
- Squeezes M workers (excess supply of M) so I_L also falls

Some Key Comparative Statics

Consider a rise in A_H (SBTC):

- Increase share of tasks done by H
- Raises W_H / W_m and W_H / W_L
- Lowers W_M / W_L! Why? Because H and M are closer substitutes than H and L.

Consider a rise in high-skilled labor supply H :

- Increase share of tasks done by H
- *Lowers* W_H / W_m and W_H / W_L
- Lowers W_M / W_L (Rise in A_H is isomorphic to rise in H)

Identical comparative statics for rise in A_L or L.

Change in productivity or supply of middle-skill workers

Subtle effects

What happens when either M or A_M rises?

- Depends critically on this term:

$$\left|\beta_L'\left(I_L\right)I_L\right| \gtreqless \left|\beta_H'\left(I_H\right)\left(1-I_H\right)\right|$$

- Measures *comparative advantage* of L versus H workers in M tasks
- If $\beta_L'\left(I_L\right)$ is low relative to $\beta_H'\left(I_H\right)$), high skill workers have *strong comparative advantage* for tasks above I_H.

Hence, rise in M displaces L workers more than H iff:

$$\frac{d\ln\left(w_H/w_L\right)}{d\ln M} > 0 \text{ iff } \left|\beta_L'\left(I_L\right)I_L\right| < \left|\beta_H'\left(I_H\right)\left(1-I_H\right)\right|$$

- Implicitly I_L falls more than I_H rises.

How Technology Enters

Easy to model a 'task replacing technology'

- Both K and Labor can supply tasks (all are perfect substitutes)
- K will supply task if can accomplish more cheaply than L, M, or H.

Example: Routine Task Replacing technology

- Capital that out-competes M in a subset of tasks i' in the interval $I_L < i' < I_H$

Own wage effects

- Immediately lowers wage of M by narrowing set of M tasks

Cross-price effects on W_L and W_H?

- Again depend on $\left|\beta_L'(I_L)\,I_L\right| \gtreqless \left|\beta_H'(I_H)(1 - I_H)\right|$
- If M workers better suited to L than H tasks, then W_H/W_L rises

Routine Task Replacing Technology

Focal case

- Task replacing technology concentrated in middle-skill/routine tasks
- Strong comparative advantage of H relative to L at respective margins with M

Leads to wage and employment 'polarization'

1. Wages:
    - Middle wages fall relative to top and bottom.
    - Top rises relative to bottom
2. Employment:
    - Middle-skill/routine tasks mechanized
    - Declining labor input in Routine tasks
    - Given comparative advantage, middle-skill workers move disproportionately downward in task distribution.

Offshoring

Offshoring works identically to capital that competes for tasks

- In this sense, our model is like Grossman and Rossi-Hansberg (2008)
- But the comparative advantage setup here is more general (plausible)

Two further extensions

Endogenous choice of skills

- Workers can have a bundle of l, m, and h skills
- When comparative advantage of one skill sufficiently eroded, may switch skills
- Example: Former manager, now driving delivery truck

Endogenous technical change

- Endogenous tech change favoring *skills* is well understood from Acemoglu (1998, 2007)
- We also consider endogenous technical change *favoring tasks* in this model

Ricardian Model: Summary

Model's inputs

1. Explicit distinction between *skills* and *tasks*
2. Allow for *comparative advantage* among workers in different tasks
3. Allow for multiple sources of competing task 'supplies'

What the model delivers

- A natural concept of occupations (bundles of tasks)
- An endogenous mapping from skill to tasks via comparative advantage
- Technical change (offshoring) that can raise and *lower* wages
- Migration of skills across tasks as technology changes
- Polarization of wages and employment as *one possible outcome*

Where the Canonical Model is Silent (or Mis-speaks)

Can the Ricardian model rationlize these facts?

1. Wage inequality rises less than predicted
2. *Real wage levels fall* for some groups
3. Wage changes non-monotone in skill
4. Polarization of employment growth across high/low-skill occupations (also non-monotone)
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Some potential empirical directions

Some loose observations only

- Model suggests that we want to relate technical change to prices of skills via *changes in comparative advantage*
  - Measuring comparative advantage is difficult, but not impossible
  - One idea is to look at patterns of occupational specialization from 'pre-period' as a measure
- More generally, model makes conceptual link btwn skills, tasks and occupations
  - Occupations *do not really exist* in standard competitive wage models
  - Here, they do exist. But there is *still a 'law of one price' for skill*

Conclusions

Canonical model has been a huge conceptual and empirical success

- But not able to shed light on some key phenomena of interest
  - Falling real wages for some groups
  - Non-monotone wage changes
  - Polarization of employment
  - Reallocation of skill groups across occupations
  - Rising power of occupation as predictor of wages

Possible additional insights gained by

1. Distinguishing between *skills* and *tasks*
2. Allowing for *comparative advantage* among workers in different tasks
3. Allowing for multiple sources of competing task ‘supplies’