Aalto University
School of Business

Topics in Labor Economics II

Matching, Scale-of-Operations, and Superstar Effects

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Introduction

How do differences in abilities and tastes translate into wage differences?

1. How much you produce depends on who/what you produce with
   - Ability rents*
   - Scale effects (scale of operations, span of control)
   - Superstar effects
   - Matching workers with co-workers (team production)
   - Matching workers and firms/jobs
2. Compensating differentials

Introduction to Matching

In the canonical model (each type of) labor is a divisible cardinal-scale input $\rightarrow$ tendency to wage = MPL

Indivisible qualities $\leftrightarrow$ ordinal scale

How do differences in indivisible inputs translate to differences in cardinal outputs? How do ability dispersion and technological change affect wage dispersion?

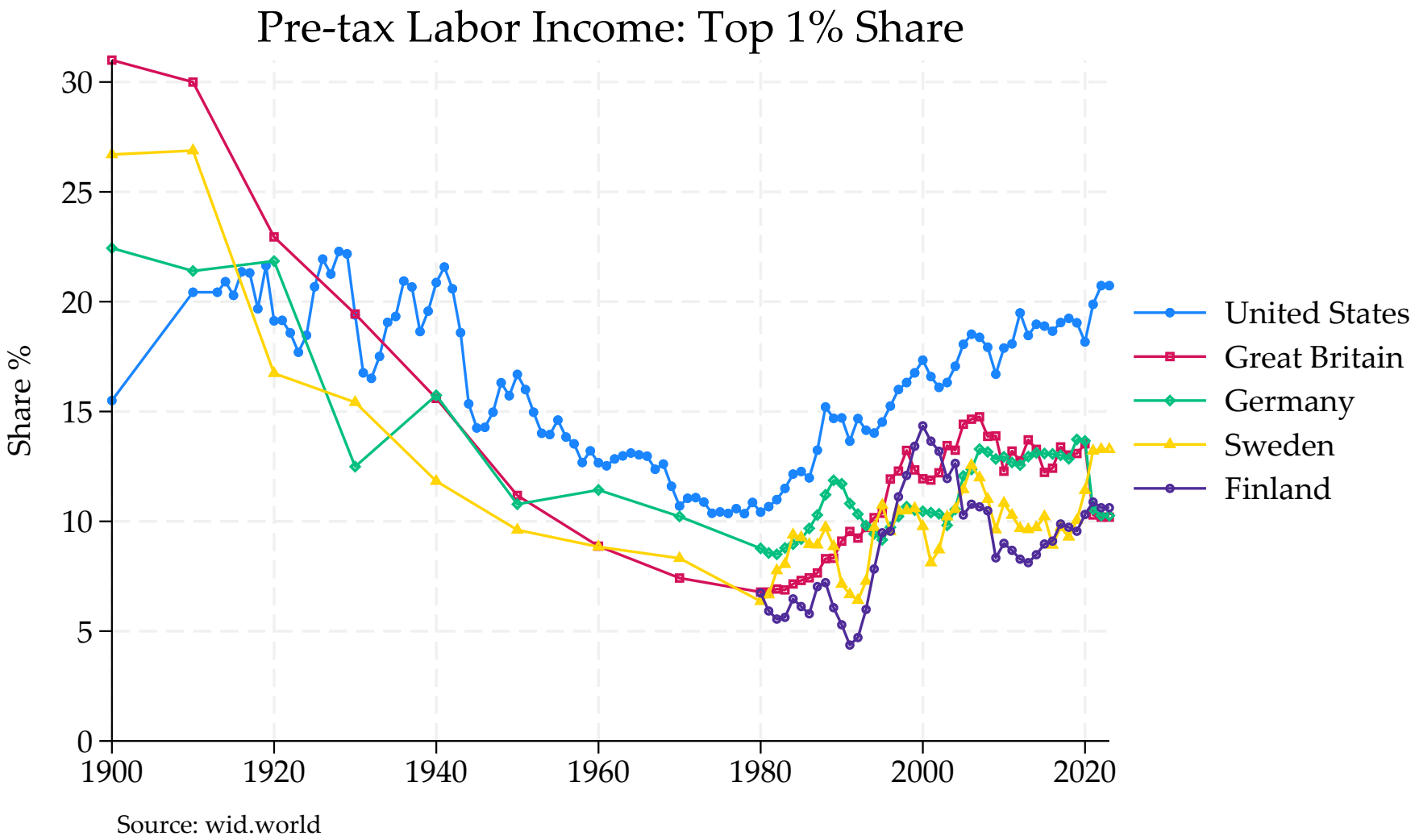
We have tractable models with results that can be understood!

One indivisible factor $\rightarrow$ Scale effects
More than one indivisible factor $\rightarrow$ Matching (aka Assignment)

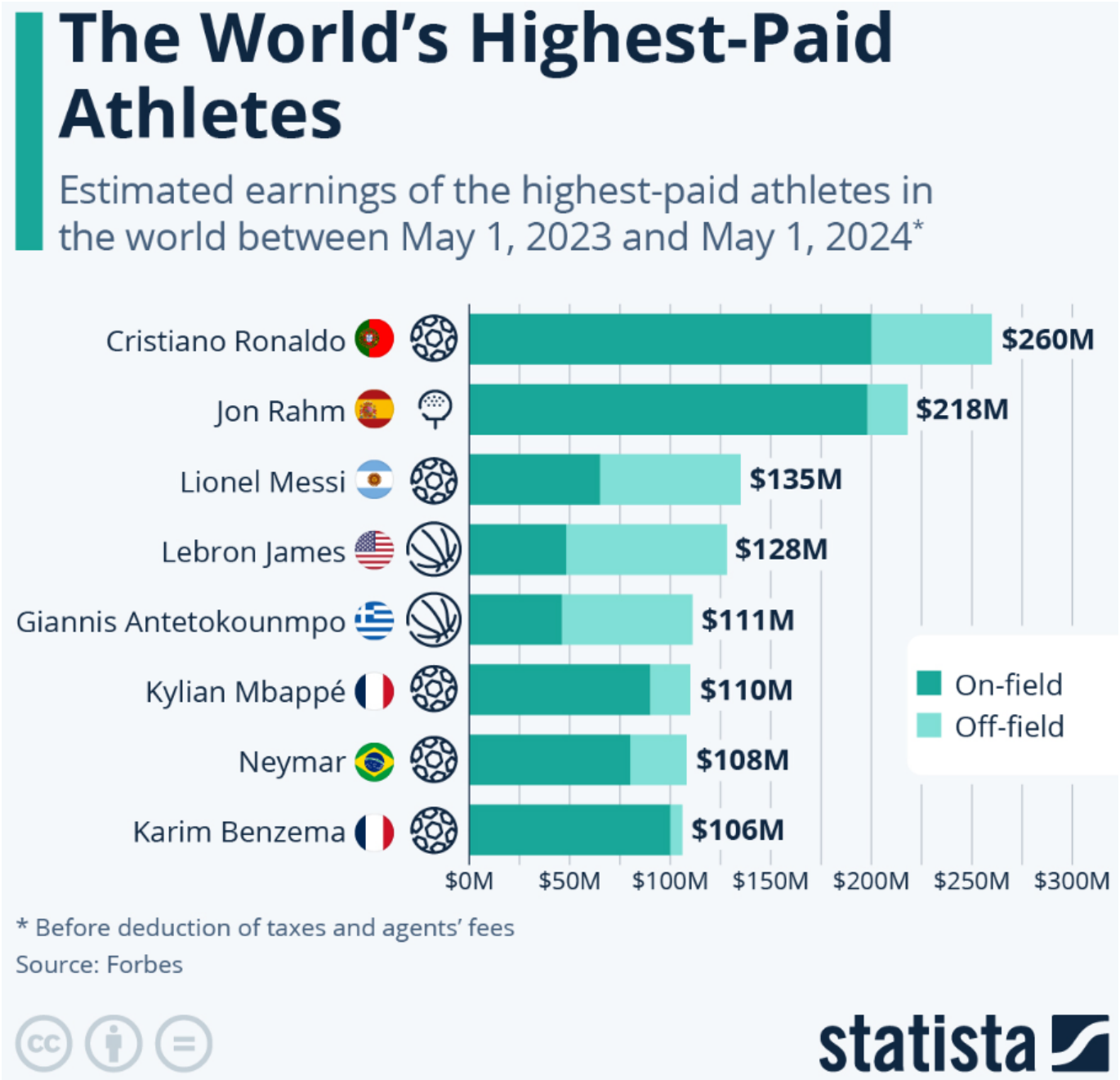
A recurring theme is winner-take-more economics. Intuitive assumptions tend to lead to right-skewed wage distributions.

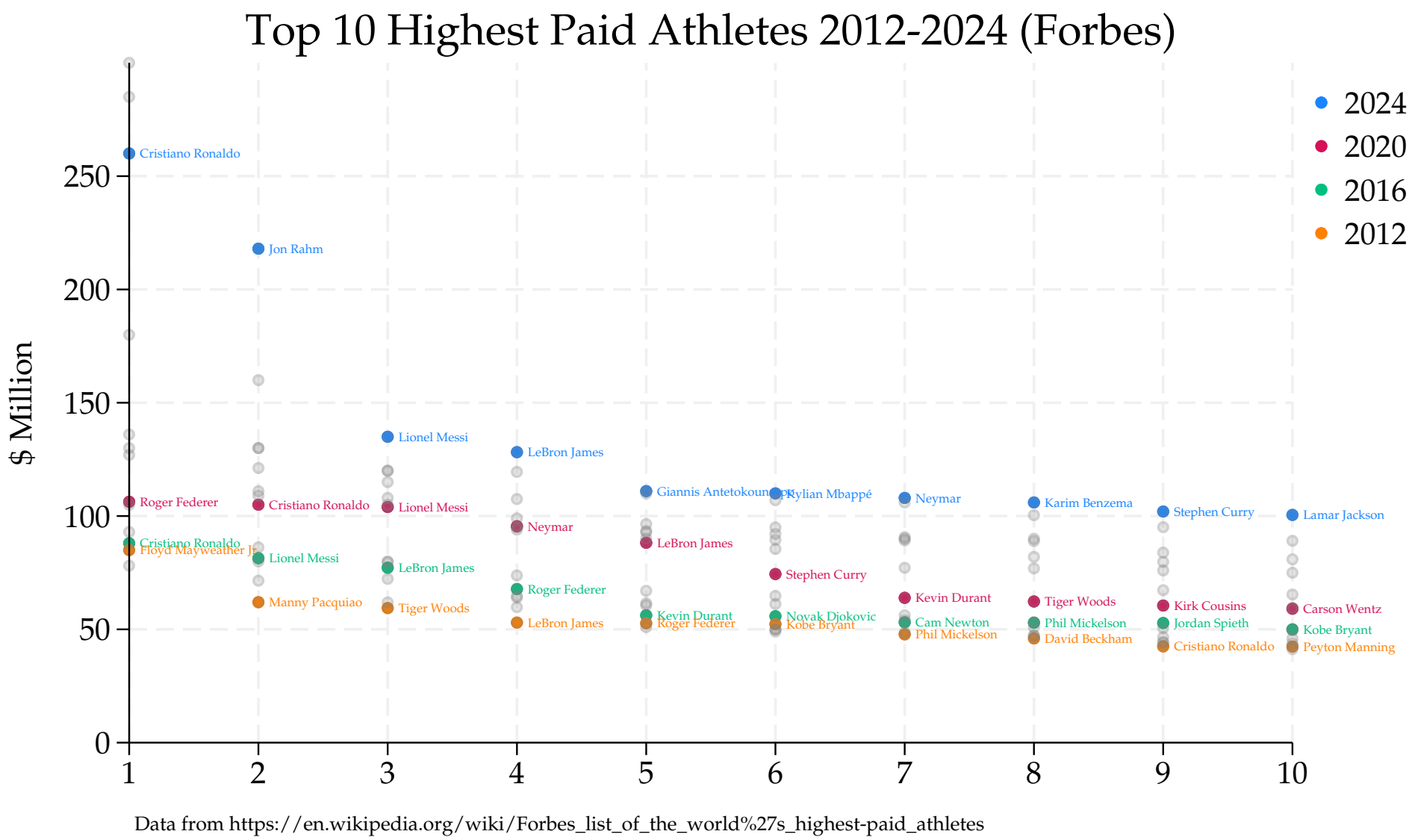
Evolution of Top 1% Labor Income Share

World Inequality Database



Source: wid.world

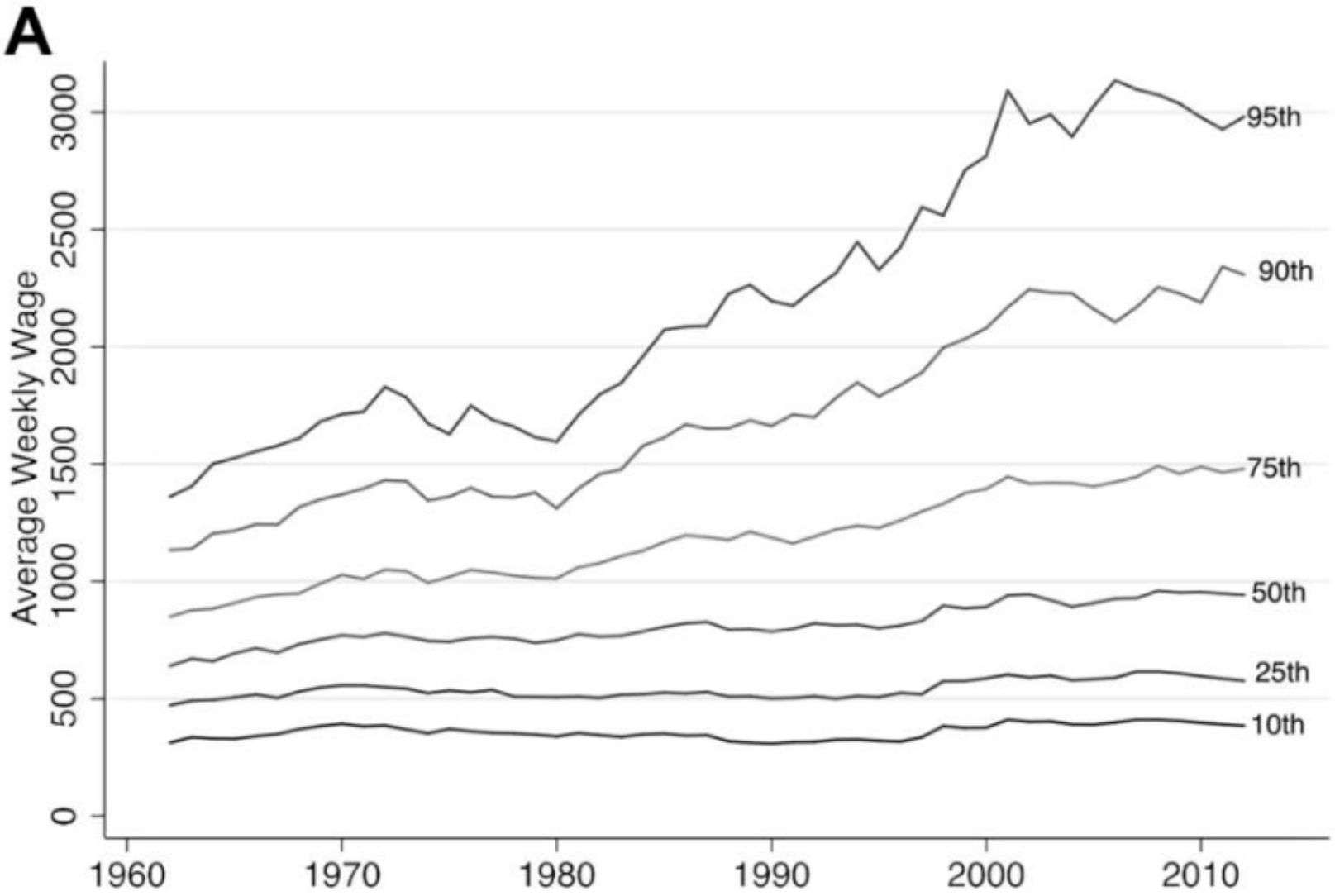

The World's Highest-Paid Athletes
Estimated earnings of the highest-paid athletes in the world between May 1, 2023 and May 1, 2024*
Cristiano Ronaldo
$260M
Jon Rahm
$218M
Lionel Messi
$135M
Lebron James
$128M
Giannis Antetokounmpo
$111M
Kylian Mbappé
$110M
Neymar
$108M
Karim Benzema
$106M
On-field
Off-field
$0M
$50M
$100M
$150M
$200M
$250M
$300M
* Before deduction of taxes and agents' fees
Source: Forbes
statista



Data from https://en.wikipedia.org/wiki/Forbes_list_of_the_world%27s_highest-paid_athletes

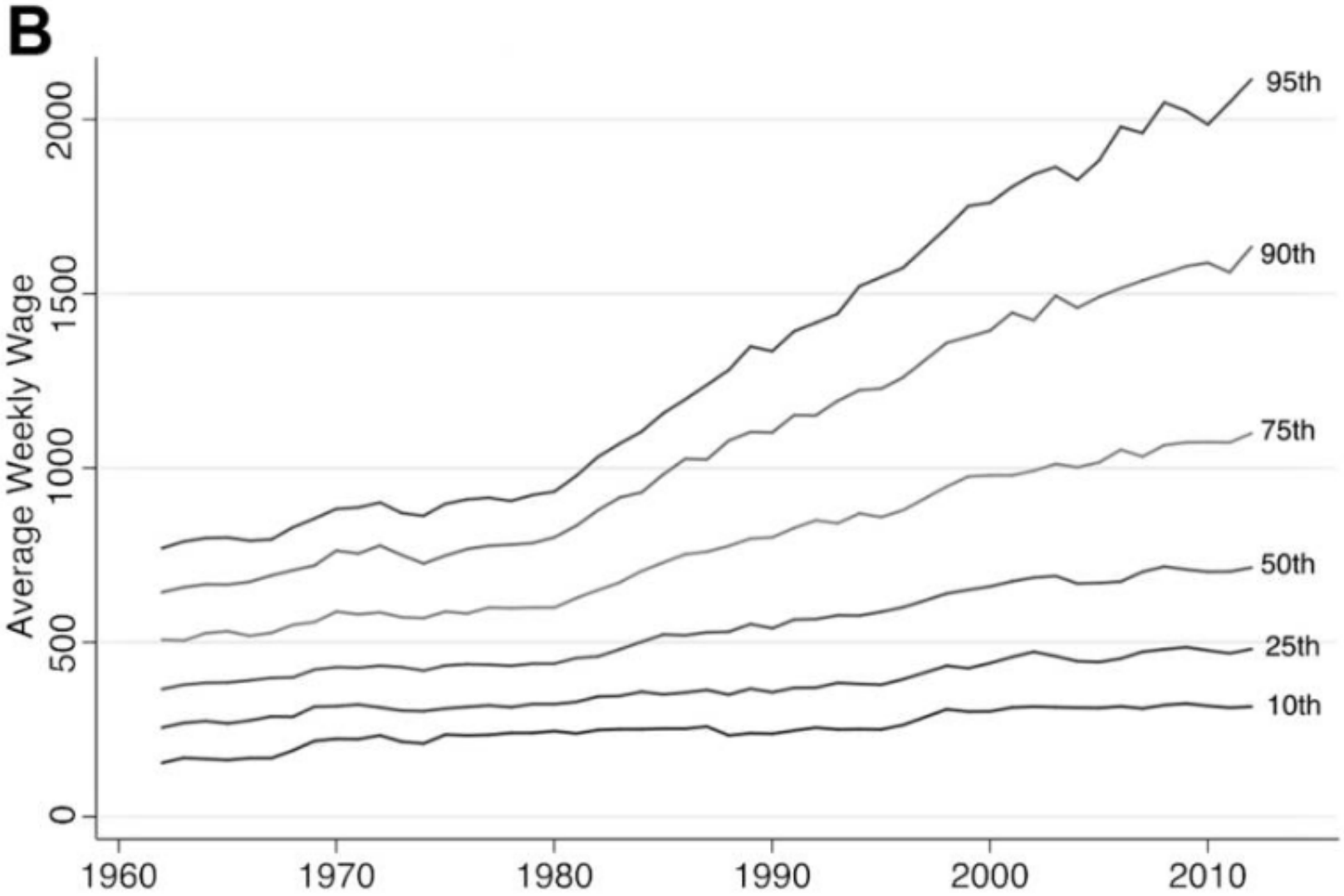
Evolution of Wage Distribution (US Men)

Murphy and Topel (2016)



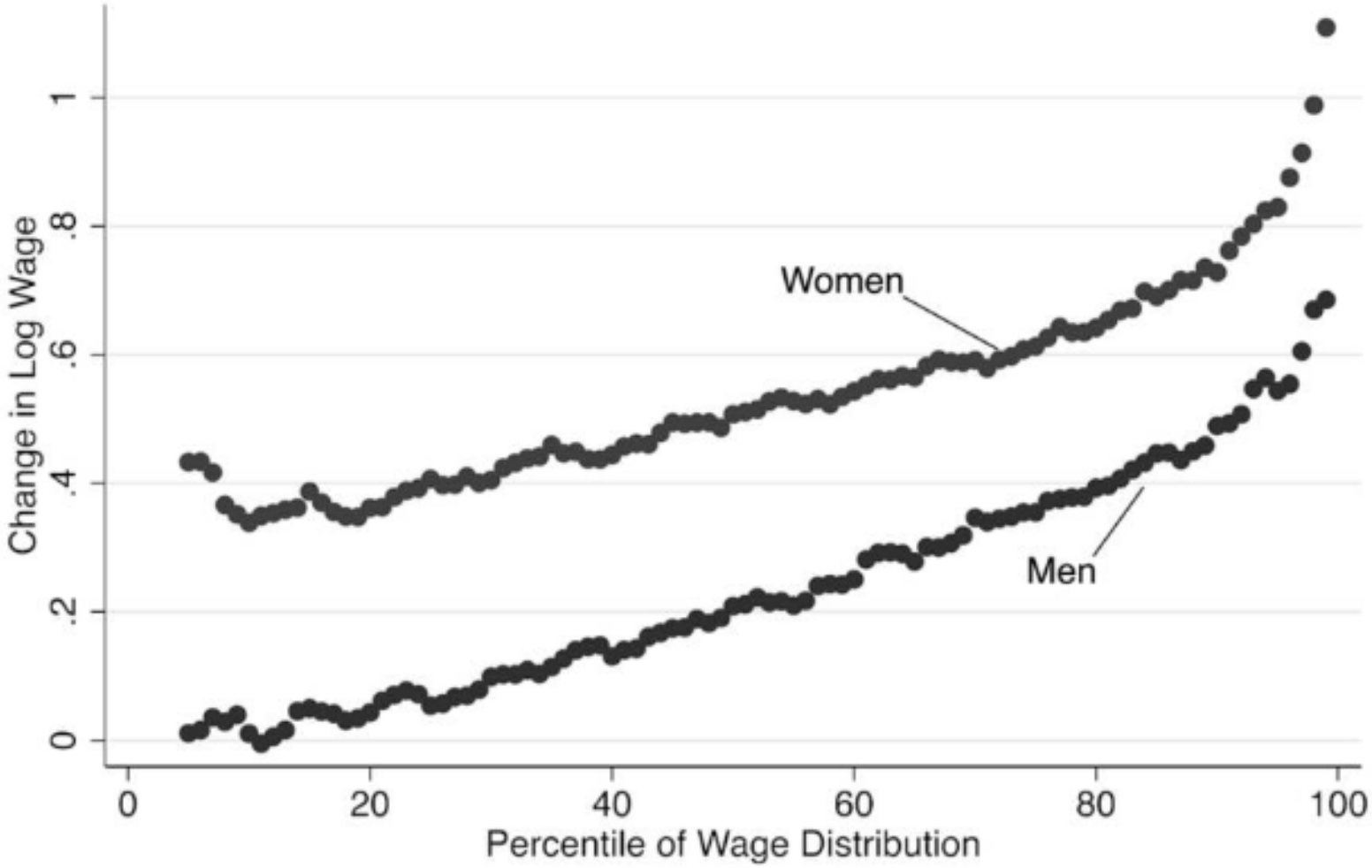
Evolution of Wage Distribution (US Women)

Murphy and Topel (2016)



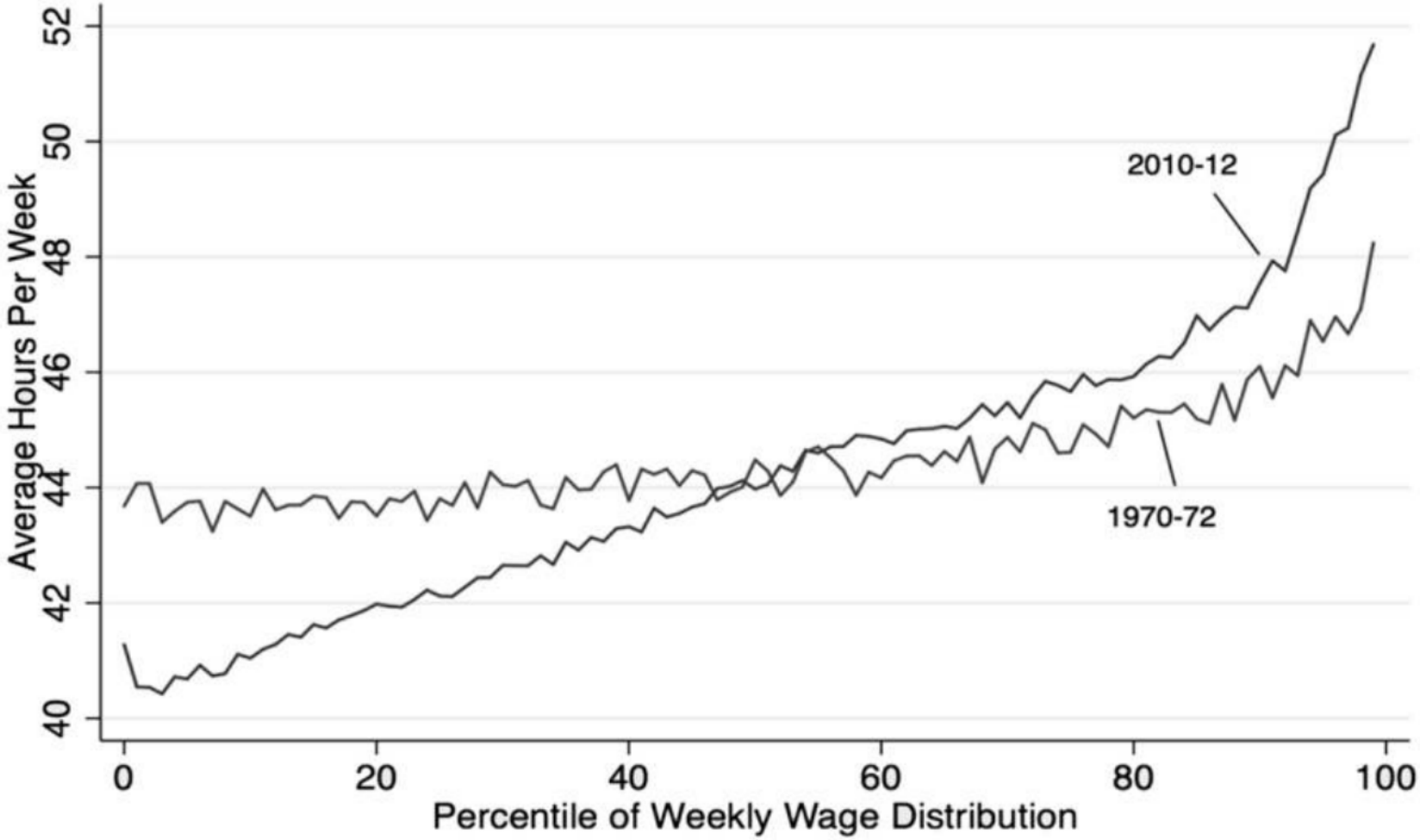
Change in Wage by Percentile 1972-2012 (US)

Murphy and Topel (2016)



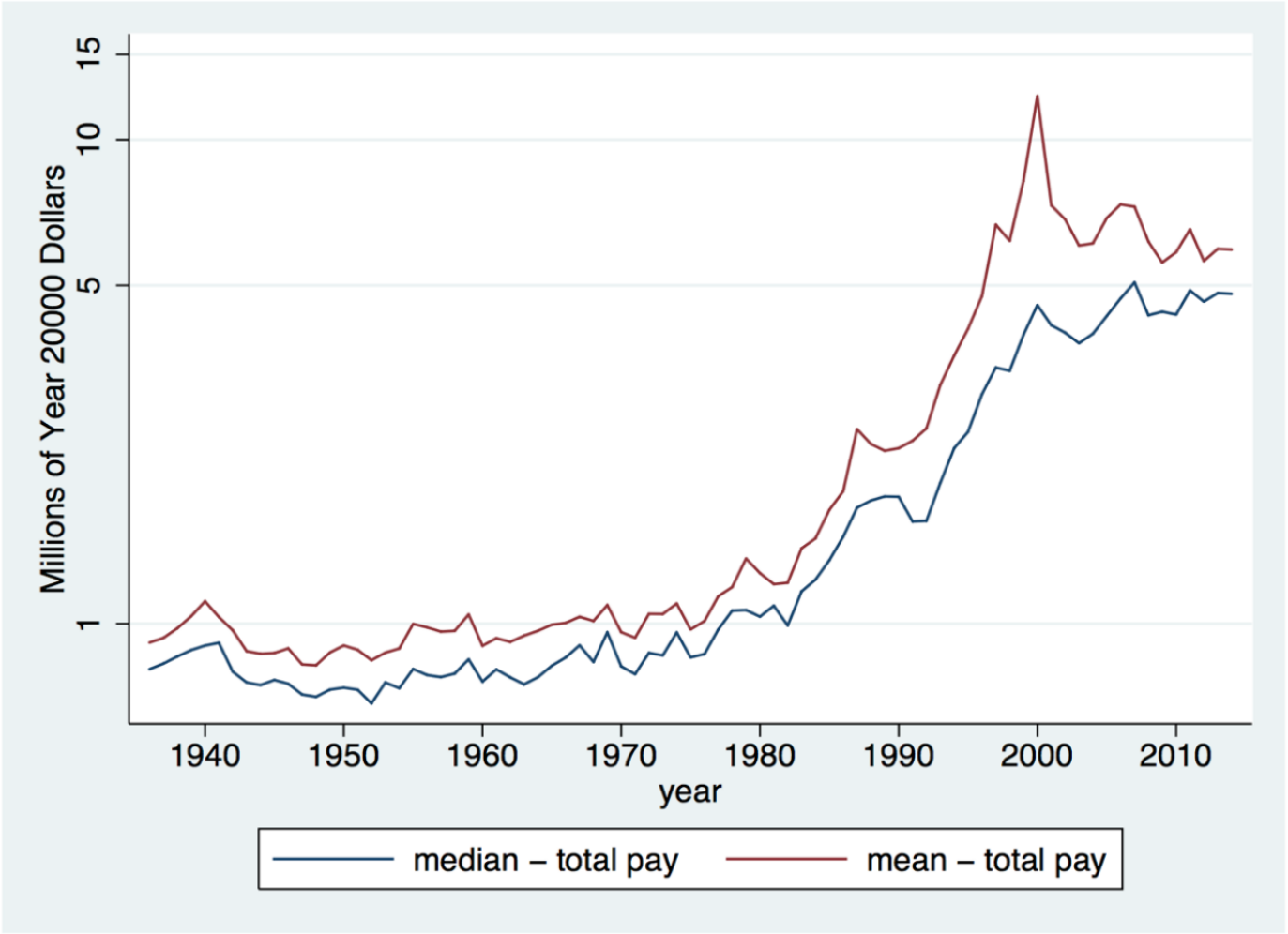
Change in Hours Worked (US Men)

Murphy and Topel (2016)



Evolution of CEO Pay (US)

Frydman (2016) from David Autor's Lecture Notes

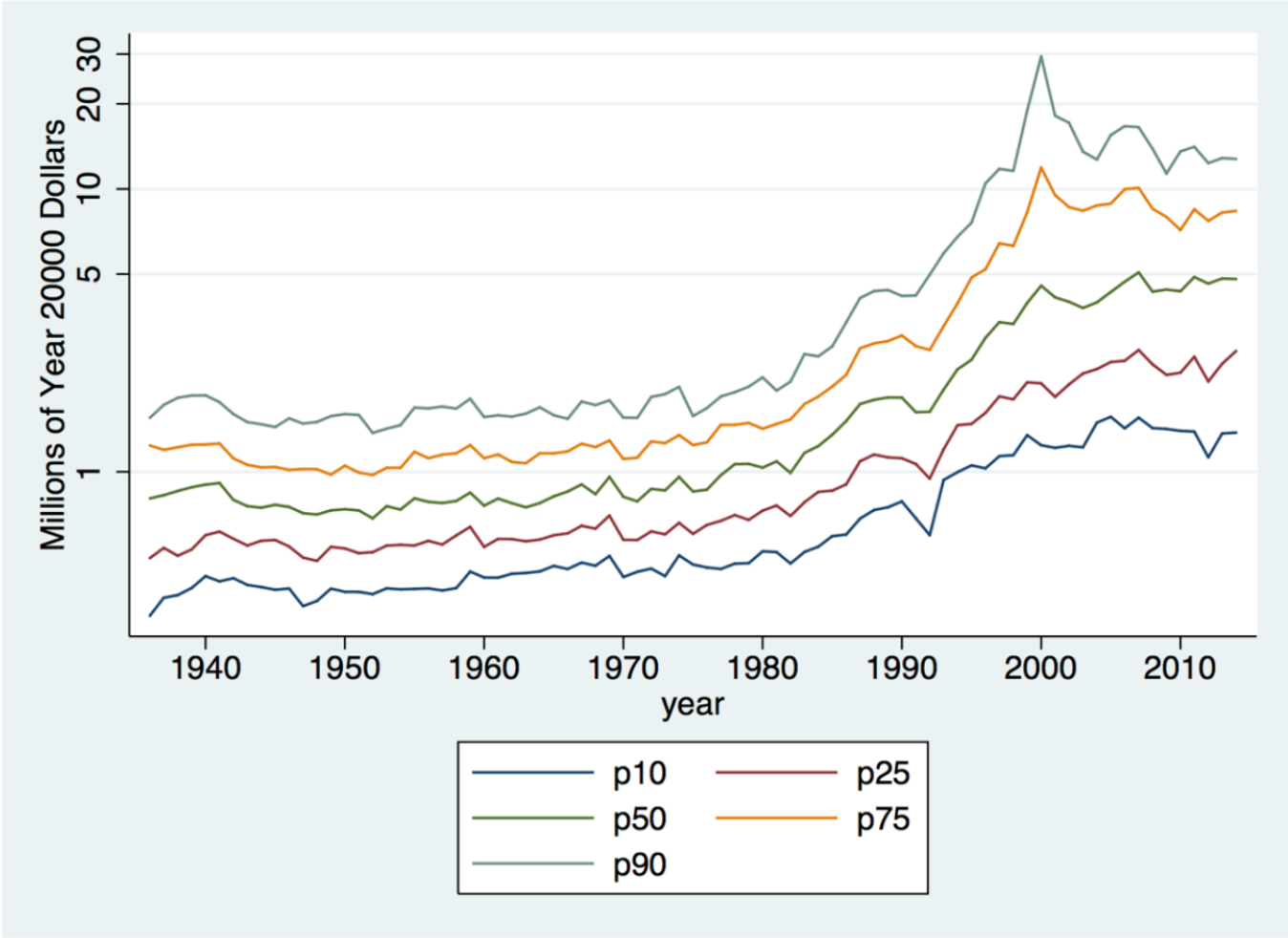


Frydman, 2016

Note: logarithmic y-scale

Evolution of CEO Pay (US)

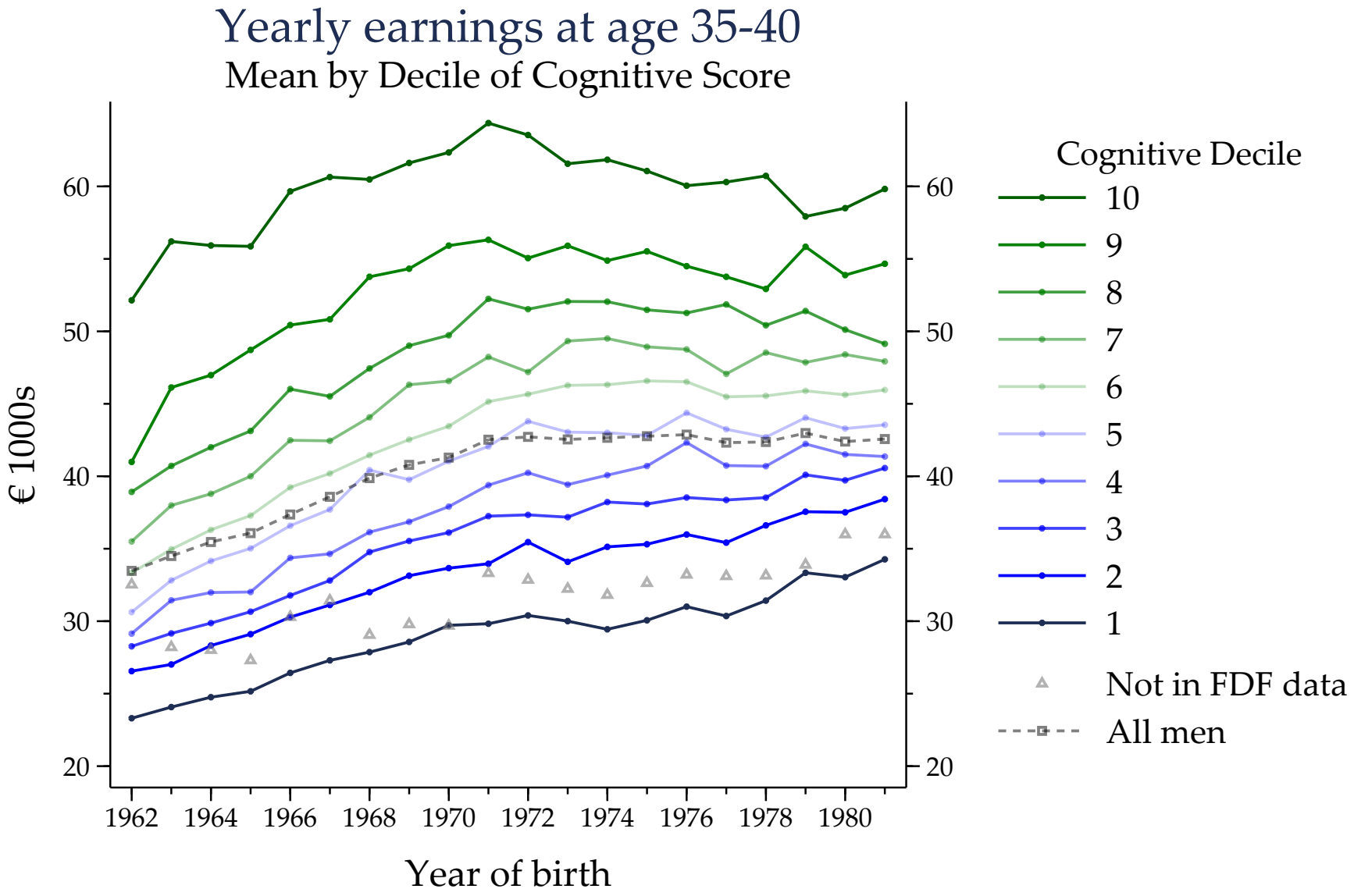
Frydman (2016) from David Autor's Lecture Notes



Frydman, 2016

Note: logarithmic y-scale

Labor earnings by cognitive ability (Finland, Men)



Modeling labor markets

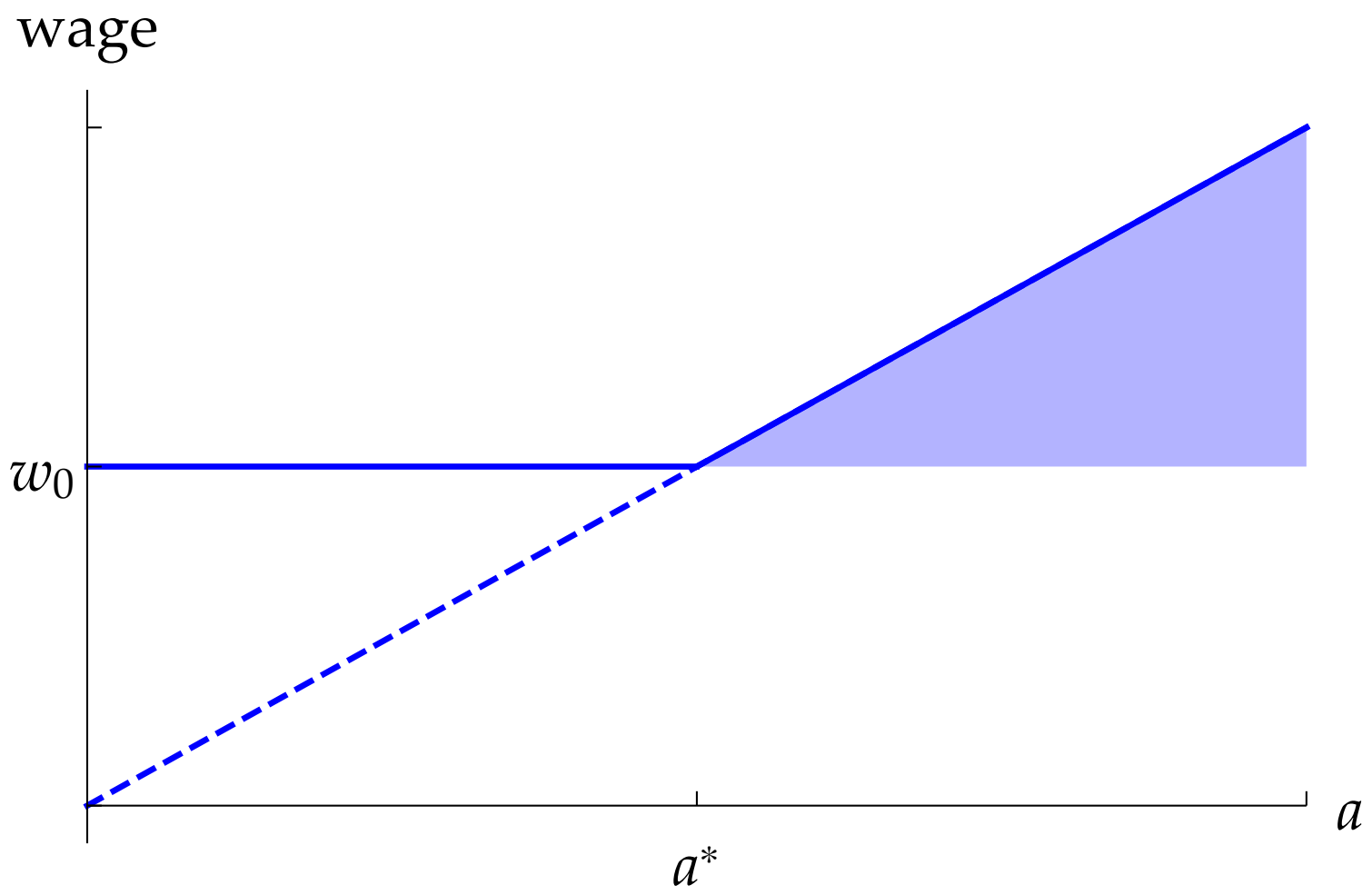
How differences in individual productivity translate to differences in wages? Indivisibilities or not...

- Step 1. Which allocation of resources would maximize total surplus?
- Step 2. Which distribution of wages would make this allocation an equilibrium?
- Variant: Under this structure of information, which allocation would maximize expected surplus?
- Consider: which resources are indivisible, in which time frame? Types of capital, ability, education, effort...

The world's simplest model of wage differences: Ricardian rents in partial equilibrium

- Adapted from the analysis of land rents by Ricardo (1809)
  That is where the definition of "rents" in economics comes from!
- Population of potential workers, with heterogeneous ability a and outside value w_0
- Ability a is measured as the revenue worker generates for the firm, gross of the wage $\rightarrow$ Profit $\pi(a) = a - w(a)$
- Competitive firms bid up the wages to $w(a) = a$
- Workers with $a < w_0$ will take the outside opportunity,
  marginal worker $a^* = w_0$ earns w_0,
  inframarginal workers $a > w_0$ earn ability rents $a - a^*$

Ricardian model: Ability rents in partial equilibrium



Equilibrium wage $w(a) = a$ if $a \geq w_0$.

Ricardian ability rents: Market equilibrium

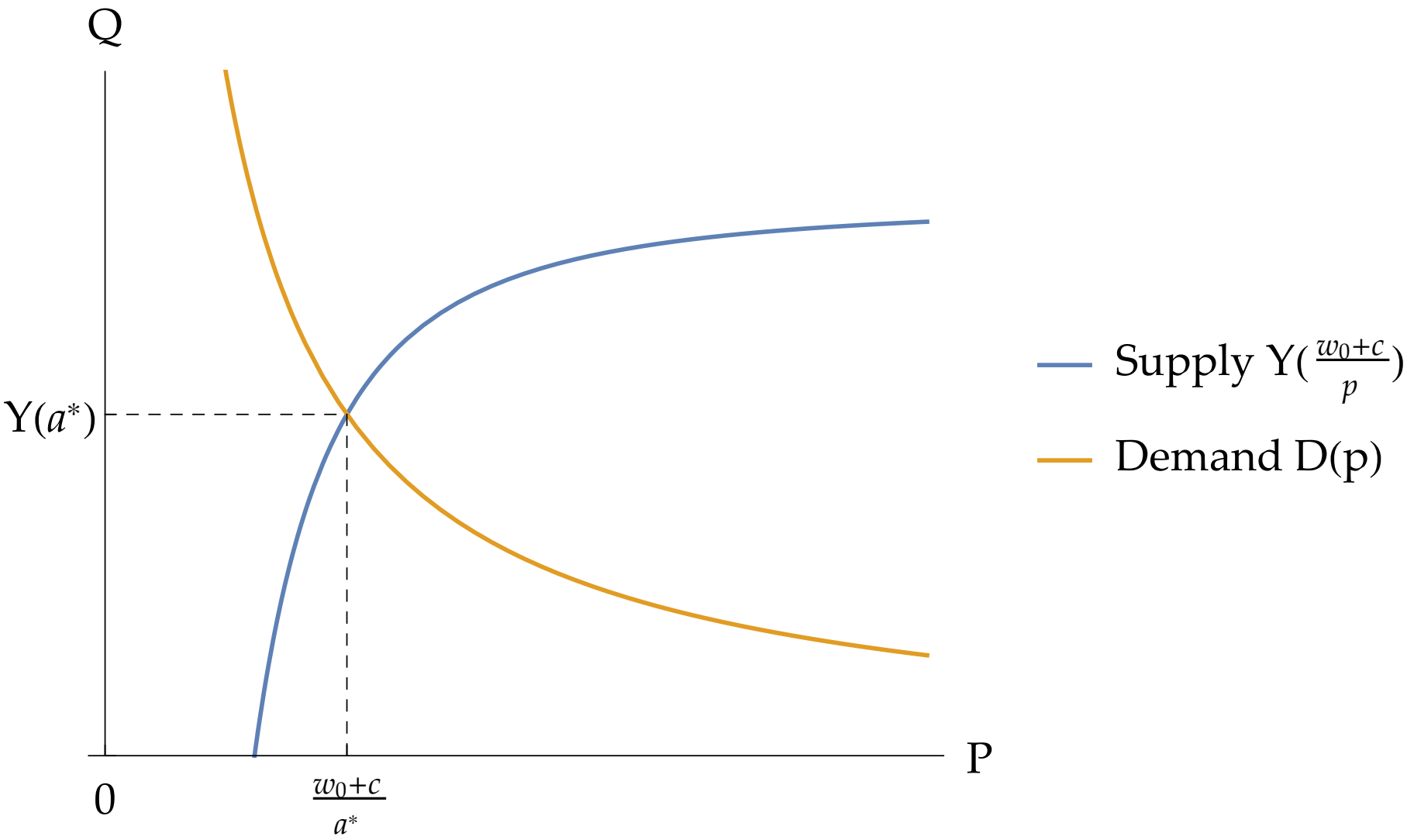
- Worker ability a measured as the level of output
  Worker outside option w_0
- Population of N workers with ability distributed $F(a)$, $a \in [0, \bar{a}]$
- Fixed production cost c
  Firms make zero profits $\rightarrow$ wages $w(a) = pa - c$
- Surplus generated by a worker is $y(a) = pa - c - w_0$
- Demand for output: $D(p)$
- Market price of output, p, determined in equilibrium $\rightarrow a^*, w$

Ricardian ability rents: Market equilibrium

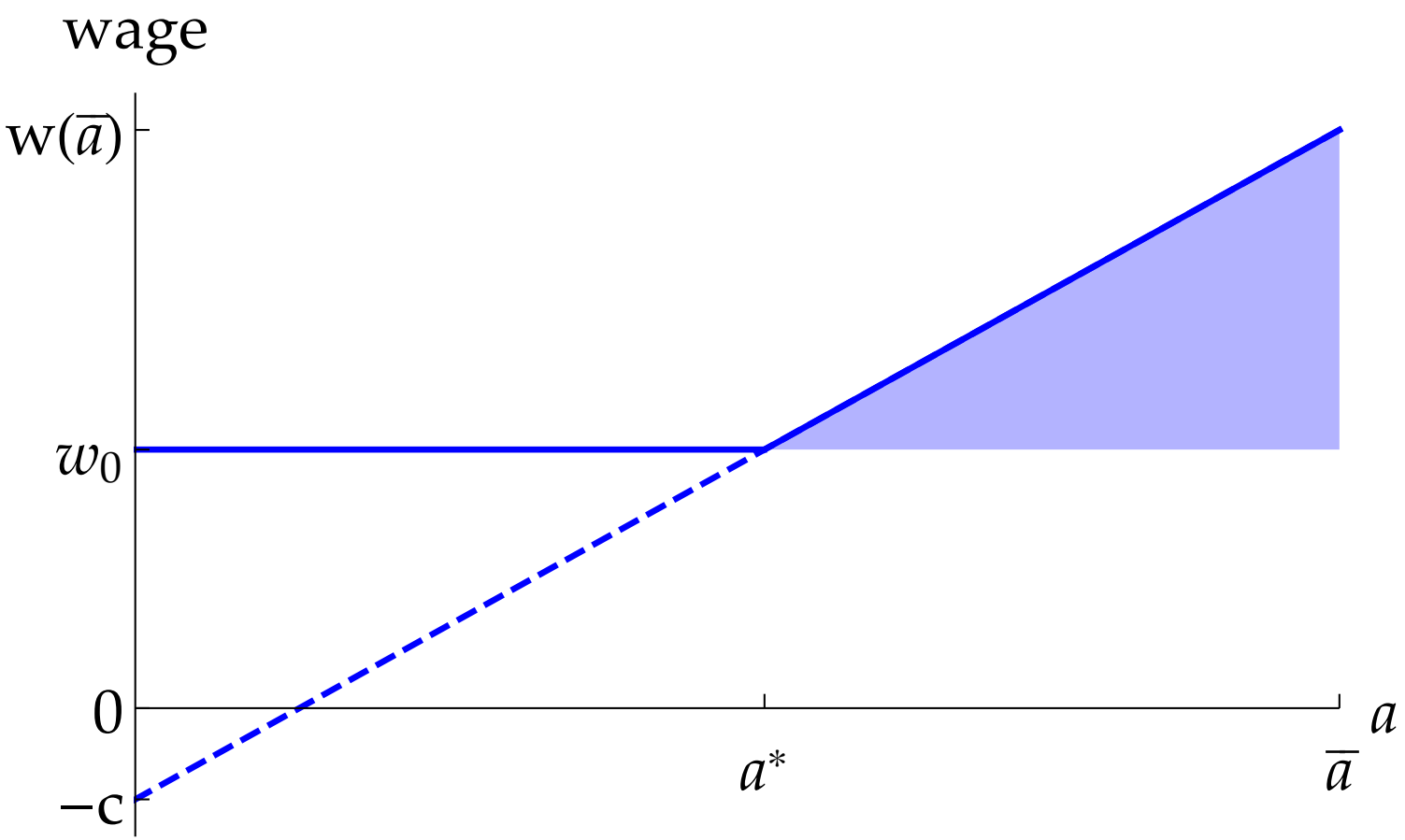
- Marginal worker type a^* earns w_0
- Wages $w(a) = p(a - a^*) + w_0$,
  where $p(a - a^*)$ is the ability rent.
- Marginal worker produces zero surplus:
  $pa^* - w_0 - c = 0 \rightarrow p^* = \frac{w_0 + c}{a^*}$
- Workers with $a \geq a^*$ produce,
  total output $Y(a^*) = N \int_{a^*}^{\bar{a}} af(a)\,\mathrm{d}a$,
  supply $S(p) = Y(\frac{w_0 + c}{p})$
- Market clears when
  p such that $S(p) = D(p) \iff$
  a^* such that $Y(a^*) = D(\frac{w_0 + c}{a^*})$

Ricardian model: Market equilibrium

(Under the hood)

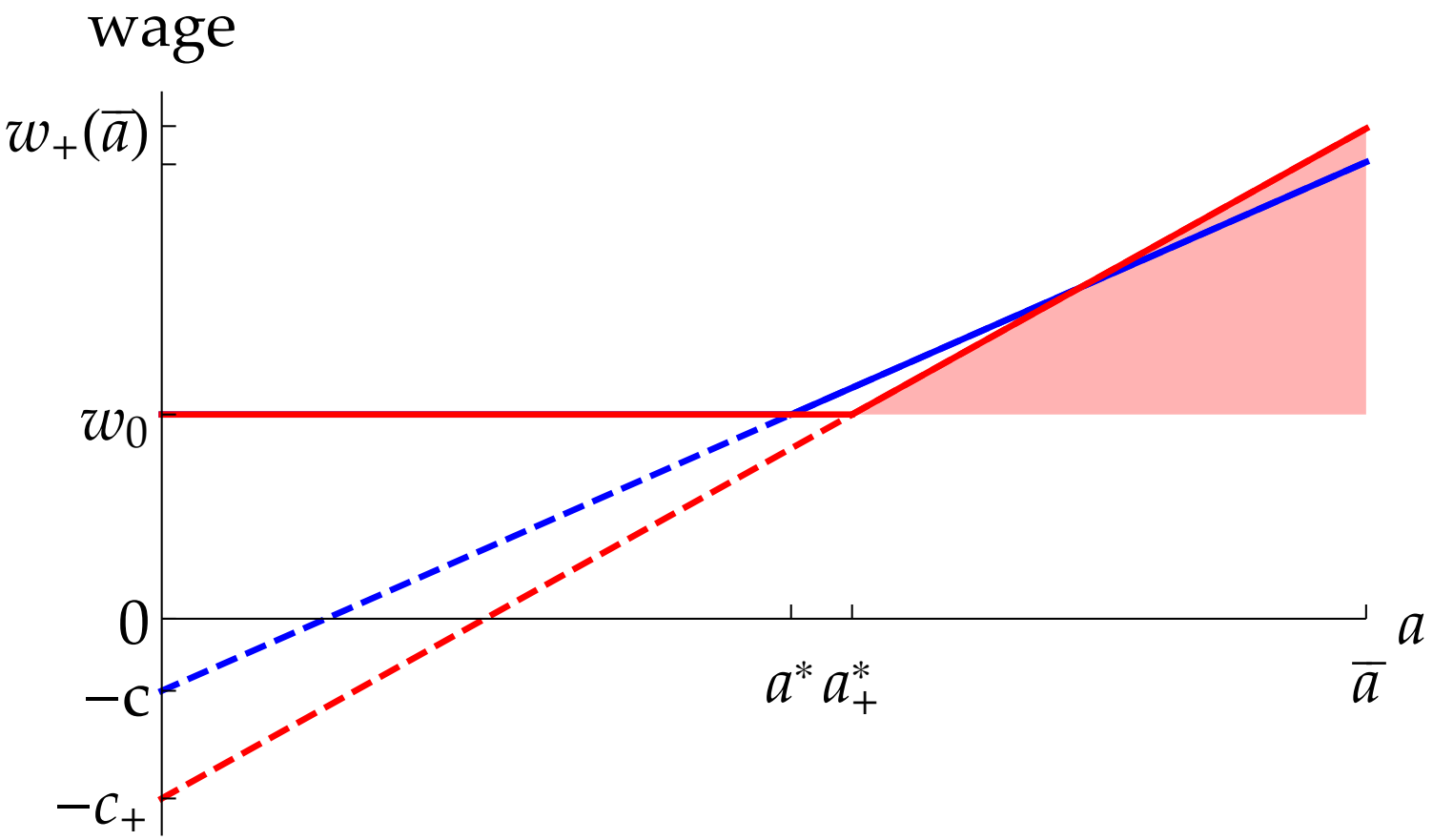


Ricardian model: Ability rents



Equilibrium wage $w(a) = w_0 + p^*(a - a^*) = w_0 + (w_0 + c)\frac{a-a^*}{a^*}$

Ricardian model: Ability rents



Increase in non-labor costs $c \implies \uparrow p^*, \uparrow a^*$

Ability rent $p^*(a - a^*)$ can be affected only linearly, via p^* or a^*

Ricardian ability rents, aka talent rents

In a market for a skill with individual productivity differences

- With a given output price p, ability rents $p(a - a^*)$ proportional to ability difference wrt marginal worker
- In equilibrium, higher non-labor cost of production per worker
  1. scales up the value of any ability difference.
  2. raises the ability threshold a^*
  3. w reduced for lower abilities,

     w may be increased for highest abilities (depends on F, D)

Good to be talented in a resource-intensive occupation – but you need to be higher up the tail to benefit

Scale of operations effect

How to allocate scarce productive resources between individuals?

Meyer (1960), Lucas (1978), Rosen (1982), “folk theorem”

Individual ability a, resources k.

Complementarity between factors: $y_{ak} > 0$.

$$y(a, k) = a\, g(k)$$

a is indivisible, k is adjustable, $g' > 0$, $g'' < 0$.

Workers & capital,

Managers & personnel (span of control),

Talent & education/training/effort...

Scale of operations effect

Allocate resources k to maximize surplus at every job.

$$\frac{\partial}{\partial k}\left(ag(k) - rk - w_0\right) = 0 \Longrightarrow k^*(a) = g'^{-1}\left(\frac{r}{a}\right)$$

Example: $g(k) = k^{\beta}, \quad \beta \in (0,1)$ captures scale economies

$$k^*(a) = \left(\frac{a\beta}{r}\right)^{\frac{1}{1-\beta}}$$

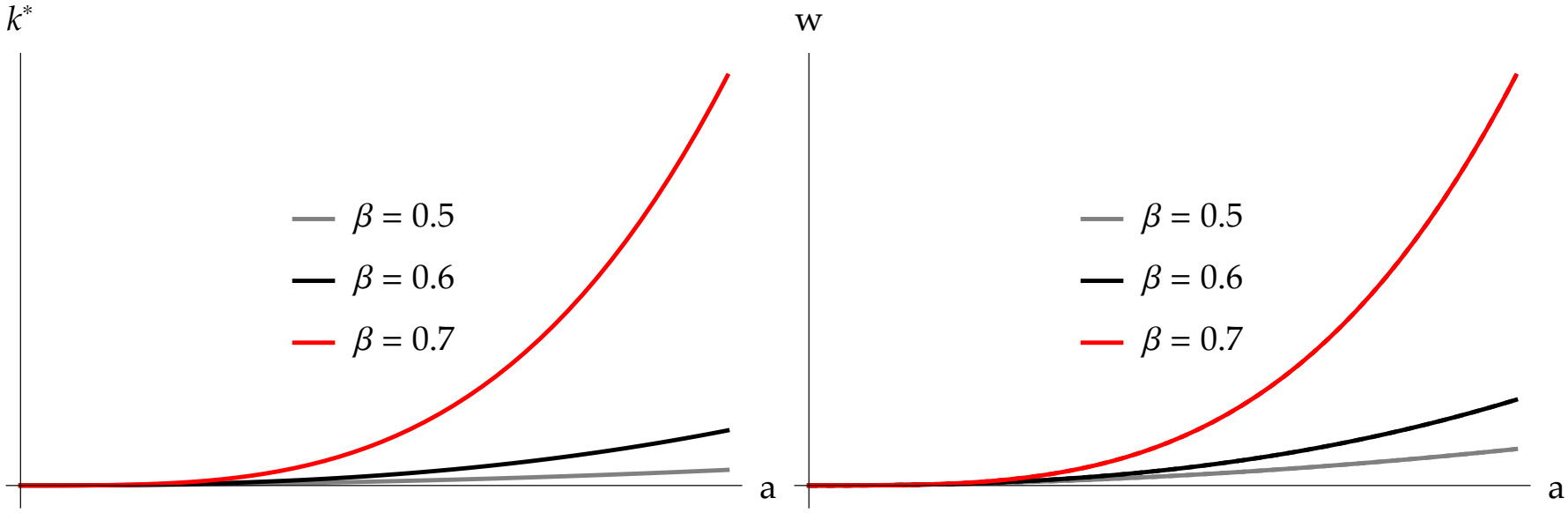
$$w(a) = ag(k^*(a)) - rk^*(a)$$

$$= b(\beta)a^{\frac{1}{1-\beta}} r^{\frac{-\beta}{1-\beta}}$$, where $b(\beta) > 0$ is an ugly-ish constant

For those who have a, more k shall be given to work with.

Q. How do $\log(k)$ and $\log(w)$ vary with $\log(a)$, $\log(r)$?

Scale of operations effect: technological change



Scale economies for complementary factor $\rightarrow$

Higher and more skewed wages.

With $\beta = 0$, $w(a) \propto a$. What if $\beta \geq 1$?

In Rosen (1982), subordinate labor is complementary

Improvements in communication tech $\rightarrow$

higher, more skewed wages for managers in fewer, larger firms

On the measurement units of indivisible factors

Ability is an indivisible factor of production. This means that it cannot be transferred between individuals.

Hence any positive monotone transformation of units a is meaningless in terms of observables.

Suppose $\tilde{y}(\tilde{a}, k) = \tilde{a}^{\alpha} k^{\beta}$, where $\alpha > 0$
Redefine units $a = \tilde{a}^{\alpha}$ and use $y(a, k) = ak^{\beta}$
Any positive monotone transformation of a is wlog (and woag)

Superstar effects: Rosen (1981)

1801 Elizabeth Billington, 300$\times$ median wage

2011 Lady Gaga, 3500$\times$ median wage

2023 Taylor Swift (touring only) 4000$\times$ median wage

2023 Taylor Swift (all income) 10000$\times$ median wage (Forbes)

In Rosen (1981) indivisible ability and a scale effect in production

Consumers: quantity and producer ability are imperfect substitutes

At the same unit price, consumers would only buy from the highest-quality producer, but the best cannot serve all due to DRS

Implication of superstar economics:
The winner-take-more tendency of (most?) technological progress

Superstar effects: the megatrend

Marshall (1890), as cited in Rosen (1981)

"so long as the number of persons who can be reached by a human voice is strictly limited, it is not very likely that any singer will make an advance on [...] Mrs Billington [in 1801]"

Now consider long-run technological change

- Distribution of entertainment: concert hall, radio, recordings, web
- Design & handicraft vs Design & mass production
- Hardware vs Software
- Globalization, increasing dominance of English
- Sports, entertainment, management
- Complementary services to any of the above. . .

Matching aka assignment: historical notes

More than one indivisible factor of production $\longrightarrow$
the units of production must be *matched*.

Workers and jobs. Tinbergen (1951)

Generalized assignment problem. Koopmans and Beckmann (1957)

Becker's marriage model (1973)

Sattinger's assignment model (1975) and JEL survey (1993)
The dog and bone economy, the impact of rank

The world's simplest matching problem

Surplus function

$$Y(a,b) = ab$$

Two workers, types $a_2 > a_1$. Two jobs, types $b_2 > b_1$.

Total output maximized with Positive Assortative Matching (PAM)

$$\begin{aligned} a_2 b_2 + a_1 b_1 &> a_2 b_1 + a_1 b_2 \iff \\ a_2(b_2 - b_1) &> a_1(b_2 - b_1) \iff \\ (a_2 - a_1)(b_2 - b_1) &> 0 \end{aligned}$$

Consider e.g., $a_1 = 1, a_2 = 2, b_1 = 1, b_2 = 2$

$Y(2,2) + Y(1,1) = 5 > Y(2,1) + Y(1,2) = 4.$

When is there PAM?

Supermodular Y is sufficient for PAM

Y is supermodular Y if, for all $a_2 > a_1$, $b_2 > b_1$,

$$Y(a_2, b_2) + Y(a_1, b_1) > Y(a_2, b_1) + Y(a_1, b_2)$$

When Y is differentiable, this is equivalent with

$$\frac{\partial^2 Y(a, b)}{\partial a \partial b} > 0 \text{ for all } (a, b)$$

An arbitrary increasing function Y unlikely to result in PAM or NAM

Example of NAM: $Y(a, b) = \bar{Y}(1 - \frac{1}{ab})$, where $(a, b) \in [1, \infty)^2$

General version of the assignment problem is analytically intractable $\rightarrow$ numerical black box

Matching workers with workers (team production)

Kremer (1993) O-Ring Theory of Production

Worker quantity not substitutable with worker quality

$$y(a_1, \ldots, a_n, k) = \bar{y} k^{\beta} \Pi_{i=1}^{n} a_i \qquad \text{(production)}$$

$$\pi(a_1, \ldots, a_n, k) = y(a_1, \ldots, a_n, k) - \sum_{i=1}^{n} w(a_i) - rk \qquad \text{(profit)}$$

a_i probability that worker i succeeds

k^{β} contribution of capital (DRS)

$\bar{y}$ output if $k = 1$ and all n workers succeed

Workers (team members) are complements $\Longrightarrow$ PAM

Teams are complements with capital $\Longrightarrow$ Scale effect

Kremer (1993) O-Ring Theory of Production

Workers (team members) are complements $\Longrightarrow$ PAM.

Continuous distribution of a $\Longrightarrow$ homogeneous teams.

The teams have a scale-of-operations effect wrt k,

capital is adjustable $\Longrightarrow$ $k^*(a)$ increasing but earns just $rk^*(a)$

$\Longrightarrow$

1. Skill-segregation between firms
2. Right-skewed wage distribution

Extension: Choice of n from a schedule $\bar{y} = B(n)$ of complexity by product.

Kremer lists 10 conclusions. Dev econ: in developed countries, firms are larger and specialize in more complex products

Assignment Model

Matching without frictions: full info, market clears at once

1. Technology: Net and gross surplus functions

$$Y(a,b) = \max_{\mathbf{x}} \left\{ y(a,b,\mathbf{x}) - \left(w_0 + \pi_0 + c(\mathbf{x}) \right) \right\}$$

$$\tilde{Y}(a,b) = Y(a,b) + \left(w_0 + \pi_0 \right)$$

Adjustable factors $\mathbf{x}$ chosen optimally for the given match.

2. Factor supply: Distributions of indivisible factors
3. Outside prices: w_0, π_0

Scale of operations effect is a limiting case where distribution of b degenerate

Distributions of factor quality

Definition: quantile function (aka inverse CDF)

$$x(i) = x \text{ s.t. } \{F(x) = i\} \quad \Longrightarrow \quad x'(i) = \frac{1}{f(x(i))}$$

Quantiles $i \in [0, 1]$ are convenient and have empirical content

Example: Pareto distribution (x_0,γ)

$$F(x) = 1 - \left(\frac{x}{x_0}\right)^{-\gamma} \qquad \text{for } x \geq x_0$$

$$f(x) = \frac{\gamma}{x_0}\left(\frac{x}{x_0}\right)^{-(1+\gamma)} \qquad \text{for } x \geq x_0$$

$$x(i) = x_0(1-i)^{-\frac{1}{\gamma}} \qquad i \in [0, 1)$$

$$x'(i) = \frac{x_0}{\gamma}(1-i)^{-(1+\frac{1}{\gamma})} \qquad i \in [0, 1)$$

Assignment Model: Equilibrium

An assignment model determines the equilibrium division of surplus between indivisible factors

Assume $Y_{ab} > 0 \implies$ PAM: $a(i)$ matched with $b(i)$, for some $[i_0, 1]$

Marginal unit is the lowest to i_0 cover the outside opportunities:
$\tilde{Y}(a(i_0), b(i_0)) = w_0 + \pi_0$

Let's discard the inactive quantiles and normalize $i_0 := 0$.
Inframarginal units of indivisible factors always earn rents.

Equilibrium factor rents must add up:
$Y(a(i), b(i)) = w(i) + \pi(i)$ for $i \in [0, 1]$

We can solve for either factor rent, say $w(i)$; the other gets the rest.

Assignment Model: Equilibrium rents

Continuum of factor owners, so price-taking decision makers and no bargaining rent.

1. All participants get at least zero rents

2. Every factor-owner chooses best match by maximizing own surplus.

3. $Y_{ab} > 0$, so total surplus is maximized by PAM

2. & 3. imply that every firm $b(i)$ is maximizing profits by hiring $a(i)$, taking as given the entire a, w

Observable incomes = Factor rents mixed up with compensation to adjustable inputs (return to capital, to education, effort. . .)

Assignment Model: Equilibrium rents

Firm i factor rent if hire worker $j \in [0,1]$ is

$$\pi(j|i) = Y\big(a(j), b(i)\big) - w(j)$$

Firm i first order condition

$$\frac{\partial \pi(j|i)}{\partial j} = Y_a\big(a(j), b(i)\big)a'(j) - w'(j)$$

FOC must hold at $i = j$ by PAM:

$$Y_a(a(i), b(i))a'(i) - w'(i) = 0$$

Added surplus from matching with $a(i)$ instead of $a(i-\varepsilon)$ is worth paying $w(i) - w(i-\varepsilon)$ for $b(i)$ but, by $Y_{ab} > 0$, not for $b(i-\varepsilon)$. $\Longrightarrow$ SOC

Assignment Model: Equilibrium rents

Equilibrium wage distribution by integrating FOC(i) over i

$$w(i) = w_0 + \int_0^i Y_a\big(a(j), b(j)\big)\, a'(j)\mathrm{d}j \tag{1}$$

Firm profits analogously, or as the residual $Y(a(i), b(i)) - w(i)$

$$\pi(i) = \pi_0 + \int_0^i Y_b\big(a(j), b(j)\big)\, b'(j)\mathrm{d}j$$

Division of surplus at quantile i depends on the production function and the distributions of both factors below i.

Inherent symmetry. Both matching factors earn rents, benefit from high quality matches below, no impact from above.

Marginal Product of Indivisible Factors

With more than one indivisible factor of production, indivisible units must be *matched* to produce.

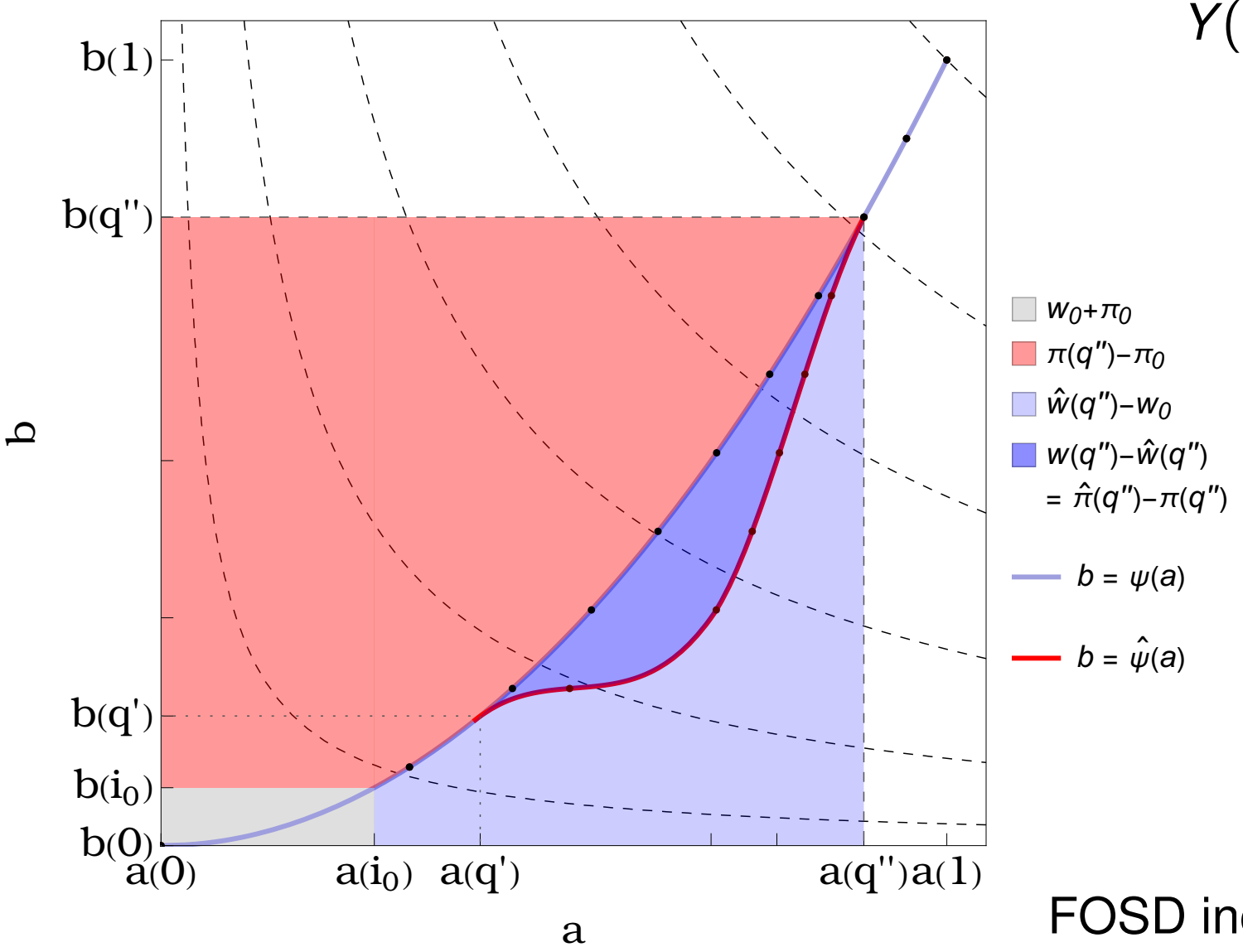
There can be no "marginal product" to a factor where there is no margin at which the amount of that factor could be adjusted. (Compare with MPL in the canonical model).

The correct margin is "How does total surplus change if this unit leaves the market, taking into account the resulting optimal rearrangement of matches in the whole market."

In equation (1), $w(i) - w_0$ is the marginal product of individual i in this proper sense: if worker i is removed, all firms $j \in (0, i]$ will have to match with a slightly lower-ability worker.

Wage Spillovers in a Matching Market

$$Y(a,b) = ab$$



FOSD increase in a

Application to CEO pay in the US

Terviö (2008): The Difference that CEOs Make: An Assignment Model Approach

1. What explains growth in level of top CEO pay?
2. What is the impact of heterogeneous CEO ability vs heterogeneous firm quality?

$w(i), \pi(i)$ observed. But: π must be purged of the value of adjustable capital. Market value –> stock to flow.

Assuming functional form Y, distributions $b(i)$ and $a(i)$ can be inferred via AM equilibrium conditions

Firm size is an unobserved type, market value is an equilibrium outcome

What is the indivisible factor at firms/jobs?

Beyond scale effects

Not adjustable capital or labor, not outcomes

Firm quality is persistent. Bloom and Van Reenen (2011)

Legacy of past decisions and luck.
Sunk capital, organizational capital/corporate culture, brand

The natural scale of the market niche: technology, location

What is ability? Whatever generates surplus – not critical acclaim or technical proficiency!

Terviö (2008): Difference that CEOs make

Model assumptions

(This notation simplified from the paper)

$$\tilde{Y}_t(a,b) = \max_k \left\{ abh_t(k) - rk \right\}$$

$$Y_t(a,b) \propto G_t ab$$

Firm's market value v_t is the present value of $Y_t(a,b) - w_t(a)$, $t = 1, \ldots, \infty$. Assuming 1. distributions of a and b are stable, 2. $h_t(k) = g_t h(k)$, and 3. discount rate, π_t can be calculated from v_t and w_t.

The shape of distributions a and b inferred up to a multiplier. Counterfactuals about firm heterogeneity sensitive to assumed h, so only consider counterfactuals about CEO heterogeneity.

Terviö (2008): The Difference that CEOs make

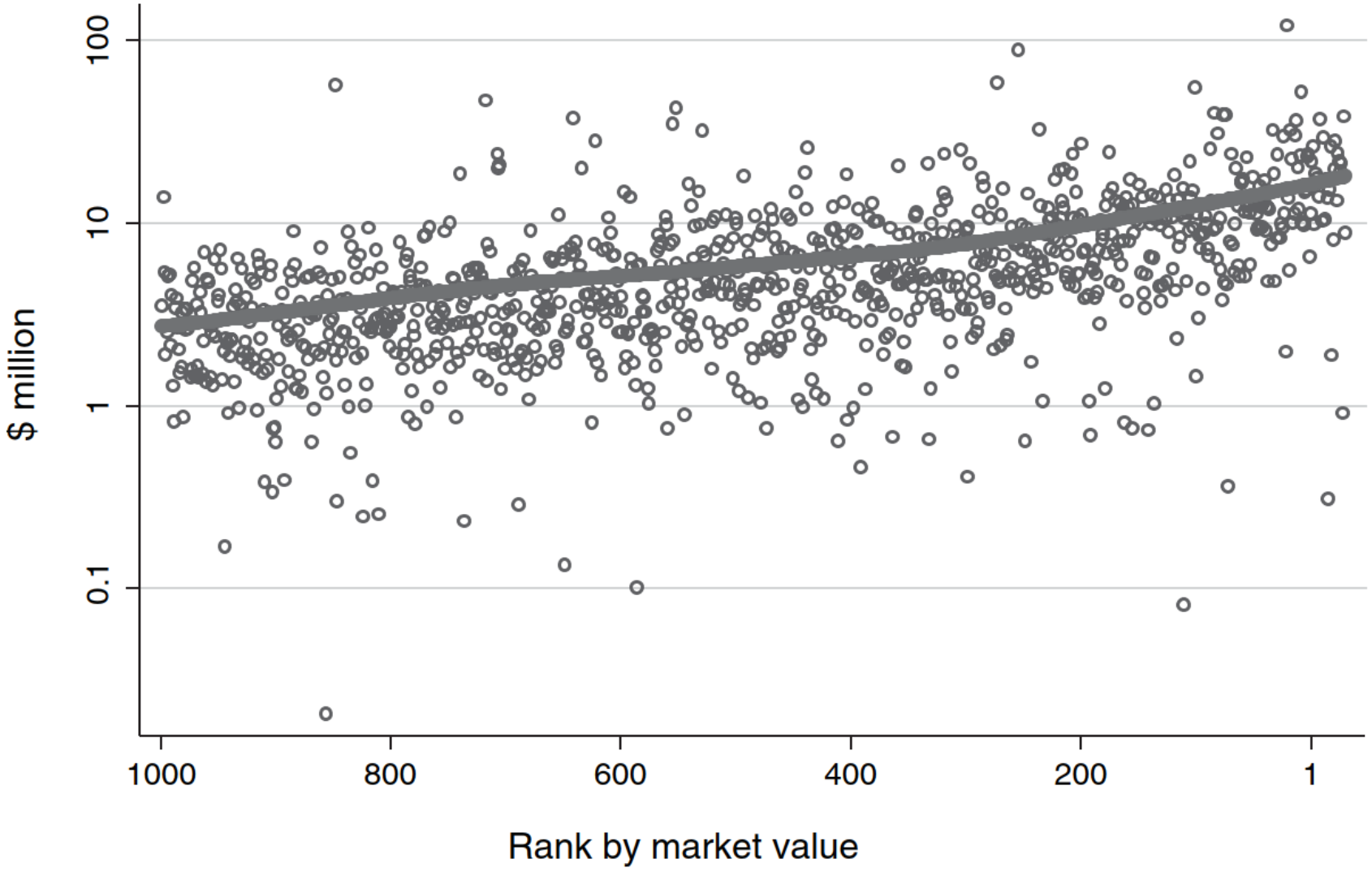


FIGURE 2. RELATION OF CEO PAY AND FIRM RANK BY MARKET VALUE IN 2004

Terviö (2008): The Difference that CEOs make

How consistent is data with model, if G_t the only change?

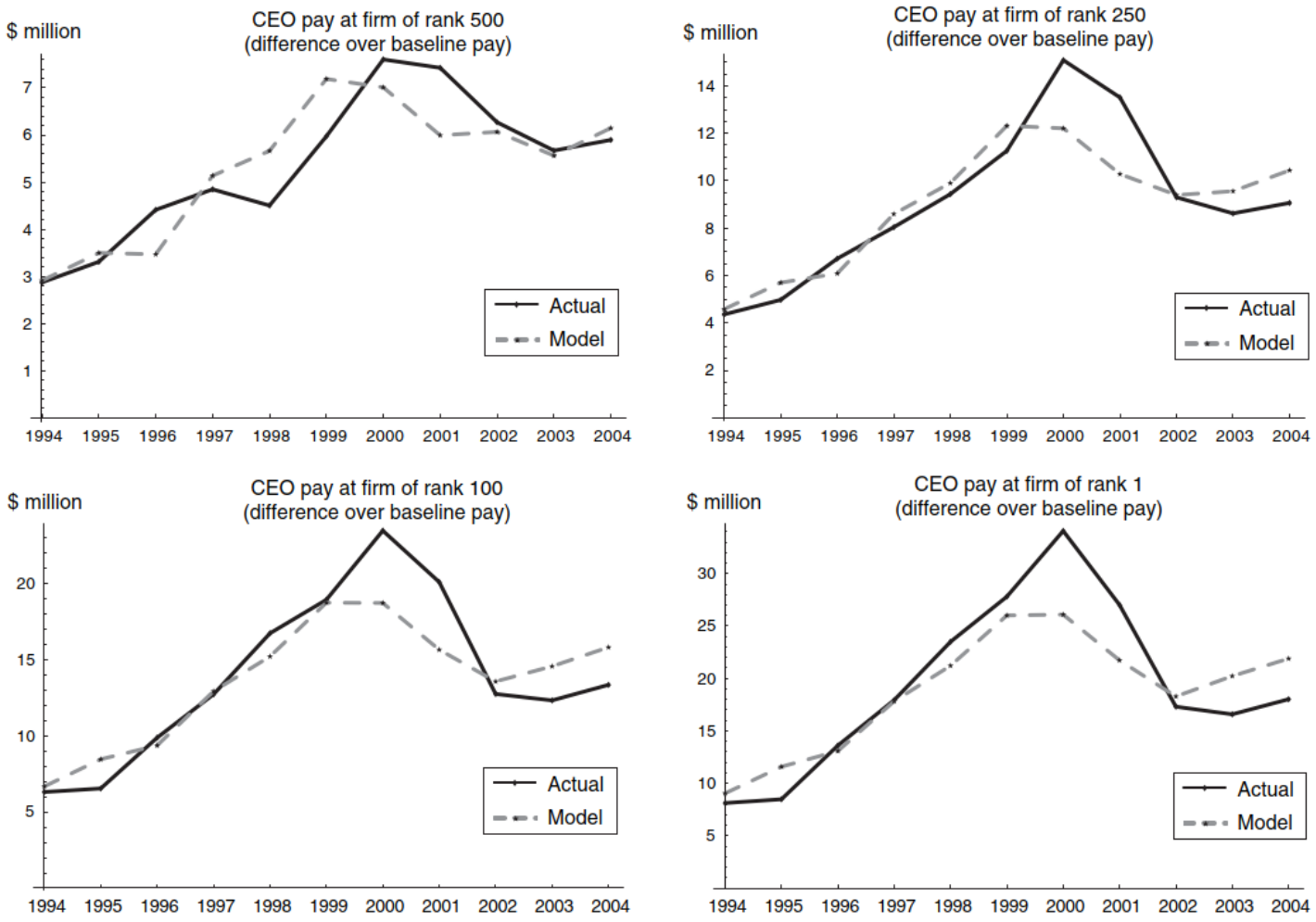


FIGURE 6. THE DIFFERENCE IN PAY BETWEEN THE CEOS OF SELECTED RANKS AND THE BASELINE (1,000TH) CEO

Terviö (2008): The Difference that CEOs make

How consistent is data with model, if G_t the only change?

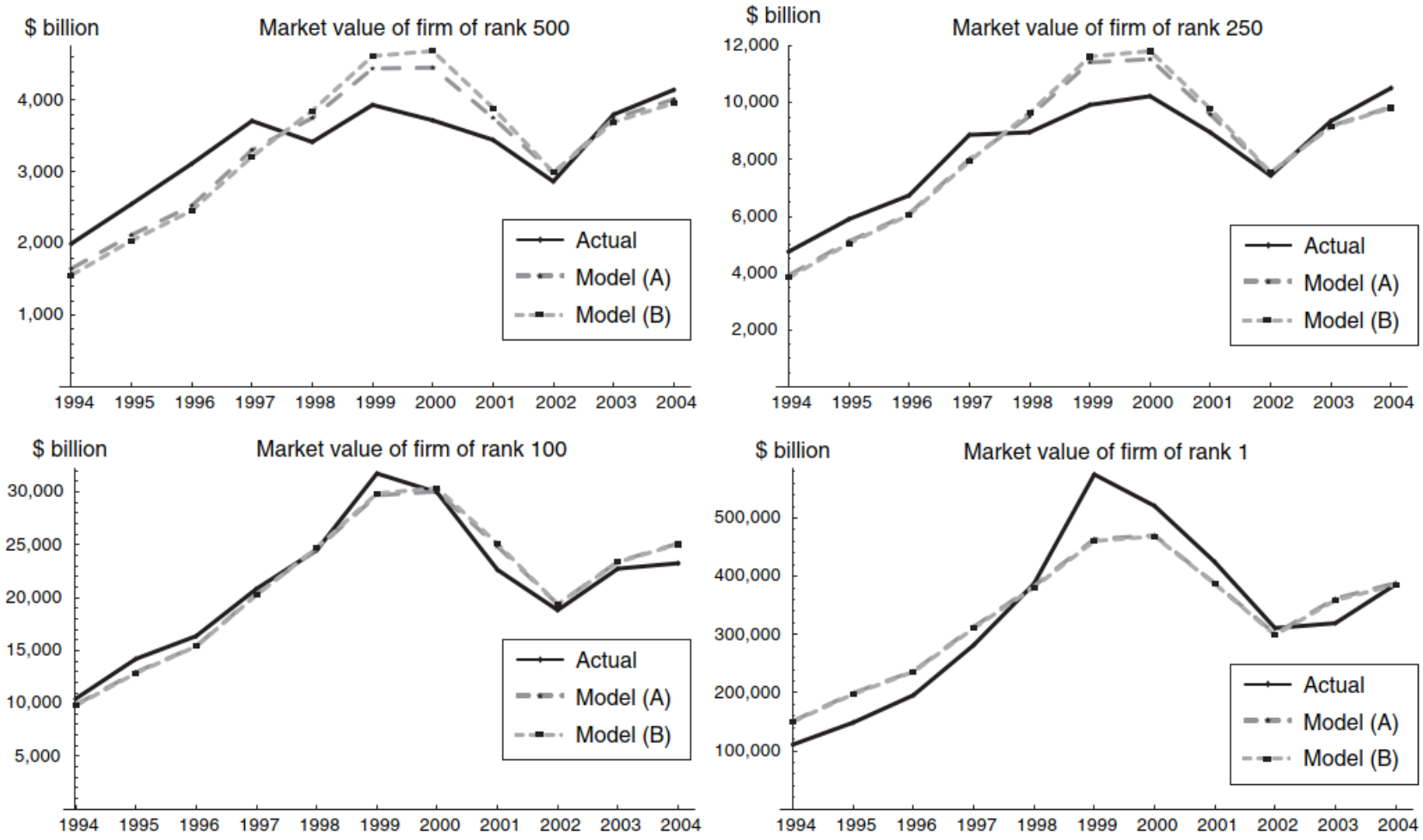


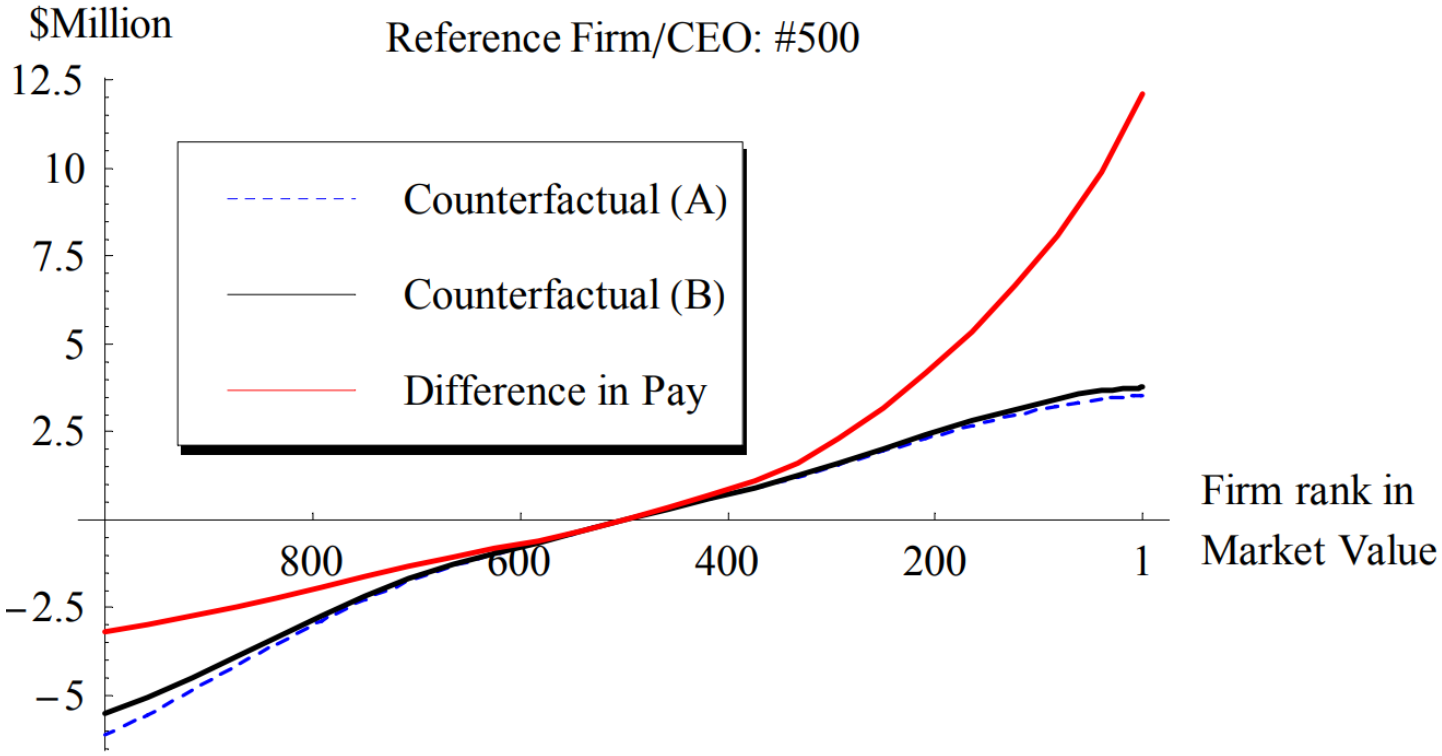
FIGURE 7. PREDICTED MARKET VALUES IN THE TIME-INVARIANT CALIBRATION

NB label typo: “billion” should be “million”

Terviö (2008): The Difference that CEOs make

How much surplus would other CEOs produce at firm 500?

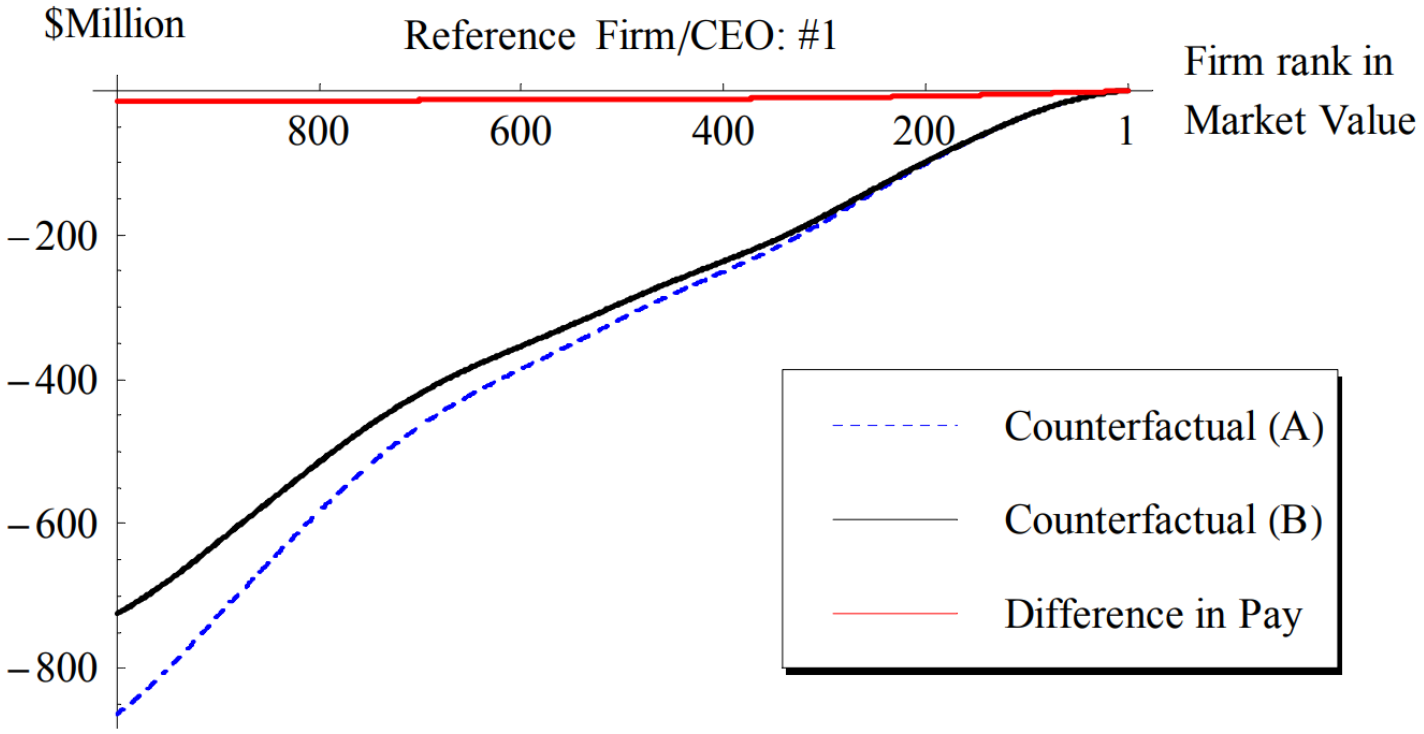
$Y(a(i), b(0.5)) - Y(a(0.5), b(0.5))$ and $w(i) - w(0.5)$



Terviö (2008): The Difference that CEOs make

How much surplus would other CEOs produce at the top firm?

$Y(a(i), b(1)) - Y(a(1), b(1))$ and $w(i) - w(1)$



Koenig (2023): Rollout of television

The rollout of television associated with

1. Fraction of entertainers with top 1% incomes doubled
2. Total employment share of entertainers declined 13%

Causal?

Tech shock 1. Rollout of local television across many labor markets in 1940s & early 50s

Placebo. Exogenous permitting shock: cancellation of planned rollout in some markets 1948–1956

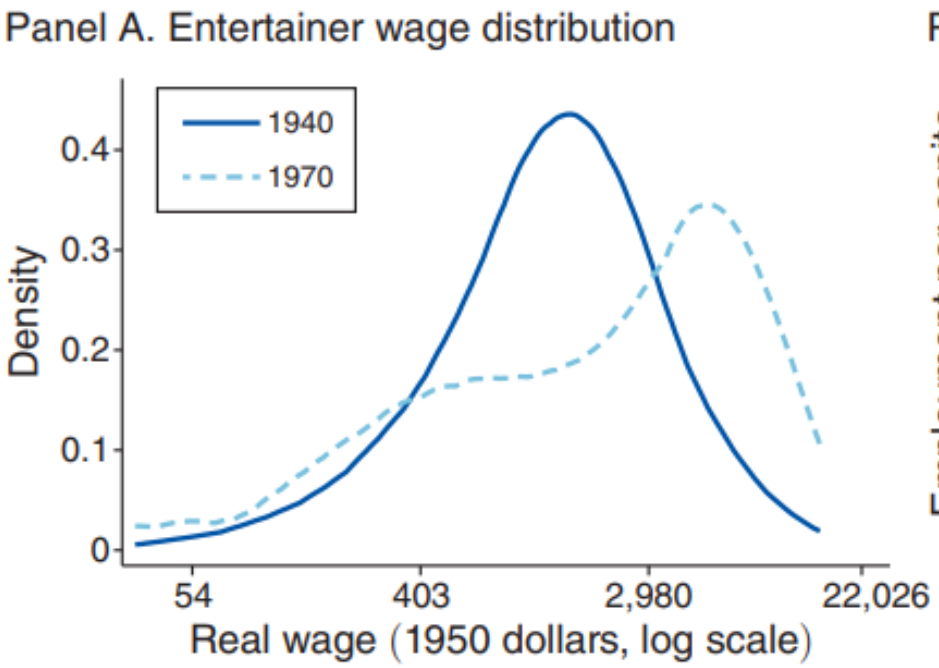
Tech shock 2. Introduction of taped television (multi-market/national television) after 1956

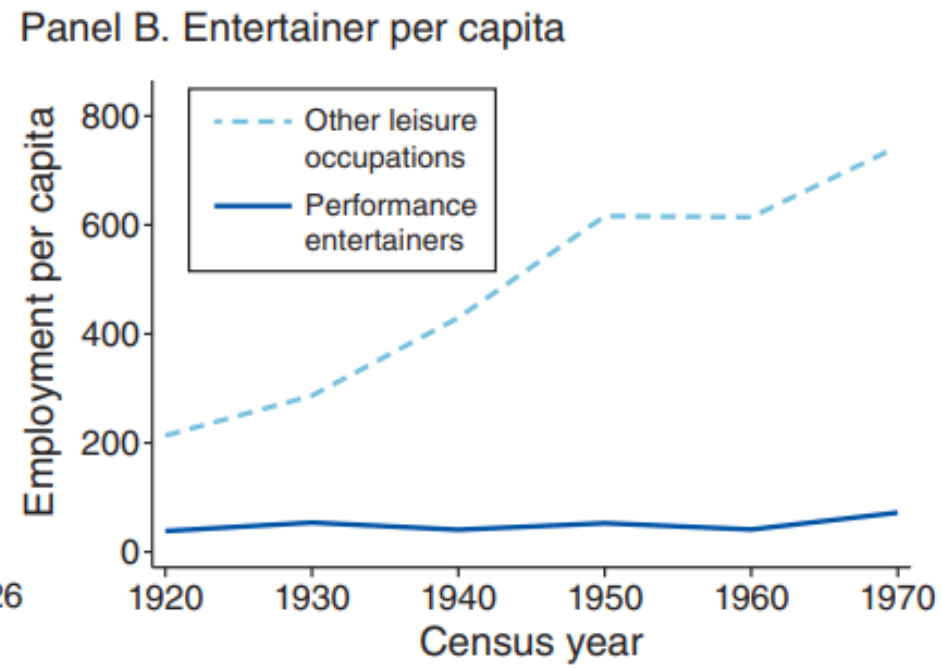
Koenig (2023): Rollout of television

Data from 722 CZs in the US

Decennial census: occupation and income

Hand-coded: television signal and permit rollout by CZ-year





Koenig (2023): Rollout of television

Superstar matching model: performers of various ability, matched with employers of various size.

$$Y(a, b) = (ab)^x$$

where $x \uparrow$ captures "Scale-Related Technical Change" (SRTC) enables the best to serve a larger fraction of the market

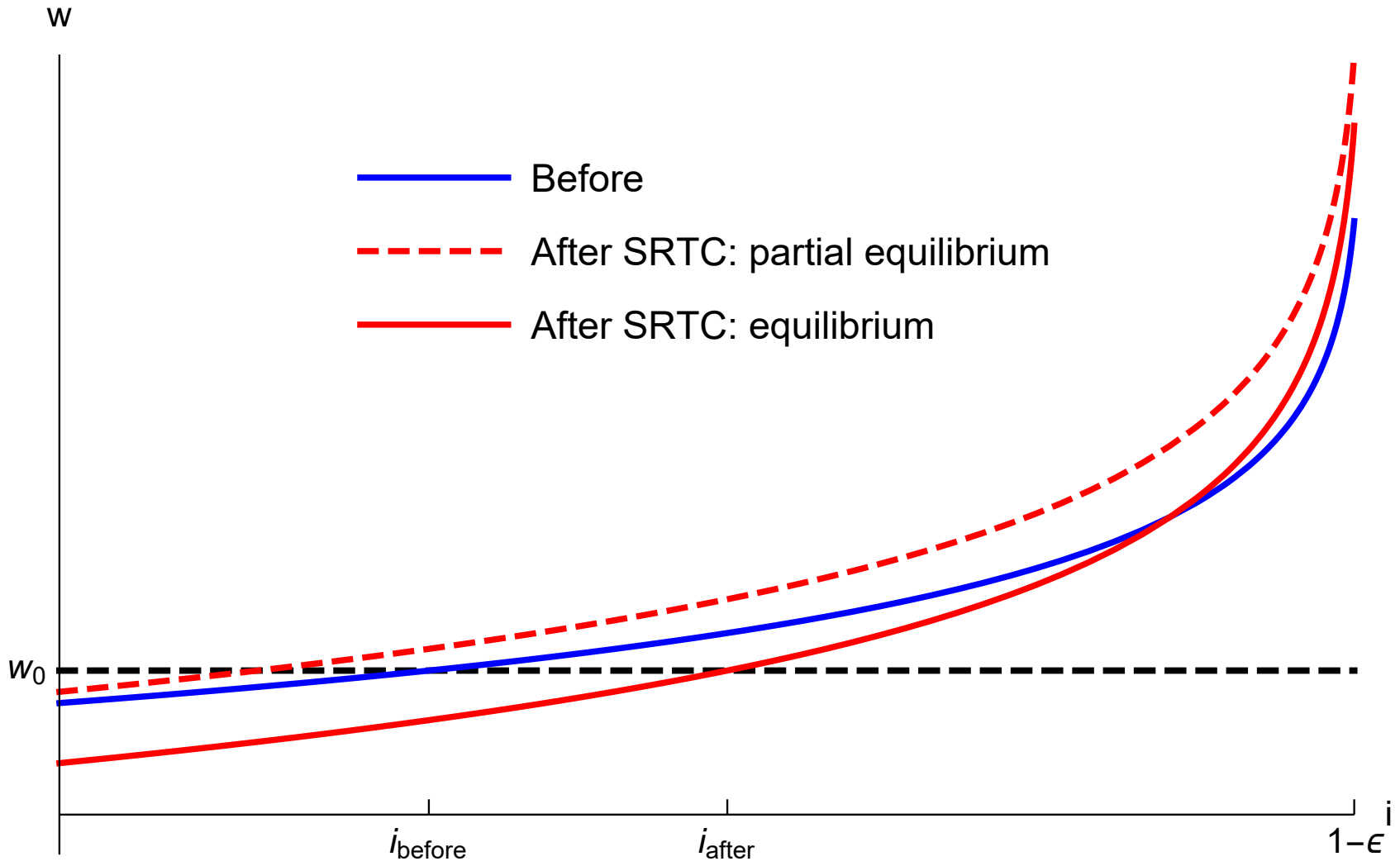
a,b have stable distributions (assumed Pareto)

Model predicted impact of SRTC

1. Wages more right-skewed, top wages and wage shares grow
2. Midlevel wage decline
3. Employment loss, lowest abilities exit

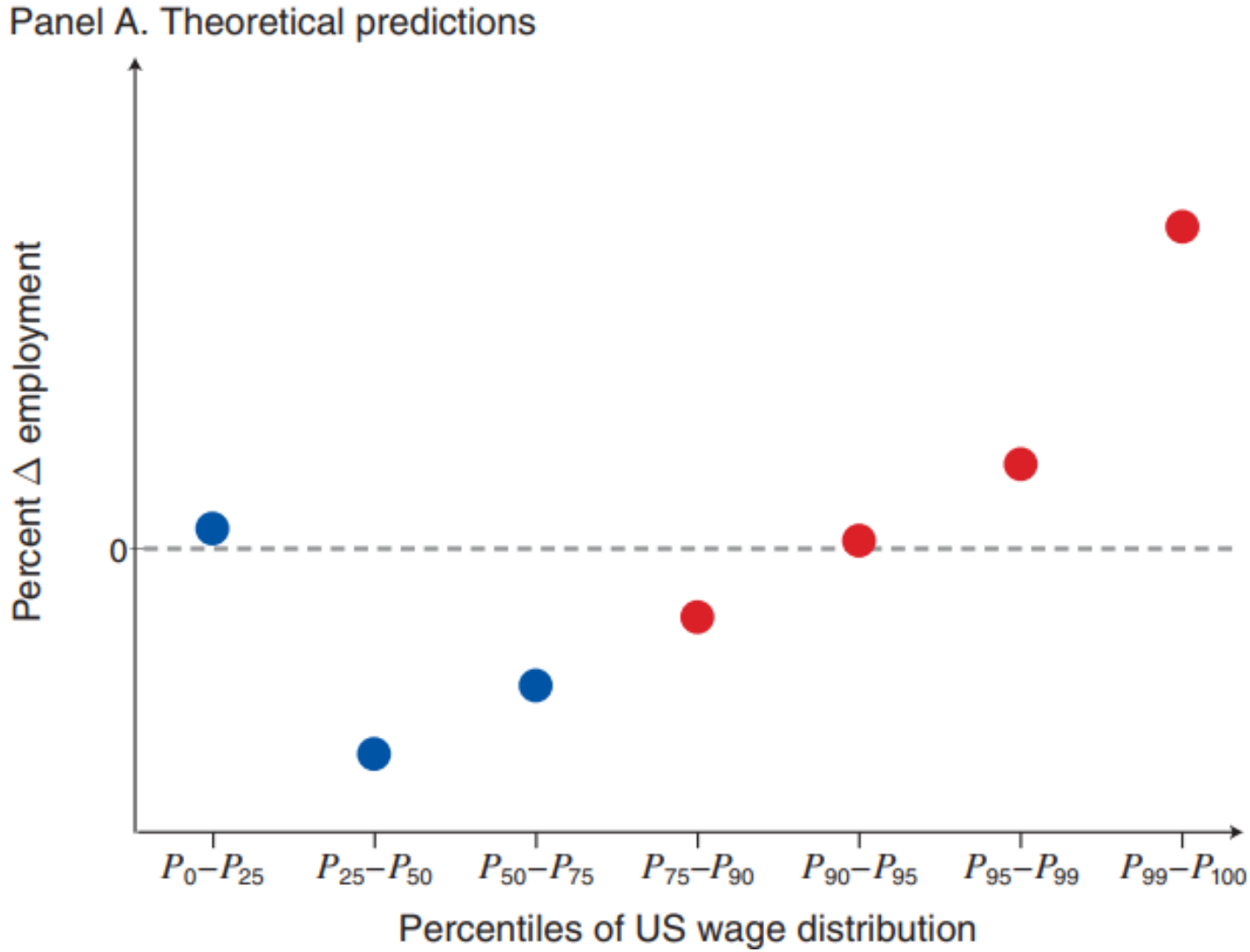
Koenig (2023): Rollout of television

SRTC and equilibrium wages



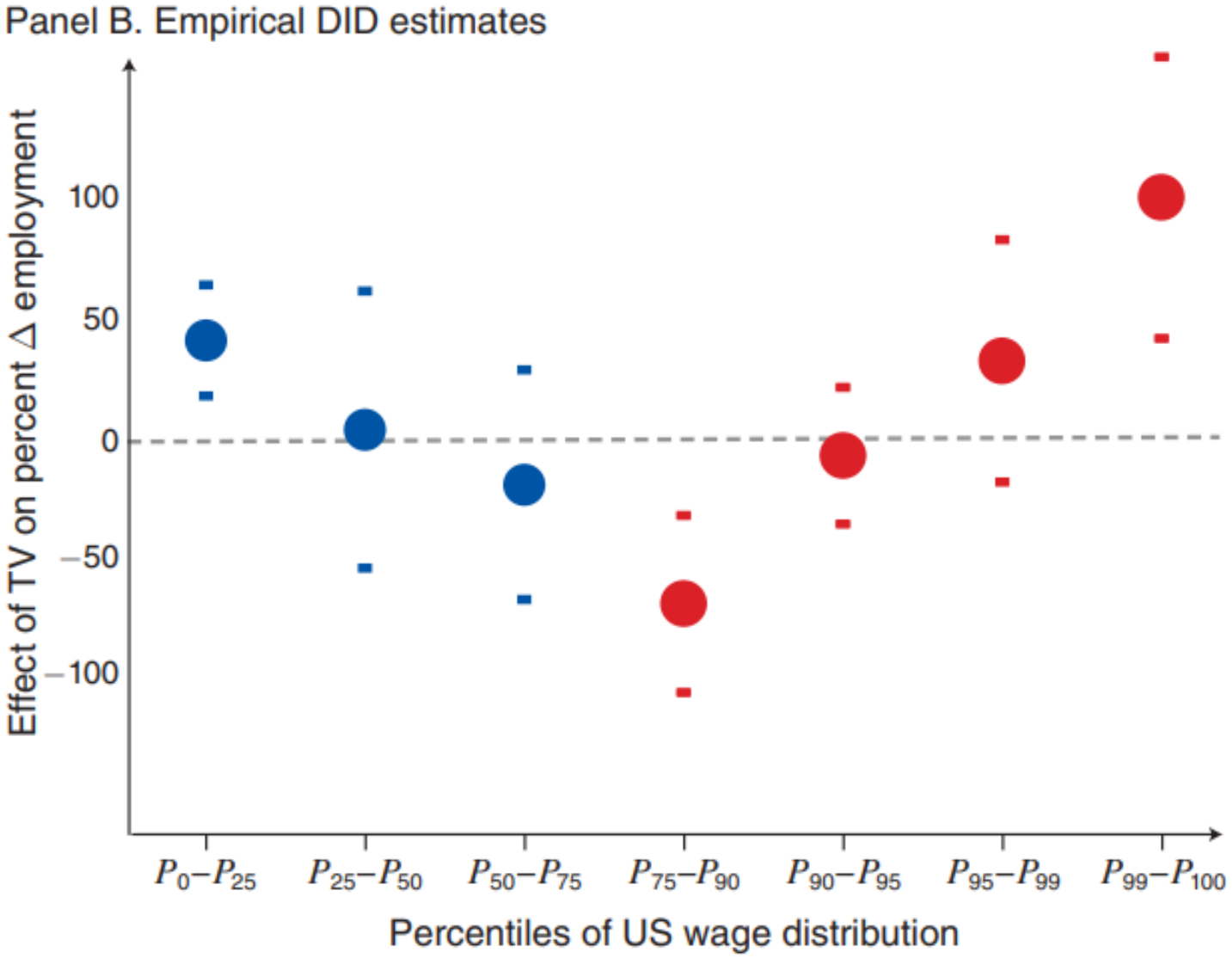
Koenig (2023): Rollout of television

Figure 1A



Koenig (2023): Rollout of television

Figure 1B



Koenig (2023): Rollout of television

TABLE 1—EFFECT OF TV ON ENTERTAINER EMPLOYMENT

	ln(*Employment in Entertainment*)			
	(1)	(2)	(3)	(4)
Panel A. Sample 1940–1970				
TV signal$_t$	−0.128	−0.114	−0.139	
	(0.061)	(0.061)	(0.062)	
Panel B. Placebo sample 1940–1970				
Placebo TV signal$_t$	0.053	0.044	0.053	
	(0.083)	(0.083)	(0.084)	
Panel C. Sample 1930–1970				
TV signal$_{t+1}$				0.039
				(0.033)
TV signal$_t$	−0.133	−0.127	−0.133	−0.123
	(0.059)	(0.059)	(0.061)	(0.060)
Number of CZ cluster	722	722	722	722
Year-Occupation FE	Yes	Yes	Yes	Yes
CZ FE	Yes	Yes	Yes	Yes
Demographics	—	Yes	—	—
CZ level trends	—	—	Yes	—

Koenig (2023): Rollout of television

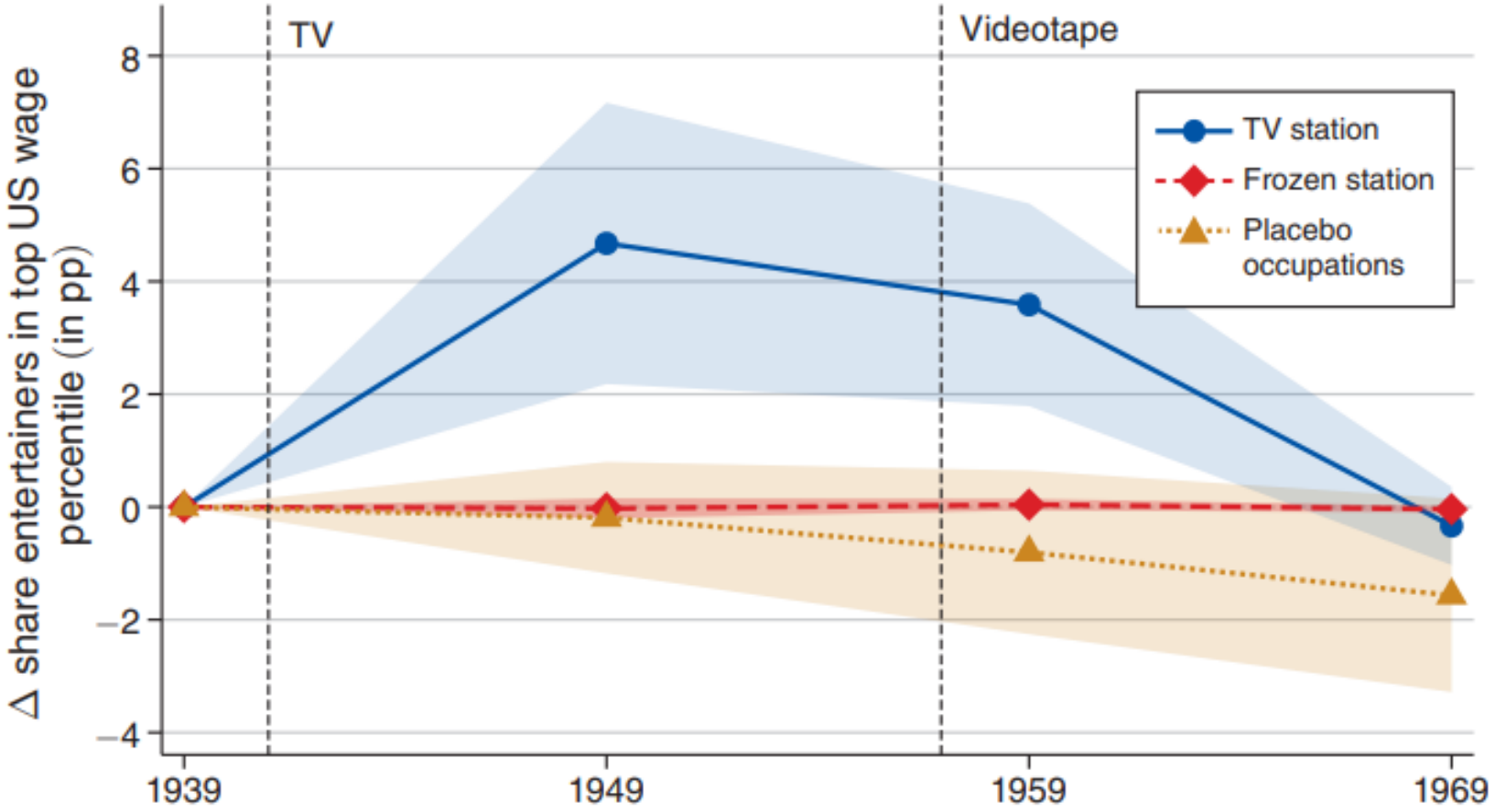
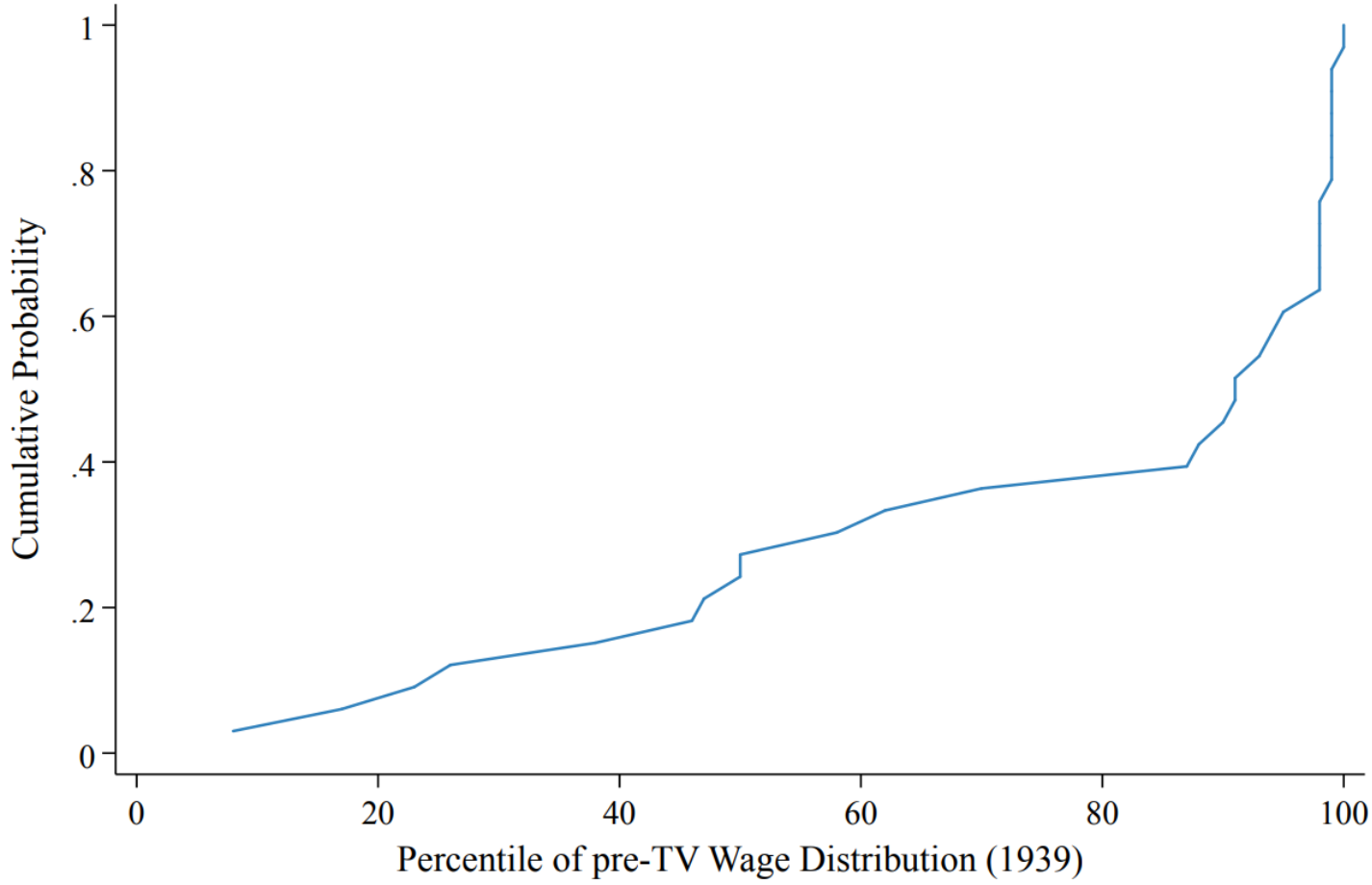


FIGURE 3. DYNAMIC TREATMENT EFFECT OF TV ON CHANGES IN THE SHARE OF ENTERTAINERS IN THE TOP US WAGE PERCENTILE

Koenig (2023): Rollout of television

Addendum with “who is who” lists of TV stars from 1950s

Figure A1. : Wage Rank of Future TV Stars in the 1939 US Wage Distribution



Matching and Dynamics

In the frictionless matching framework, worker movements between firms reflect changes in (expected) skills and firm types.
No amount of mobility will enable estimation of $\{a, b, Y\}$ from a LEED wage panel.
Be careful interpreting AKM/TWFE results. Bonhomme, Lamadon, and Manresa (2019), Lopes de Melo (2018)

Matching with learning about type. Anderson and Smith (2011)

Matching with frictions and search. Chade, Eeckhout and Smith (2017)

Matching while learning from coworkers. E.g., Herkenoff, Lise, Menzio, Phillips (2024)

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Recommended Browsing

- Acemoglu, Daron, and David Autor: Lectures in Labor Economics https://bit.ly/3YvJUS4
- Autor, David: Graduate Labor Economics https://economics.mit.edu/people/faculty/david-h-autor/courses
- Handbook of Labor Economics https://www.sciencedirect.com/handbook/handbook-of-labor-economics/volumes

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