Uneven Growth
Automation’s Impact on Income and Wealth Inequality

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Uneven Growth in the United States: Stagnant incomes at bottom, rising incomes at top

Real Household Income at Selected Percentiles: 1967 to 2014

Note: The 2013 data reflect the implementation of the redesigned income questions. See Appendix D of the P60 report, "Income and Poverty in the United States: 2014," for more information. Income rounded to nearest $100.


Source: U.S. Census (2015)
Candidate Cause: Technology

- Huge literature: technology affects wage inequality
- Examples: SBTC and polarization of wages
- But what about capital income and wealth?
What We Do

- Theory that links tech to income & wealth distribn, not just wages
- Use it to examine distributional effects of automation technologies = technologies that substitute labor for capital in production
- Tractable framework to study dynamics of
  1. macro aggregates
  2. factor income distribution: capital vs labor
  3. personal income, wealth distribution
- Key modeling difference to growth model: perpetual youth ⇒
  - nondegenerate wealth distribution
  - long-run capital supply elasticity < ∞
Our Main Point

Why now?

Technology ⇒ returns ⇒ distributional consequences

Analytic version in our theory:

\[
\text{return to wealth} = \rho + \sigma g + \text{premium}(\alpha)
\]

where \(\alpha\) = capital share = average automation

1. **New mechanism**: technology increases inequality via return to wealth
   - income/wealth distributions have **Pareto tail** with fatness = \(\alpha\)

2. Automation more likely to lead to **stagnant wages**
   - productivity gains partly accrue to capital owners

Paraphrasing these results

- if “robots” increasingly outperform labor, this benefits people owning lots of robots rather than “workers”
But what about interest rates?

Just told you that

\[ \text{return to wealth} = \rho + \sigma g + \text{premium}(\alpha) \]

Natural question: But haven’t interest rates decreased over time?

More later but two points already:

1. Treasury rates = return on specific asset, ave return on US capital ↑
   - for all asset classes except bonds, \( r \uparrow \) or \( r - \sigma g \uparrow \)

2. Even with \( r = t\text{-rate} \), theory = data if \( r \downarrow \) due to \( \rho^* = \rho + \sigma g \downarrow \)
   - what matters for wealth inequality is \( r - \rho^* = \text{premium}(\alpha) \)
   - estimates/models of \( \rho, g \) suggest \( r - \rho^* \) may have increased
Calibrate incidence of automation using exposure to routine jobs

- accounts for changes in wage inequality 1980-2014

Conservative (i.e. high) value for long-run capital supply elasticity

Examine consequences of automation for

- aggregates? Small expansions in $I, Y$
- income, wealth inequality? Sizable increase, uneven growth
- wages? Stagnation except for top of distribution

Even small movements in returns can have large effects
Literature and Contribution

**Automation and inequality** (Acemoglu-Restrepo, Caselli-Manning, Hémous-Olsen, ...)

- capital income & wealth, not just wages
- capital supply elasticity $< \infty$ very different from $= \infty$

**Technology and wealth distribution** (Kaymak-Poschke, Hubmer-Krusell-Smith, Straub,...)

- new mechanism: technology $\Rightarrow$ return $\Rightarrow$ wealth inequality
  (in addition to: technology $\Rightarrow$ wage dispersion $\Rightarrow$ wealth inequality)

**Returns as driver of top wealth inequality** (Piketty, Benhabib-Bisin, Jones,...)

- tractable form of capital income risk, integrated in macro model
- Piketty: $r - g \uparrow$ due to lower taxes, lower $g$. This paper: technology.

**Tractable** theory of macro aggregates, factor and personal income dist

**Perpetual youth literature** (Blanchard): closed form for wealth distribution
Plan

1. Framework and model of automation
2. Steady state
3. Transition dynamics – skip today
4. Model meets data
1. Framework: Households and Technology
Modeling Philosophy

We make some strong assumptions with some unrealistic implications

- perpetual youth ⇒ unrealistic age and age-wealth distributions
- linear policy functions ⇒ unrealistic consumption & saving behavior

In return we get

- in steady state, analytic solution for everything incl distributions
- transition dynamics same difficulty as neoclassical growth model

Key mechanisms present in richer, less tractable theories

Long-run capital supply elasticity < ∞ (Aiyagari,...)

\[ r^* \]

+ returns ⇒ wealth inequality

(Benhabib-Bisin, Piketty, Jones, ...)
Framework: Perpetual Youth Households

Households: age \( s \), skills \( z \), solve

\[
\max_{\{c_z(s), a_z(s)\}_{s \geq 0}} \int_0^\infty e^{-(\rho + p)s} \frac{c_z(s)^{1-\sigma}}{1 - \sigma} ds \quad \text{s.t.} \quad \dot{a}_z(s) = r a_z(s) + w_z - c_z(s)
\]

- \( w_z \): wage for skill \( z \), \( \ell_z \) households
- \( r \): return to wealth
- \( \rho \): discount rate
- \( p \): probability of dying (\( p = 0 \) ⇒ rep agent)
- \( \rho = \rho + p \): effective discount rate

Key assumption: “imperfect dynasties”

- average wealth of newborn < average wealth of living
- stark implementation: eat wealth when die ⇒ no accidental bequests, \( a_z(0) = 0 \)
- other mechanisms: annuities, pop growth, estate taxation
Framework: Technology (Zeira, Acemoglu-Restrepo)

Task-based model: machines/software substitute for tasks, not jobs

First: “reduced form” production side, next slide: where this comes from

1. Each skill type $z$ works in different sector that produces $Y_z$

\[ Y = A \prod_z Y_z^{\gamma_z} \quad \text{with} \quad \sum_z \gamma_z = 1 \]

2. $Y_z$ produced using Cobb-Douglas tech with skill-specific exponent $\alpha_z$

\[ Y_z = \left( \frac{k_z}{\alpha_z} \right)^{\alpha_z} \left( \frac{\psi_z \ell_z}{1 - \alpha_z} \right)^{1-\alpha_z} \]

$\alpha_z = \text{share of tasks technologically automated. Automation: } \alpha_z(t) \uparrow$

3. Capital mobile across sectors, labor immobile
Derivation from Task-based Model (Zeira, Acemoglu-Restrepo)

For simplicity, derivation with only one skill type. Reduced form:

\[ Y = \left( \frac{K}{\alpha} \right)^\alpha \left( \frac{\psi L}{1 - \alpha} \right)^{1-\alpha} \] (*)

Comes out of following task-based model:

1. Final good produced combining unit continuum of tasks \( u \)

\[ \ln Y = \int_0^1 \ln \mathcal{Y}(u) du \]

2. Tasks produced using capital \( k(u) \) or labor \( \ell(u) \) at prices \( R \) and \( w \)

\[ \mathcal{Y}(u) = \begin{cases} \psi \ell(u) + k(u) & \text{if } u \in [0, \alpha] \\ \psi \ell(u) & \text{if } u \in (\alpha, 1] \end{cases} \]

- \( \alpha = \) share of tasks technologically automated. Automation: \( \alpha(t) \uparrow \)
- Example: HR manager, tasks = screen CVs, interview applicants,…
- Displacement vs productivity effects
Derivation from Task-based Model (Zeira, Acemoglu-Restrepo)

For simplicity, derivation with only one skill type. Reduced form:

\[ Y = \left( \frac{K}{\alpha} \right)^{\alpha} \left( \frac{\psi L}{1 - \alpha} \right)^{1-\alpha} \]  

(*)

Comes out of following task-based model:

1. Final good produced combining unit continuum of tasks \( u \)

\[ \ln Y = \int_{0}^{1} \ln \mathcal{Y}(u) du \]

2. Assumption 1 (full adoption): \( w/\psi > R \) (sufficient to have \( L < \bar{L} \))

\[ \mathcal{Y}(u) = \begin{cases} 
\psi \ell(u) + k(u) & \text{if } u \in [0, \alpha] \\
\psi \ell(u) & \text{if } u \in (\alpha, 1]
\end{cases} \]
Derivation from Task-based Model (Zeira, Acemoglu-Restrepo)

For simplicity, derivation with only one skill type. Reduced form:

\[ Y = \left( \frac{K}{\alpha} \right)^\alpha \left( \frac{\psi L}{1 - \alpha} \right)^{1-\alpha} \]  

Comes out of following task-based model:

1. Final good produced combining unit continuum of tasks \( u \)

\[ \ln Y = \int_0^1 \ln \gamma(u) du \]

2. Assumption 1 (full adoption): \( w/\psi > R \) (sufficient to have \( L < \bar{L} \))

\[ \gamma(u) = \begin{cases} 
  k(u) & \text{if } u \in [0, \alpha] \\
  \psi \ell(u) & \text{if } u \in (\alpha, 1]
\end{cases} \]

- 1. and 2. with \( k(u) = K/\alpha, \ell(u) = L/(1 - \alpha) \) imply \((*)\).\( \square \)
2. Characterizing Steady State
Output, Factor Payments and Capital Demand

- Aggregate output:
  \[ Y = \mathcal{A}K \sum_z \gamma_z \alpha_z \prod_z (\psi_z \ell_z)^{\gamma_z(1-\alpha_z)} \]
  \( \alpha = \sum_z \gamma_z \alpha_z \) : aggregate capital-intensity, \( \mathcal{A} = \text{constant}(\alpha_z, \gamma_z) \)

- Factor payments:
  \[ w_z \ell_z = (1 - \alpha_z) \gamma_z Y, \quad RK = \alpha Y, \quad \bar{w} = (1 - \alpha) Y \]
  \( \alpha_z \)'s ⇒ relative wages, factor shares. But effect on levels unclear.

- Aggregate capital demand
  \[ \frac{K}{\bar{w}} = \frac{\alpha}{1 - \alpha} \frac{1}{R} \]

- Expositional assumption for presentation: \( \delta = 0 \Rightarrow R = r \)
Steady State Capital Supply

Households’ consumption and saving decisions:

\[ c_z(s) = \left( \frac{\rho - r}{\sigma} + r \right) \left( a_z(s) + \frac{w_z}{r} \right) \]

\[ \dot{a}_z(s) = \frac{1}{\sigma} (r - \rho) \left( a_z(s) + \frac{w_z}{r} \right) \]

Useful later: relevant state = effective wealth = assets + human capital

\[ x_z(s) := a_z(s) + \frac{w_z}{r} \]

Find aggregate capital supply by integrating (*) with \( \bar{w} := \sum_z w_z \ell_z \):

\[ 0 = \dot{K} = \frac{1}{\sigma} (r - \rho) \left( K + \frac{\bar{w}}{r} \right) - pK \]

Wealth accumulated by surviving households  Imperfect dynasties
Steady-State Equilibrium: Return to Wealth

\[ r^* = \rho + p\sigma \alpha \]

\[
\text{Supply} \quad \frac{K}{\bar{w}} = \frac{1 - \rho/r}{\rho + p\sigma - r}
\]

\[
\text{Demand} \quad \frac{K}{\bar{w}} = \frac{\alpha}{1 - \alpha r}
\]
Same diagram as in richer theories (Aiyagari, Benhabib-Bisin,...)

Demand and Supply of Capital

Supply \[ \frac{K}{\bar{w}} = \frac{1 - \rho/r}{\rho + p\sigma - r} \]

Demand \[ \frac{K}{\bar{w}} = \frac{\alpha}{1 - \alpha r} \]

\[ r^* = \rho + p\sigma \alpha \]

\[ \rho + p\sigma \]
Automation $\Rightarrow$ higher $r$ and modest expansion in $K$
But haven’t interest rates declined?

1. Decline in $r$ due to other secular trends captured by $\rho^* = \rho + \sigma g$
   - what matters for wealth inequality is $r - \rho^* = \text{premium}(\alpha)$
   - lit: aging, $g$, ... account for $r \downarrow$, suggests $r - \rho^*$ flat or increasing
     Auclert-Malmberg-Martenet, Eggertson-Mehrotra-Robbins, Farhi-Gourio, Rachel-Smith, Rachel-Summers, ...

2. Treasury rates $\uparrow$ but return to entire US capital stock $\uparrow$
   Caballero-Farhi-Gourinchas, Gomme-Ravikumar-Rupert, ...

Note: “return to capital” := agg capital income/agg capital stock from NIPA
Recall wealth dynamics: \( \dot{a}_z(s) = \frac{1}{\sigma} (r - \rho) \left( a_z(s) + \frac{W_z}{r} \right) \)

**Proposition:** stationary distribution of effective wealth by skill type is

\[
g_z(x) = \left( \frac{W_z}{r} \right)^{\zeta} x^{\zeta - 1}, \quad \frac{1}{\zeta} = \frac{1}{p} \frac{r - \rho}{\sigma}
\]

Pareto distribution with scale \( w_z/r \) and inverse tail parameter \( \zeta \).
Steady State Income and Wealth Distributions

\[ \dot{x}_z(s) = \frac{1}{\sigma}(r - \rho)x_z(s), \quad x_z(s) := a_z(s) + \frac{w_z}{r} \]

**Proposition:** stationary distribution of effective wealth by skill type is

\[ g_z(x) = \left( \frac{w_z}{r} \right)^\zeta \xi x^{-\zeta - 1}, \quad \frac{1}{\zeta} = \frac{1}{p} \frac{r - \rho}{\sigma} \]

Pareto distribution with scale \( w_z/r \) and inverse tail parameter
Steady State Income and Wealth Distributions

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Pareto distribution with scale \( w_z/r \) and inverse tail parameter \( \frac{1}{p} \frac{r-\rho}{\sigma} \)
Steady State Income and Wealth Distributions

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\dot{x}_z(s) = \frac{1}{\sigma} (r - \rho) x_z(s), \quad x_z(s) := a_z(s) + \frac{w_z}{r}
\]

**Proposition:** stationary distribution of effective wealth by skill type is

\[
g_z(x) = \left( \frac{w_z}{r} \right)^\zeta x^{-\zeta - 1}, \quad \frac{1}{\zeta} = \frac{1}{p} \frac{r - \rho}{\sigma} = \alpha \quad \text{(recall } r = \rho + p\sigma\alpha)\]

Pareto distribution with scale \( w_z/r \) and inverse tail parameter \( \alpha \)
Distribution of Wealth

- Closed form for entire distributions:

\[
\Pr(\text{wealth} \geq a | z) = \left( \frac{a + \frac{w_z}{r}}{w_z / r} \right)^{-\zeta}, \quad \frac{1}{\zeta} = \text{fatness}(r) = \alpha
\]

\[
\Pr(\text{wealth} \geq a) = \sum_z \ell_z \left( \frac{a + \frac{w_z}{r}}{w_z / r} \right)^{-\zeta}.
\]

- Automation has two effects on wealth distribution
  1. **via wages**: determine **scale** of wealth distribution by type
  2. **via return**: determines **fatness** of tail
Distribution of Income

- Again, two sources of inequality: wages and return to wealth

- Again, closed form for entire distributions:

\[
\Pr(\text{income } \geq y | z) = \left( \frac{\max\{y, w_z\}}{w_z} \right)^{-1/\alpha}
\]

\[
\Pr(\text{income } \geq y) = \sum_z \ell_z \left( \frac{\max\{y, w_z\}}{w_z} \right)^{-1/\alpha}.
\]
Wage Stagnation with Upward-sloping Capital Supply

- CRS aggregate production function with technology indexed by $\theta$
  \[ F(K, \{l_z\}_{z \in Z}; \theta), \quad F_\theta > 0 \]

- Question: effect of technological change $d\theta > 0$ on factor prices?
  \[
  \begin{aligned}
  d \ln \text{TFP} > 0 & \iff d \ln R + (1 - \alpha) d \ln \bar{w} \leq 0, \\
  \bar{w} := \sum_z w_z l_z
  \end{aligned}
  \]

  (Derivation: see e.g. Jaffe-Minton-Mulligan-Murphy (2019), uses $F = RK + \sum_z w_z l_z$)

- Bulk of literature: $d \ln R = 0$ because perfectly elastic capital supply
  - rep agent or small open economy (Acemoglu-Restrepo, Caselli-Manning, ...)
    \( \Rightarrow \) all productivity gains accrue to labor, wages track TFP

- Our paper: $d \ln R > 0 \Rightarrow$ wages may stagnate or even decrease
  \( \Rightarrow \) lackluster investment response
3. Transition Dynamics

Skip this today
4. Model meets Data
Aggregate and Distributional Effects of Automation

Consequences of automation for income inequality and aggregates?

- interpret each \( z \) as percentile of wage dist; focus on 1980-2014
- use variation in routine jobs across wage percentiles \( z \)
  
  \[ \Delta \alpha_z(t) \approx - \text{exposure}_z \times \Delta \text{Labor share}(t) \]

\( \text{exposure}_z \): share of wages paid to routine jobs in \( z \) (2000 Census)

scale: automation drives decline in \( \text{Labor share}(t) = 1 - \alpha(t) \)

- calibrate \( \psi_z \) so automation yields cost-saving gains \( \ln \frac{w_z}{\psi_z R} = 30\% \)
- calibrate \( p = 3.85\% \) to target capital-supply elasticity \( \frac{d \log K}{d r} = 50 \)
Automation of Routine Jobs: The Shock

Panel A. Calibrated behavior of $\alpha_z(t)$

Panel B. Implied behavior of aggregate labor share
- 1 pp increase in return to wealth \( \Delta \text{Data} \); 15% increase in \( K/Y \) \( \Delta \text{Data} \).

\[
\frac{d\ln \text{TFP}}{3\%} = \alpha \frac{d\ln R}{0.4 \, 10\%} + \left(1 - \alpha \right) \frac{d\ln \bar{w}}{0.6 \, -2\%}, \quad \bar{w} := \sum_z w_z \ell_z
\]
Declining wages except at top

Recall \[ w_z(t) = (1 - \alpha_z(t))\gamma_z\frac{Y(t)}{\ell_z} \]
... and substantial uneven growth
... and substantial uneven growth
... and substantial uneven growth
... and substantial uneven growth

Change in income by percentile of the income distribution

- Total income growth
- Part due to wage income
- Part due to capital income
- Rep. household model

percent change

income percentile

top tail
Empirical counterpart: uneven growth in IRS, Piketty-Saez-Zucman data

Panel A. Change in income by percentile of the income distribution, IRS data

Panel B. Change in income by percentile of the income distribution, PSZ data
Caveat: model transition too slow

Good news: know how to fix this (Gabaix-Lasry-Lions-Moll)

- heterogeneous returns or saving rates
Conclusion

- Tractable framework to think about uneven growth
  - have used it to study distributional effects of automation
  - not just on wages but also on income and wealth distributions
- Technology $\Rightarrow$ returns $\Rightarrow$ distributional effects
  - rising concentration of capital income at top
  - stagnant or declining wages at the bottom
- Framework has lots of other potential applications
  - trade: globalization’s impact on income and wealth inequality?
  - PF: optimal capital income and wealth taxation?
  - ...
- Needed: better evidence on asset returns (x-section & time-series)