Does Productivity Growth Threaten Employment?
“Robocalypse Now?”

David Autor ¹  Anna Salomons ²

¹MIT
²Utrecht University

European Central Bank Annual Conference, Sintra, Portugal
27 June 2017
Longstanding concern: Automation threatens employment

Automation and Jobs: 200 Years of Concern

1. Luddites—Skilled weavers in the 19th century
2. U.S. Labor Secretary James Davis in 1927
4. Wassily Leontief in 1982: Role of workers will diminish — like horses
5. Right now!
Fundamentally, does rising productivity mean fewer jobs?

**Citizen, policy-maker, intellectual concern**

- The more work done by machines, the less work done by people
- Steam-powered hammer vs. “steel-driving man”

**Professional economic opinion**

1. Elastic demand: Advancing sectors may *expand* (Bessen 2017)
2. Income effects: Rising wealth creates *new demands* (Clark 1951)
3. Sectoral reallocation: Advancing sectors *contract*, but labor moves to lagging sectors (Baumol 1967)
Productivity $\rightarrow$ Employment: An ‘Inverted U’ (Bessen ’17)

Employment first expands then contracts as productivity rises in textiles, iron, steel

Textile, Cotton, Fiber Workers

Primary Iron & Steel Workers

Figure 1. Production Employment in Three Industries

pattern appears to be quite general for manufacturing industries (Buera and Kaboski 2009, Rodrik 2016).
Economists appear to be losing confidence in these long-held theories: “Robocalypse Now?”

Labor’s share of national income falling cross-nationally

![Graphs showing the labor share of GDP for the United States, Japan, China, and Germany from 1975 to 2015](image)

*GLOBAL DECLINE OF THE LABOR SHARE*

*Karabarbounis and Neiman, 2014*
It’s not just the falling labor share that has scholars worried...

An age of ‘brilliant machines’ (Brynjolfsson-McAfee ’14)

1. Computers managing financial portfolios, beating ‘Go’ players
2. Websites and drones eliminating sales workers, warehouse workers
3. Robots leaving the assembly lines, coming for your jobs...
Economists have taken notice...

**Emerging understanding makes clear that this can happen**

- Machines can directly *replace* specific job tasks, *complement* workers in other job tasks, possibly spur creation of *new* labor-using tasks
- Autor-Levy-Murnane ’03, Acemoglu-Autor ’11, Acemoglu-Restrepo ’16

**Growing literature: models of labor immiseration**

1. Inter-generational market failure: Sachs & Kotlikoff ’12, Berg et al. ’17
2. Task encroachment: No place left to hide (Susskind ’17)
3. New tasks *might* endogenously be created ‘fast enough’ – or perhaps not (Acemoglu & Restrepo ’16)
Evidence does not (yet) strongly support immiseration view

Vast literature makes clear that computerization has been skill-biased

- Autor-Katz-Kearney ’08; Akerman-Kostol-Mogstad, ’14

But little work on overall employment impact of technological $\Delta’s$

1. Alexopoulos-Cohen ’16: Technological progress strongly employment-creating — but in the 1910s–1940s

2. Gregory-Salomons-Zierahn ’16: Employment-reducing effects of Routine-Replacing Technical Change (RRTC) offset by compensatory demand + local spillover effects

3. Graetz-Michaels ’15: Industrial robots raising wages and value-added, raising demand for skilled workers across Europe (industry-level data)

4. Acemoglu-Restrepo ’17: Industrial robots lowering wages and employment in U.S. local labor markets
This paper asks: Is recent labor-augmenting technological progress eroding employment?

1. Does productivity growth cause advancing industries to grow or shrink?

2. Do cross-industry spillovers offset or augment direct own-industry effects—and what’s the net effect?

3. Has the employment-productivity relationship changed in the 2000’s?

4. Is productivity-growth skill-biased—should we worry about jobs or skills?
Is recent labor-augmenting technological progress eroding employment?

Approach

- Study the **impact of productivity growth on employment** across 19 countries, 37 years
- Focus on **overall** productivity growth: (1) output per worker, (2) value-added per worker, (3) total factor productivity

Outcomes

- \(\Delta\) Employment by industry
- \(\Delta\) Employment to working-age population—i.e., overall employment
- \(\Delta\) Final consumption by industry—corroborating productivity effects
- \(\Delta\) Skill inputs within industries
- \(\Delta\) Skill inputs economy-wide—due to induced sectoral shifts
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Big picture: Employment rate usually rises with productivity


Figures are for the total economy, excluding agriculture, public administration, private households and extraterritorial organizations. All growth rates obtained as log changes x 100. Graph 6 reports unweighted mean growth rates across the remaining 14 countries. Productivity is gross output per worker.

Autor & Salomons

Not just the 'Big Five' countries: Employment rates rise with productivity

Graphs show employment to working age population growth and labor productivity growth for Austria, Denmark, Italy, Netherlands, Spain, and South Korea from 1970 to 2010.

Figures are for the total economy, excluding agriculture, public administration, private households and extraterritorial organizations. All growth rates obtained as log changes x 100. Graph 6 reports unweighted mean growth rates across the remaining 14 countries. Productivity is gross output per worker.
Data sources

Primary: EU KLEMS 1970-2007 (O’Mahony & Timmer ’09)

- **19 developed countries**
  - AUS, AUT, BEL, DNK, ESP, FIN, FRA, GER, GRC, IRL, ITA, JPN, KOR, LUX, NLD, PRT, SWE, UK, USA

- **28 industries**
  - All non-farm employment except public administration, private households, and extraterritorial organizations

- **Employment and labor productivity**
  - Real gross output per worker, real value added per worker, total factor productivity (TFP) by country-industry-year

**Additional measures: World Input Output Tables (WIOT)**

- Measuring consumption responses to productivity gains
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Do ‘advancing’ industries grow or shrink?

Testing whether rising productivity raises or lowers employment...

- Using KLEMS data for 17 countries, 25 industries, 37 years, fit country- by-industry- by-year stacked first-difference OLS model

\[
\Delta \ln E_{cit} = \beta_0 + \beta_1 \Delta \ln LP_{cit} + [\alpha_c + \delta_t + \gamma_i] + \epsilon_{cit}
\]

- \(\Delta \ln LP_{cit}\) is growth in labor productivity
- \(i\) indexes industries
- \(c\) indexes countries
- \(t\) indexes years
- \(E\) is employment

Models are weighted by the time-averaged employment shares of industries within countries
What should happen to industry employment as $\Delta \ln L_P^{cit}$ rises?

1. **Lump-of-labor**
   - Could *fall one-for-one* with labor productivity growth: $\frac{\partial \ln E_i}{\partial \ln L_P^i} = -1$

2. **Demand surge (iPhone, textiles)**
   - Could *surge* as price/quality improve: $\frac{\partial \ln E_i}{\partial \ln L_P^i} > 0$

3. **Unbalanced growth (Baumol)**
   - Could *fall* somewhat less than *one-for-one*: $-1 < \frac{\partial \ln E_i}{\partial \ln L_P^i} < 0$
What **does** happen: Rising labor productivity $\rightarrow$ Falling industry employment

![Bar chart showing estimated coefficients for Gross output per worker, Value added per worker, and Gross output based TFP.](image)

**Legend:**
- No FE
- Country, year FE
- Country*year, country*industry, industry*year FE
- Country FE
- Country, year, industry FE

95% confidence interval

All models are estimated by OLS and control for population growth whenever country-year fixed effects are not included.
Do ‘advancing’ industries grow or shrink?

Rising labor productivity → Falling industry employment

Using **gross-output** based labor productivity growth: Found in every industry

From a model with a full set of industry interactions in all productivity terms; country, industry, and year fixed effects; and controlling for population growth. Productivity is gross output per worker.
Reality check: Is there a consumption response? Check!

Consumption of industry output rises with industry productivity, even as employment falls.
Unbalanced growth: Employment in ‘advancing’ sectors shrinks

**Cumulative Productivity Growth**

- Mining, utilities, construction
- Manufacturing
- Education, health
- Low-tech services
- High-tech services

Unweighted average across all 19 countries. Productivity is gross output based.

**Cumulative Change in Employment**

- Mining, utilities, construction
- Manufacturing
- Education, health
- Low-tech services
- High-tech services

Shares normalized to 0 in 1970. Unweighted average across all 19 countries.
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Negative employment impact at industry level but seemingly not at aggregate level. Why not?

Reconciling the evidence

- Perhaps there are employment spillovers elsewhere in economy
  - Rising final demand — income effects
  - Inter-industry demand linkages

Use industry-level and country-level data to estimate

\[ \Delta \ln E_{cit} = \beta_0 + \beta_1 \Delta \ln LP_{cit} + \sum_{k=0}^{3} \beta_{2+k} \Delta \ln \tilde{LP}_{ct-k,j \neq i} [\alpha_c + \delta_t + \gamma_i] + \epsilon_{cit} \]

- \( \tilde{LP}_{ct-k,j \neq i} \) is aggregate labor productivity excluding own-industry \( i \)
- \( LP_{cit} \) is own-industry labor productivity
- \( c \) indexes countries
- \( t \) indexes years
### Direct and Spillover Effects of Productivity Growth

Spillover effects fully offset internal effects: Net impact on emp/pop is weakly positive

<table>
<thead>
<tr>
<th></th>
<th>Estimated Coefficient</th>
<th>Direct Effect</th>
<th>Spillover Effect</th>
<th>Net Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross Output (GO) per worker</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Value added per worker</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Peak-to-peak (GO per worker)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gross output based TFP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trough-to-trough (GO per worker)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All models are estimated by OLS; contain country, year, and industry FE; and control for population growth.

 Autor & Salomons
Is all productivity growth equally job-creating?

Industry productivity growth raises aggregate employment on average—but does it matter where productivity originates?

- We have so far restricted effects of industry productivity to have uniform impacts
- But internal and external effects of productivity growth may vary across sectors
  - Relative weight in the economy
  - Product market competition
  - Demand saturation
  - Integration in international production chains.
Is all productivity growth equally job-creating?

Allow direct effects and spillovers to differ by sector

1. Mining, utilities and construction
2. Manufacturing
3. Education and health
4. Low-tech services: Retail, sales, hotels, restaurants, etc.
5. High-tech services: Finance, business services, telecoms

\[
\Delta \ln E_{ict} = \beta_0 + \sum_{s(i)=1}^{5} \beta_{1,s(i)} \Delta \ln LP_{ict} + \sum_{s(i)=1}^{5} \sum_{k=0}^{3} \beta_{2+k,s(i)} \Delta \ln \tilde{LP}_{ct-k,s(i),j\neq i} 
\]

\[
[+\alpha_c + \delta_t + \gamma_i] + \epsilon_{ict}
\]

\(\hat{\beta}_{1,s(i)}\) are sector-specific effects of own-industry labor productivity

\(\hat{\beta}_{2+k,s(i)}\) are sector-specific spillovers to other industries
Sizes of **direct and spillover effects differ by sector**

Manufacturing has **least negative** direct effect; low-tech services has **largest positive** spillovers

Model is estimated by OLS; includes country, industry, and year FE; and controls for population growth. Productivity is gross output per worker.
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Translating direct+spillover effects into total emp/pop

What do direct + spillover effects imply for emp/pop in net?

- Use estimates to infer how much each sector’s productivity growth has augmented or decreased total employment-to-population

\[
\Delta \hat{E}_{ict} = \{E_{ic,t=\text{base}} \times 1(i \in s) \times \hat{\beta}_{1,s(i)} \times \Delta \ln LP_{ict}\} \\
+ \{E_{ic,t=\text{base}} \times \sum_{s(i)=1}^{5} \sum_{k=0}^{3} \hat{\beta}_{2+k,s(i)} \times \Delta \ln \tilde{LP}_{ct-k,s(i),j\neq i}\}
\]
Implied cumulative **direct** effects of productivity growth on total $\Delta$ employment-to-population in % pts, 1970–2007

Based on model 5 from Table 7; prediction averaged across all 19 countries. Productivity is gross output per worker.
Implied cumulative **spillover** effects of productivity growth on total $\Delta$ employment-to-population in % pts, 1970–2007

Based on model 5 from Table 7; prediction averaged across all 19 countries. Productivity is gross output per worker.
Implied cumulative **net effects** of productivity growth on $\Delta$ employment-to-population in % pts, 1970–2007

Based on model 5 from Table 7; prediction averaged across all 19 countries. Productivity is gross output per worker.
Adding it up

Implied cumulative **net effects** of productivity growth on $\Delta$ employment-to-population in % pts: Five largest economies

<table>
<thead>
<tr>
<th>Year</th>
<th>1. France</th>
<th>2. Germany</th>
<th>3. Japan</th>
<th>4. UK</th>
<th>5. USA</th>
<th>6. Mean of all others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1980</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1990</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>2000</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2010</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Based on model 5 from Table 7. Productivity is gross output per worker.
How big are these effects? Pretty big actually...

Actual changes in emp-to-pop vs. **contribution of productivity growth**: Five largest economies

Figures are for the total economy, excluding agriculture, public administration, private households and extraterritorial organizations. Productivity is gross output per worker.
What’s the key driver of job growth? **Population growth!**

*Actual growth in total workers vs. contribution of population growth & productivity growth*

**Figures are for the total economy, excluding agriculture, public administration, private households and extraterritorial organizations. Productivity is gross output per worker.**
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Productivity ⇒ Job growth: Is this time (period) different?

Productivity and job growth appear to diverge in some countries in 2000s (e.g., U.S.)

- Consider whether the productivity-employment relationship has changed over time
- **Why?** Changing technologies, growing global production chains, shifting market structure, demand saturation

Add decade-specific effects to baseline equation

$$
\Delta \ln E_{ict} = \beta_0 + \sum_{d(t)=1}^{4} \beta_{1,d(t)} \Delta \ln L_{Pict} + \sum_{d(t)=1}^{4} \sum_{k=0}^{3} \beta_{2+k,d(t)} \Delta \ln \tilde{L}_{Pct-k,j \neq i} 
+ \alpha_c + \delta_t + \gamma_i + \epsilon_{ict}
$$

- where \(d(t)\) indicates decades
Internal effect more (−) and spillover less (+) in 2000s
But 2000s do **not** look very different from the 1980s

Model is estimated by OLS; contains country, year, and industry FE; and controls for population growth. Productivity is gross output based.
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Even if productivity growth is neutral for employment, may be non-neutral for skill demand

Labor productivity growth may shift skill demands in two ways

1. **Skill bias**: Firms may differentially eliminate low-, medium-, or high-skill workers
   - We find that this is not quantitatively important

2. **Sector bias**: ‘Advancing’ sectors shrink + ‘lagging’ sectors grow
   - High productivity growth in manufacturing and primary industries may shift the weight of employment towards more skill-intensive sectors
   - This turns out to be quite important
Even if productivity growth is neutral for employment, may be non-neutral for skill demand

Scale predicted employment growth by industry by average share of low-, middle-, and high-education workers

\[
\Delta \hat{E}_{iq, t=\text{base}} = \{E_{iq, t=\text{base}} \times 1(i \in s) \times \hat{\beta}_{1, s(i)} \times \Delta \ln L P_{ict}\} \\
\quad + \{E_{iq, t=\text{base}} \times \sum_{s(i)=1}^{5} \sum_{k=0}^{3} \hat{\beta}_{2+k, s(i)} \times \Delta \ln \tilde{L} P_{ct-k, s(i), j \neq i}\}
\]
Productivity growth has been strongly **skill-biased** 1970-2007 due to induced sectoral shifts.

Based on model 5 from Table 7; prediction averaged across all 19 countries.
Productivity is gross output based.
U.S. stands out for having most ‘polarized’ sectoral shifts: Reallocation towards high- and low-skill intensive sectors

Based on model 5 from Table 7. ‘Mean of all others’ is unweighted average across all remaining 14 countries. Productivity is gross output based.
Outline

1. Data sources and the ‘big picture’
2. Do ‘advancing’ industries grow or shrink?
3. Reconciling industry and aggregate-level evidence
4. Adding it up
5. Is this time (period) different?
6. Should we worry about jobs or skills?
7. Conclusions
Is productivity growth threatening employment? Not so far...

1. Employment shrinks in advancing sectors—but spillovers offset in lagging sectors
   - **Net effect:** Productivity growth modestly contributes to rising employment-to-population—as well as rising consumption
   - “Robocalypse Later?” Virtuous relationship may have weakened in the 2000s. But see Hall (2017)

2. Distribution of productivity growth across sectors matters
   - Productivity growth in services produces largest positive spillovers
   - **Good news:** Robotics have potential to raise productivity in services

3. Productivity growth good for employment, skill impacts non-neutral
   - Challenge is **not** quantity of jobs
   - Challenge is **quality** of jobs available to low- and medium-skill workers