Technology-Skill Complementarity and Labor Displacement: Evidence from Linking 150 Years of Patents with Occupations

L. Kogan[1] D. Papanikolaou[2] L. Schmidt[3] B. Seegmiller[3]

[1]MIT Sloan and NBER

[2]Kellogg School of Management and NBER

[3]MIT Sloan

Motivation

Facts:

- Worker earnings have grown slower than labor productivity
  - Leading to a decline in the labor share of output
- Skill Premium has increased along with income inequality

Question: To what extent did technological change contribute to these outcomes?

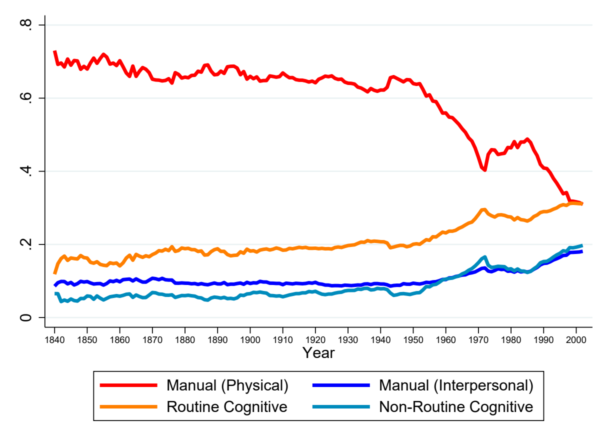
- Technological change hard to measure directly, its effects need to be inferred from observable quantities and prices

This paper: Construct direct measures of technological change linked to individual worker task descriptions.

What we do

- Leverage state-of-the-art techniques in textual analysis to identify breakthrough technologies affecting specific occupations.
  - Identify significant innovations through textual networks.
  - Relate these innovations to **specific workers** based on DOT/ONET occupation task descriptions.
- Construct time-series indices of occupation-specific technical change that span the last two centuries.
  - Examine the response of employment and wages to technology shocks both at the aggregate as well as the individual level.
- Interpret our empirical findings through the lens of a model of technology-skill complementarity with displacement.

Preview: Exposure to Technological Change Over Time, Occupation Task Categories



Manual (physical): vehicle/machine operators, electricians, mechanics
Routine cognitive: technicians, clerks, programmers
Manual (interpersonal): teachers, counselors, psychologists
Non-routine cognitive: surgeons, managers, engineers

Findings

1. At the industry level, our technology indicators are positively related to labor productivity yet predict a decline in the labor share
2. At the occupation and worker level, technological change is consistently negatively related to employment and wage growth
   - Negative relation with employment growth consistent over last 150 years
   - Technology negatively related to wage growth over the last 30 years
3. Estimates consistently negative across groups; magnitudes larger for:
   - non-college educated workers
   - older workers
   - more highly-paid workers

Caveat: We are not going to be able to say anything about the creation of new occupations. Our results thus pertain to skill displacement of workers in existing tasks.

- Autor, Salomons, and Seegmiller (2021): role of technological change in the creation of new work.

Implications

- Larger exposure of high-income workers hard to reconcile with the canonical model of technology-skill complementarity
  - We modify the standard model (Krusell et al, 2000) to allow for skill displacement
  - As technology improves, some skilled workers become unskilled.
- Implications:
  - Introduces a wedge between changes in the skill premium and the wage growth of (currently-skilled) workers.
  - Higher labor income risk for skilled workers
  - Calibrated model fits these facts in the presence of technology-skill complementarity

Measurement

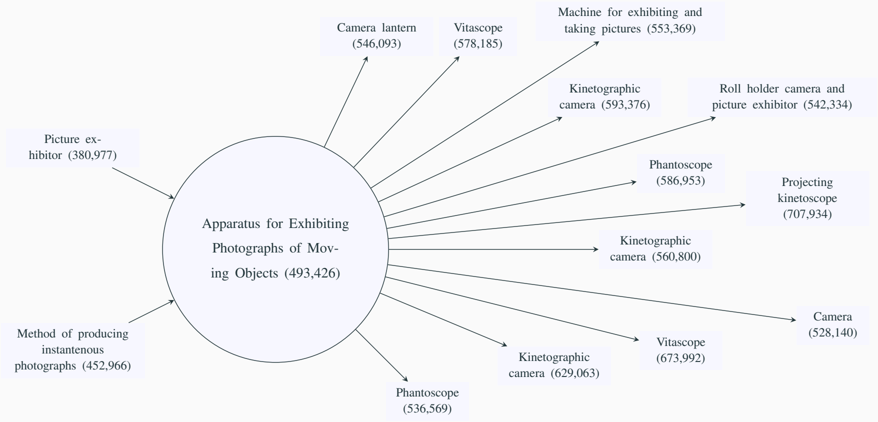
Innovation is hard to measure directly

- How do you measure knowledge?
  - R&D spending measures inputs not outputs.
- Our starting goal is patents. Why?
  - By definition, patents relate to new inventions (though not all valuable inventions are patentable)
  - They measure output not inputs (important if you think research productivity is slowing down)
- However, not all patents are equally valuable inventions.
  - pro-patent shift in US policy (Hall and Zeidonis 2001)
- To create meaningful indices of innovation, we need to weigh important patents differently from ones that are trivial.

Measurement: Broad Idea

1. We follow Kelly, Papanikoloau, Seru, and Taddy (2021) (hereafter KPST) and identify important patents as those that:
    - are distinct from previous patents but are related to subsequent patents (i.e., they are novel and impactful)
    - Implementation: We need to measure the similarity between a given patent and prior and subsequent patents (within a window).
2. We identify the exposure of occupation j to technology as
    - # of important patents that are related to the tasks occupation j performs
    - Implementation: We need to measure the similarity between a given patent and occupation task descriptions (ONET/DOT)

Patent-patent similarity example: Moving Pictures



Measuring technical change

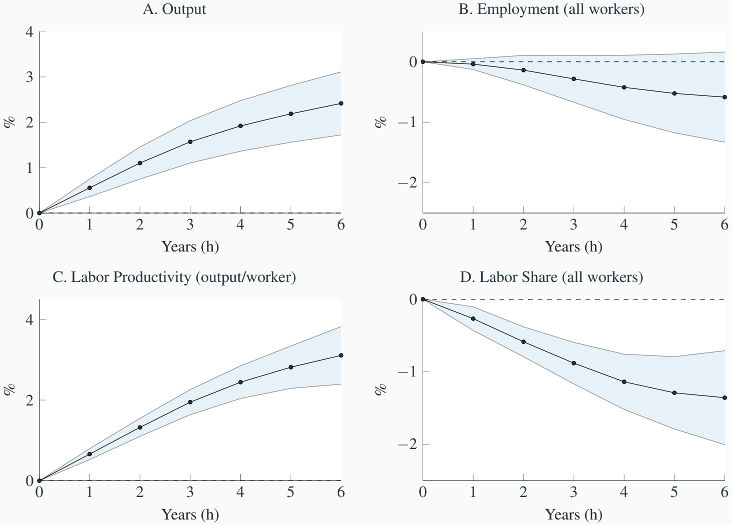
- KPST identify important patents as those that are both
  - novel (fewer past connections) and
  - impactful (have more future connections).

- Index of technological change
  - Count the # of patents / year at the right tail of the distribution of importance (breakthroughs)
  - Map these to industry NAICS codes using patent tech class crosswalks from **Goldschlag et al 2016**

- Relate to industry outcomes

$$\log(Y_{j,t+k}) - \log(Y_{j,t}) = \alpha(k) + \beta(k)\psi_{j,t} + \delta(k)Z_{j,t} + \varepsilon_{j,t}, \qquad k = 1 \ldots 6$$

Innovation: Productivity vs Labor Share



Summary and Next Steps

- Technological change is associated with increases in labor productivity, no change in industry employment, and a decline in labor share.
- Impact of technical change likely heterogenous across workers:
  - ATMs likely displaced bank tellers; impact on stock brokers unclear.
- To dig deeper into these facts, we next construct measures of technological change at the occupation level.
- **Methodology:** connect specific technologies (patents) to specific workers (occupations) based on the textual similarity between the description of the innovation and the workers' task description.
  - Note: Since our approach is based on measuring task overlap, primarily identifies patents that substitute rather than complement worker tasks.

Patent $\Leftrightarrow$ Task Description


5,911,135

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SYSTEM FOR MANAGING FINANCIAL ACCOUNTS BY A PRIORITY ALLOCATION OF FUNDS AMONG ACCOUNTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 07/408,173, filed Sep. 15, 1989 now abandoned, which is a continuation of U.S. patent application Ser. No. 07/038,817, filed Apr. 15, 1987 now U.S. Pat. No. 4,953,085.

BACKGROUND OF THE INVENTION

This relates to a method and apparatus which provides an integrated financial product package. This system is realized, in the preferred embodiment, when implemented on a real-time computer system, and accordingly will be described in such context. It will be understood, however, that the invention may be applied to numerous other contexts.

Secured lending against homes has been practiced for many years, and recently a host of new financial products has been introduced in an effort to make mortgage lending more attractive to financial institutions and to make housing more affordable to prospective homeowners. Despite the proliferation of new mortgage products in this intensely crowded and competitive area, prior practices have not been entirely successful in meeting the goals of both the mortgagor and the financial institutions. Moreover, product proliferation in the market for financial services has presented the consumer with a confusing array of choices without a convenient or mathematically correct means of selecting the best combination of financial services to realize the consumer's financial objectives.

Financial institutions have traditionally lent funds to individuals on a fully secured basis, with an interest rate greater than their own cost of funding the loan. In the last few years however, the financial industry has been deregulated and now it is possible for a variety of financial institutions and firms that market financial services (hereinafter referred to as "financial institutions") to sell an entire range of financial products. Thus, in addition to the traditional objectives of a mortgagee, many financial institutions now view mortgage lending as a vehicle to encourage the borrower to purchase one or more financial service products. Methods are needed, however, to facilitate the provision of such services.

From the point of view of the mortgagor, problems still remain with the relative inflexibility of the mortgage. The mortgagor is locked in to a payment schedule which typically extends over most of the years in which he is working.

The recently enacted Tax Reform Act of 1986 (TRA-86) has also affected the situation. While it eliminated many tax deductions and tax shelters, it provided for the continued deductibility of interest payments on mortgages up to the full amount of the cost of two homes and any improvements thereto. Moreover, certain insurance products, annuities, and pension plans continue to be attractive "tax-favored" investments under the new law.

Present mortgage practices, however, do not take advantage of deregulation of the financial services industry and the new tax laws and are not employed to offer the mortgagor a full range of financial services that would help him to maximize his financial return.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for effecting an improved personal financial management pro-

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gram incorporating means of implementing, coordinating, supervising, analyzing and reporting upon investments in an array of assets and credit facilities. Through a mathematical programming function the client specifies his financial objectives, a forecast of economic and financial variables, risk preference and the budgetary constraints to which he is subject. The mathematical programming function suggests investments and credit facilities to the client to best realize his financial objectives. Thus, the present invention provides clients a convenient, cost effective, and mathematically rigorous means of maximizing his or her financial well-being. The mathematical programming function presents the financial institution an easily definable means of managing client accounts that have potentially an infinite number of investment opportunities in a way that minimizes the detrimental aspects of enforcing compliance while satisfying the financial institution's objective.

In the preferred embodiment, the central structural element of this integrated financial product package is a type of mortgage that features a variable amortization schedule and is secured by the pledge of real property and one or more other assets. This mortgage is called a Home Owner's Preferred Equity (HOPE) mortgage. Unlike conventional mortgages which provide for regular amortization payments, the mortgage need not be amortized.

Rather, the system of the present invention gives the mortgagor the opportunity to maximize his investment earnings by a variety of means including distributing the monies that would normally be used to amortize the mortgage among assets that give him the greatest return. For example, the mortgagor, hereinafter referred to as the "client", has the option to use the funds that would otherwise have been used to amortize the mortgage to make a contribution to a pension or retirement account such as an IRA, KEOGH, S.E.P. or corporate pension plan. Alternatively, the client may purchase "tax favored" investments such as life insurance or annuities in which earnings on premium payments, or "insider buildup", are not taxed until they are withdrawn.

From the financial institution's perspective, the mortgage used in the system of the present invention is superior to the other forms of mortgages in that: (1) it offers the lender an additional source of liquid collateral that will, if properly invested, continually appreciate in value, (2) the mortgage establishes an account that will assist in the marketing of other financial service products that will produce additional fee revenue for the financial institution and (3) the mortgage should rapidly gain wide acceptance in the secondary market in the form of mortgage-backed securities or Real Estate Mortgage Investment Conduit (REMIC) form because of the mortgage's added security and longer average life.

At the same time, origination, administration and servicing of the mortgage of the present invention involves many more considerations than a conventional mortgage. For the system to operate properly, the home owner's total assets, as adjusted to provide the financial institution with a measure of security for its lending, must always be greater than some imposed minimum standard. Calculation of adjusted total assets requires the financial institution to determine the current value of each asset and multiply it by its current loan to value ratio. In practice, these values must be calculated and checked frequently to reflect a change in the value or quantity of any asset or liability which is part of the system. Thus, for example, if borrowing is made against the cash value of the client's insurance policy or if the value of the client's bond portfolio changes, the asset values must be re-calculated, a new borrowing power must be determined and the new borrowing power must be compared to the


Summary Report for:

11-3031.00 - Financial Managers

Plan, direct, or coordinate accounting, investing, banking, insurance, securities, and other financial activities of a branch, office, or department of ar

Sample of reported job titles: Banking Center Manager (BCM), Branch Manager, Credit Administration Manager, Financial Center Manager, Regi Service Center Manager

Also see: Treasurers and Controllers, Investment Fund Managers

Tasks

All 21 displayed

- Establish and maintain relationships with individual or business customers or provide assistance with problems these customers may encou
- Plan, direct, or coordinate the activities of workers in branches, offices, or departments of establishments, such as branch banks, brokerage insurance departments, or credit departments.
- Recruit staff members.
- Prepare operational or risk reports for management analysis.
- Evaluate data pertaining to costs to plan budgets.
- Oversee training programs.
- Examine, evaluate, or process loan applications.
- Approve, reject, or coordinate the approval or rejection of lines of credit or commercial, real estate, or personal loans.
- Oversee the flow of cash or financial instruments.
- Prepare financial or regulatory reports required by laws, regulations, or boards of directors.
- Develop or analyze information to assess the current or future financial status of firms.
- Communicate with stockholders or other investors to provide information or to raise capital.
- Evaluate financial reporting systems, accounting or collection procedures, or investment activities and make recommendations for changes operating systems, budgets, or other financial control functions.
- Analyze and classify risks and investments to determine their potential impacts on companies.
- Network within communities to find and attract new business.
- Review collection reports to determine the status of collections and the amounts of outstanding balances.
- Establish procedures for custody or control of assets, records, loan collateral, or securities to ensure safekeeping.
- Plan, direct, and coordinate risk and insurance programs of establishments to control risks and losses.
- Review reports of securities transactions or price lists to analyze market conditions.
- Direct insurance negotiations, select insurance brokers or carriers, and place insurance.
- Submit delinquent accounts to attorneys or outside agencies for collection.

Text Analysis Basics: Representing Text as Data

Typical Approach: Represent documents as sparse word vectors

- For two documents i and j, construct V_i and V_j as a (sparse) word vector of length W (i.e. the size of the set union for terms in (i, j))
  - Example: $D1 = \{\text{dog}, \text{eat}, \text{food}\}$ and $D2 = \{\text{cat}, \text{eat}, \text{food}\}$ leads to $V_1 = [1, 0, 1, 1]$ and $V_2 = [0, 1, 1, 1]$
- This 'bag of words' approach works well when the two documents are written in the same 'language' (lots of grammatical overlap)
- Measure similarity across documents based on cosine similarity between V_1 and V_2.

Text Analysis Basics: Representing Text as Data

However, the previous approach does not deal with synonyms.

- For example, if $D1 = \{\text{dog}, \text{cat}\}$ and $D2 = \{\text{puppy}, \text{kitten}\}$ then $V_1 = \{1, 1, 0, 0\}$ $V_2 = \{0, 0, 1, 1\}$ and

$$\text{Cosine Similarity}(V1, V2) = \frac{V_1 \cdot V_2}{||V_1|| \times ||V_2||} = 0$$

  Even though the two documents have similar meanings.

- This creates a bias towards low similarity if the two documents use different vocabulary
  - e.g. patent documents vs occupation task descriptions

Dealing With Synonyms

Potential solution: use word embeddings (e.g. word2vec).

- Each word x_k is represented as a 300-dimensional vector (arbitrary basis).
- The (cosine) distance between two word vectors is related to the probability they are synonyms (i.e., they are used in the same context within a set of documents).
- We use word vectors provided by Pennington et al. (2014) that were trained on 42 billion word tokens of web data from Common Crawl.

Dealing With Synonyms

New Approach: Represent documents as weighted averages of word vectors:

$$V_i = \sum_{x_k \in A_i} w_{i,k} x_k$$

- Now, V_i is no longer sparse but has lower dimensionality than before.
- Here $w_{i,k}$ is the term-frequency-inverse-document-frequency (TFIDF) defined as

$$w_{i,k} \equiv TF_{i,k} \times IDF_k =$$

$$\frac{f_{k,i}}{\sum_{k' \in \text{doc } i} f_{i,k'}} \times \log\left(\frac{\text{\# of documents}}{\text{\# of documents that include term } k}\right)$$

  - IDF is computed separately for patents and job descriptions
- In the example $D1 = \{\text{dog}, \text{cat}\}$ and $D2 = \{\text{puppy}, \text{kitten}\}$, now Cosine $\text{Sim}(V_1, V_2) \approx 0.81$.

From Text to Vector Representation

- Convert all words to a common root (lemmatizing).
- Keep only nouns and verbs
  - Idea: focus on what a patent/occupation *is* and what it *does*).
- Compute TF-IDF of each word in each document
- Extract estimated word vectors x_k for each word k.
- Construct document vector as TF-IDF weighted average of word vectors

From Text to Vector Representation

Example:

Document i: "The quick brown fox jumped over the lazy dog."

$\rightarrow$ Get nouns and verbs (lemmatized) : $\{fox, jump, dog\}$

$\rightarrow$ Vector representation of phrase:

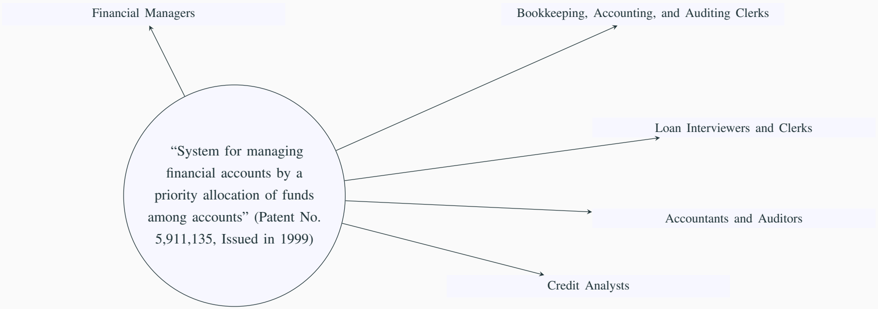
$$V_i = w_{i,fox}x_{fox} + w_{i,jump}x_{jump} + w_{i,dog}x_{dog}$$

$w_{i,k}$ is the TF-IDF weight as explained before

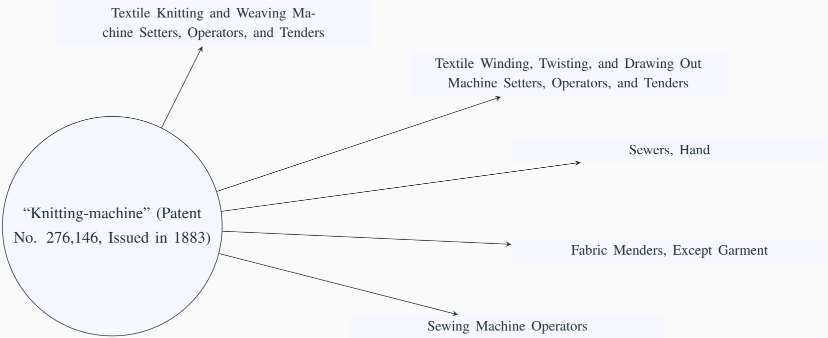
x_k is a 300-dimensional vector whose location in space is a geometric representation of the word's meaning (high cosine similarity $\rightarrow$ synonyms)

- The NLP guys already estimated x_k so we don't have to

Patent-occupation similarity example (1)



Patent-occupation similarity example (2)



Occupation-specific indices of technical change

Creating our occupation × time index of exposure:

- Denote by $\rho_{i,j}$ each element of the patent (i) X occupation (j) matrix (cosine similarity between document vectors)
- To account for shifts in language remove time × tech class FEs from all elements.
- Impose sparsity: set the bottom 80% of patent-occupation pairs to zero.
- Re-scale the remaining 20% of pairs so they range between (0,1).

Occupation-specific indices of technical change

- Denote the adjusted (tech $\times$ year fixed effect/re-scaled similarity measure by $\tilde{\rho}_{i,j}$.

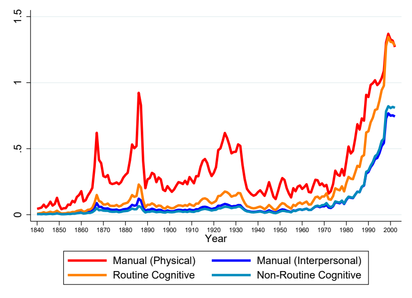
Our index then sums up occupation exposures across breakthrough patents:

$$\eta_{j,t} = \frac{1}{\kappa_t} \sum_{i \in \Gamma_t^c} \tilde{\rho}_{i,j} \times \mathbf{1}(\tilde{q}_{i,t} \geq \tilde{q}_{p90})$$

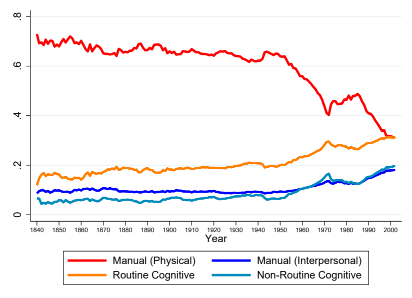
$\kappa_t =$ US population

$\tilde{q}_{i,t}$: KPST text-based measure of breakthrough patents

A. Levels



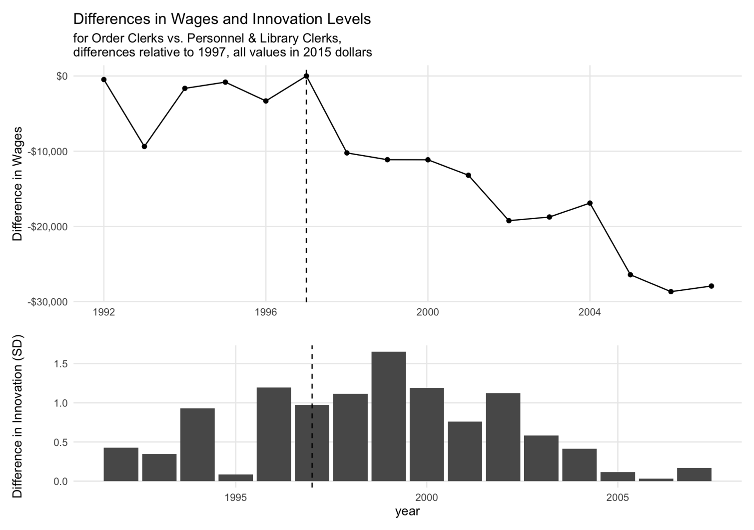
B. Composition



- Left figure shows the sum of innovation exposure for occupations in the top quintile of a given task category. Right figure shows each task category's share of total exposure.

Technology and Labor Market Outcomes

Order Clerks versus Personnel and Library Clerks



Employment and Technology Exposure (1850–present)

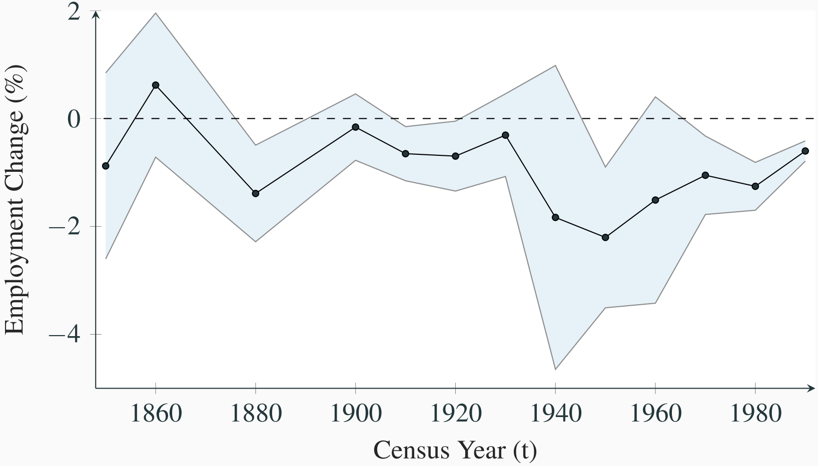
	A. Occupation-level Employment				B. Industry X Occupation level employment			
	10 Years	20 Years	10 Years	20 Years	10 Years	20 Years	10 Years	20 Years
Technology Exposure, $\eta_{i,t}$	-0.43***	-0.75***	-0.33***	-0.66***	-0.37***	-0.76***	-0.38***	-0.86***
	(-4.68)	(-6.30)	(-4.17)	(-6.33)	(-2.76)	(-3.69)	(-2.83)	(-3.92)
Observations	2,865	2,574	2,492	2,208	102,400	81,009	72,451	54,662
R^2 (Within)	0.016	0.043	0.067	0.078	0.003	0.013	0.004	0.018
Controls								
Time FE	Y	Y	Y	Y				
Industry X Time FE					Y	Y	Y	Y
Lagged Dependent Variable			Y	Y			Y	Y

Note: The table above reports results from regressions of the form

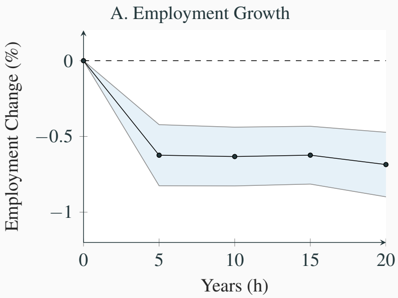
$$\frac{1}{k}\left(\log Y_{i,t+k} - \log Y_{i,t}\right) = \alpha_0 + \alpha_t + \beta(k)\eta_{i,t} + \rho\left(\log Y_{i,t} - \log Y_{i,t-k}\right) + \varepsilon_{i,t}$$

for $k = 10, 20$ years for Census years spanning from 1850-2010. Here $Y_{i,t}$ is the occupation's share in total non-farm employment. $\eta_{i,t}$ is standardized and growth rates are in annualized percentage terms. Standard errors are clustered by occupation and corresponding t-stats are shown in parentheses. Observations are weighted by occupation employment share at time t.

Employment and Technology Exposure (1850–present)



Employment, wage earnings and technology exposure (recent period: 1980–present)



Note: The Figures above plot coefficients from panel regressions of annualized wage and income growth rates over different time horizons on occupation innovation exposures:

$$y_{i,t+k} - y_{i,t} = \alpha + \beta\eta_{i,t} + \delta X_{i,t} + \varepsilon_{i,t}$$

Controls $X_{i,t}$–includes three one-year lags of dependent variable, time fixed effects, wage, and occupation employment share. Dependent variable is expressed in annualized percentage terms and $\eta_{i,t}$ is standardized. Figures plot 90% confidence interval for each time horizon. Data come from the CPS Merged Outgoing Rotation Groups (MORG) and cover the 1985–2018 period.

Impact of Innovation on Individual Workers, Panel Analysis

We now track the same workers over time using a panel of individuals in the CPS linked with their earnings/employment histories in the Detailed Earnings Record (DER).

- Observe occupation and education in year worker is in CPS
  - Only consider individuals of working age (25-55)
  - Only include individuals with occupation information ≤ 5 years old
- Merge this with annual earnings and employer data from the DER.
- Use Census patent–firm identifier crosswalks to link to patents that originate in the worker's industry (tech exposure η now varies at occupation-industry level)
- Calculate growth in age-adjusted average earnings over the next 3-, 5-, and 10-year horizons

Individual Workers

Following a one σ technology shock, worker's average wages fall about 1.1% over the next 3 years and 1.5% over the next 10 years

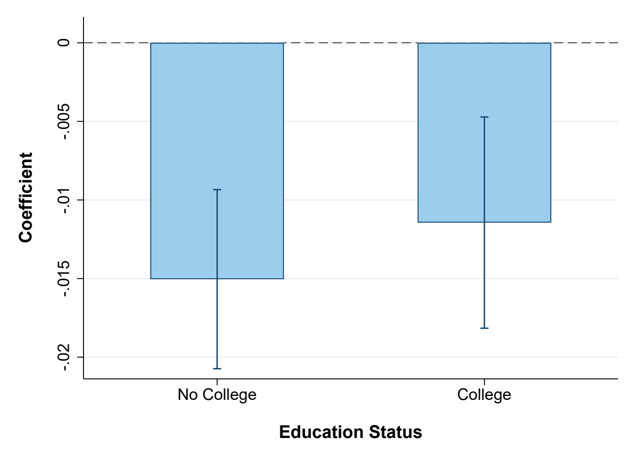
Wage Growth Responses to 1 σ Technology Shock, DER-CPS Linked Panel Data

	3 Years				10 Years			
Technology Exposure $\eta_{i,t}$	-1.14%	-1.06%	-1.09%	-1.08%	-1.50%	-1.33%	-1.53%	-1.43%
	(0.194)	(0.194)	(0.269)	(0.248)	(0.308)	(0.292)	(0.457)	(0.439)
Fixed Effects:								
Industry	Y	Y			Y	Y		
Occupation	Y		Y		Y		Y	
Year	Y				Y			
Industry x Year			Y	Y			Y	Y
Occupation x Year		Y		Y		Y		Y

Note: This table reports average wage growth responses following a σ shock to our occupation based technological change measure. Percent wage growth is measured in log points. Standard errors are clustered at the industry level (NAICS 4).

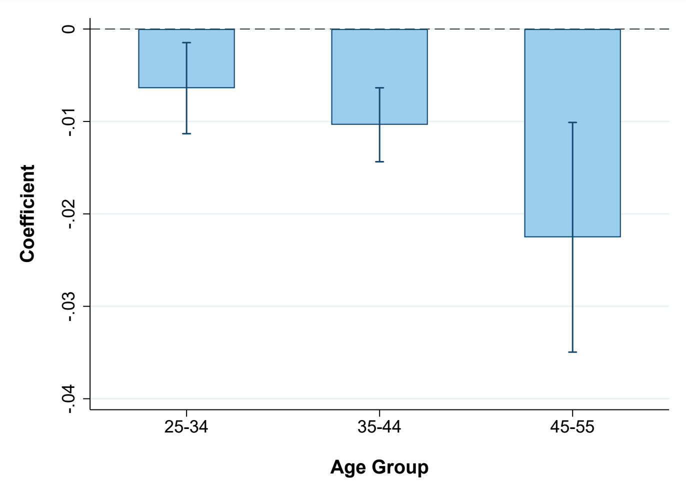
Individual Workers, by Education (5-year horizon)

Non-college educated more exposed to same technology than college-educated workers



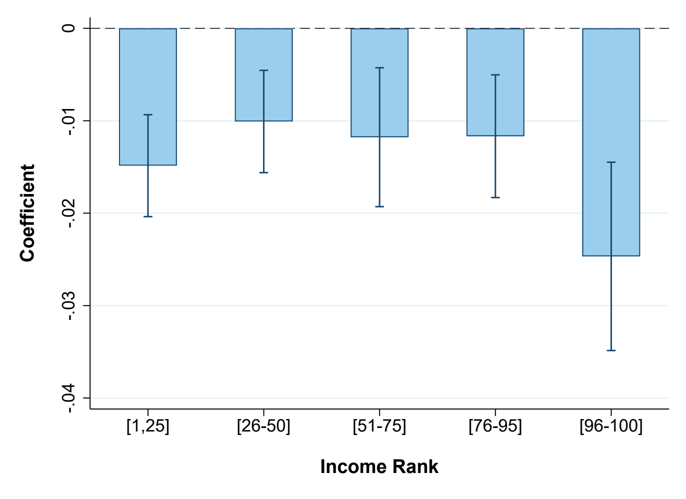
Individual Worker, by Age (5-year horizon)

Older workers more exposed to same technology than younger workers



Individual Workers–Sorted by Income Rank (5-year horizon)

Highly-paid workers more exposed to same technology than low-wage workers



Summary

- Correlation between technology and employment is negative at the occupation level
- Correlation between technology and worker wages negative, both at the occupation but also at the worker level. Magnitudes larger for:
    a. less educated
    b. older
    c. more highly-paid workers within an occupation-industry

Summary

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Q: How to square (c) with the standard assumption that skilled labor is more complementary to technology than unskilled labor?

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  b. older
  c. more highly-paid workers within an occupation-industry

Q: How to square (c) with the standard assumption that skilled labor is more complementary to technology than unskilled labor?

A: Skilled workers as a group may benefit, yet individual workers may get left behind.

Model

Setup

- Output function of technology ξ, skilled H and unskilled L labor

$$Y_{jt} = \left(\mu\left(L_{jt}\right)^{\sigma} + (1-\mu)\left(X_{jt}\right)^{\sigma}\right)^{1/\sigma}$$

where

$$X_{jt} = \left(\lambda\left(\xi_{jt}\right)^{\rho} + (1-\lambda)\left(H_{jt}\right)^{\rho}\right)^{1/\rho}$$

- Standard Assumption: Skilled labor more complementary to technology than unskilled labor:

$$\rho < \sigma < 1$$

Skill Displacement

- Individual workers i endowed with $\theta_{i,t}$ units of skilled labor and $1-\theta_{i,t}$ units of unskilled labor. Worker earnings:

$$W_{L,t} + \theta_{it} \left(W_{H,t} - W_{L,t}\right)$$

- Arrival of new technologies can render existing skills obsolete:
    - With some probability θ_{it} falls as technology ξ improves

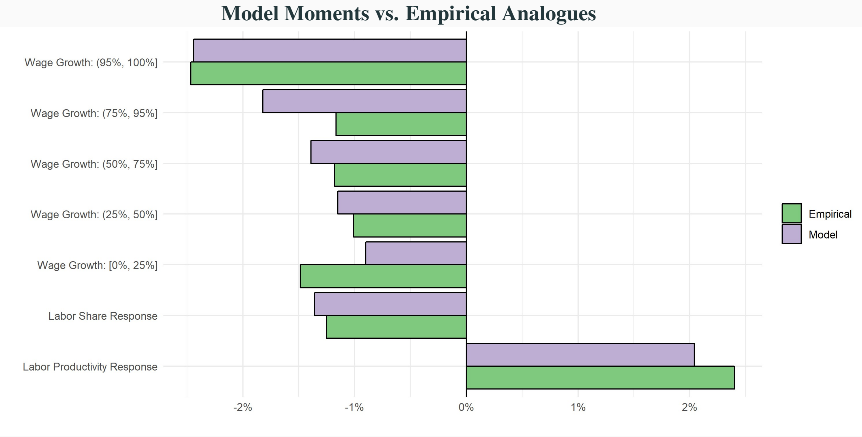
Implications

- Skill premium $W_H - W_L$ increases with ξ
  - skilled workers as a group are relatively better off!
- Yet, individual workers who experience declines in skill θ can experience significant income declines.
  - i.e. membership in the skilled group need not remain constant.
- Depending on the relative strength of these two effects, earnings of (previously) top workers can decline more than lower-paid workers.

Model Calibration

Parameter	Interpretation	Value
α	Cond. prob. of displacement	.55
ϕ	Prob. of skill increase	.38
δ	Death rate	.02
σ	Curvature of unskilled labor (outer nest)	.5
Ω	Technology jump intensity	.07
ρ	Curvature of skilled labor (inner nest)	.15
μ	Unskilled labor share (outer nest)	.44
λ	Capital share (inner nest)	.62
g	Growth rate	.02

Model: Impulse Responses



Conclusion

- We construct direct measures of technology and relate them to worker outcomes.
- We find that technological improvements are robustly negatively related to worker labor market outcomes, both at the aggregate but also at the individual levels.
  - Magnitudes larger for (a) less educated, (b) older, and (c) most highly-paid workers within occupation-industry
- Allowing for skill displacement in the standard model of technology-skill complementarity key in interpreting these findings

Census Acknowledgment

The U.S. Census Bureau reviewed this data product for unauthorized disclosure of confidential information and approved the disclosure avoidance practices applied to this release (approval number CBDRB-FY21-POP001-0176).