Technology-Skill Complementarity and Labor Displacement: Evidence from Linking Two Centuries of Patents with Occupations

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What we do

Question: How did workers' exposure to (labor-saving) technologies relates to labor market outcomes?

Construct direct measures of workers' technological exposure using data on patents and occupation task descriptions:

- Identify significant innovations through patent textual networks.
- Link to workers based on textual similarity between descriptions of the innovation (patent) and occupation tasks (DOT/ONET).
- Construct time-series indices of occupation-specific technical change.

Main Findings

- White collar occupations increasingly more exposed to technology
- Technology exposure predicts
  - occupation level: employment declines
  - worker level: wage earnings declines and left-tail risk increases
- Worker-level responses larger for older and more highly paid workers
- Interpret our empirical findings through the lens of a model of technology-skill complementarity with displacement.

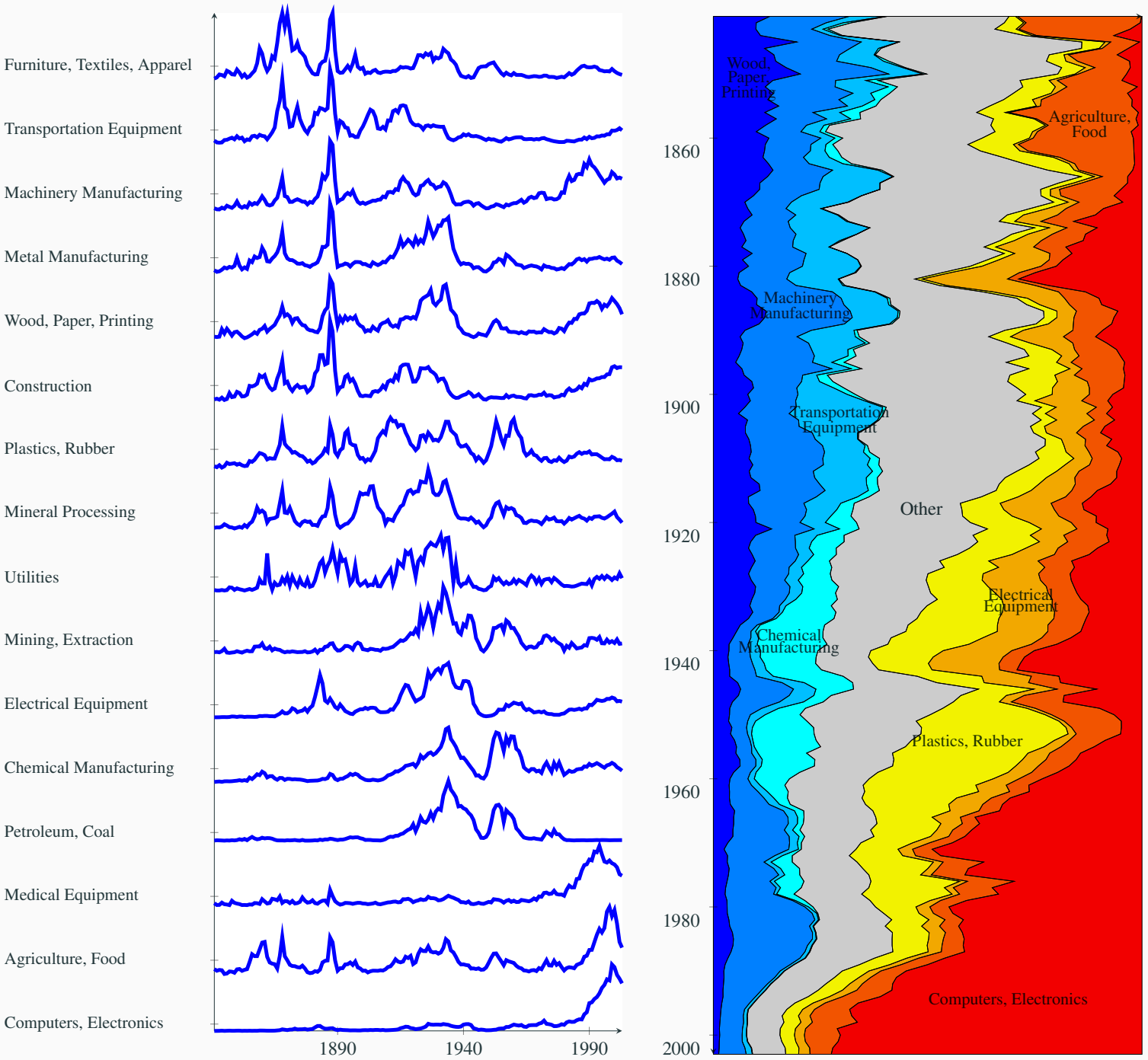
Measurement: Broad Idea

We follow Kelly, Papanikolaou, Seru, and Taddy (2021) and identify important patents as those that:

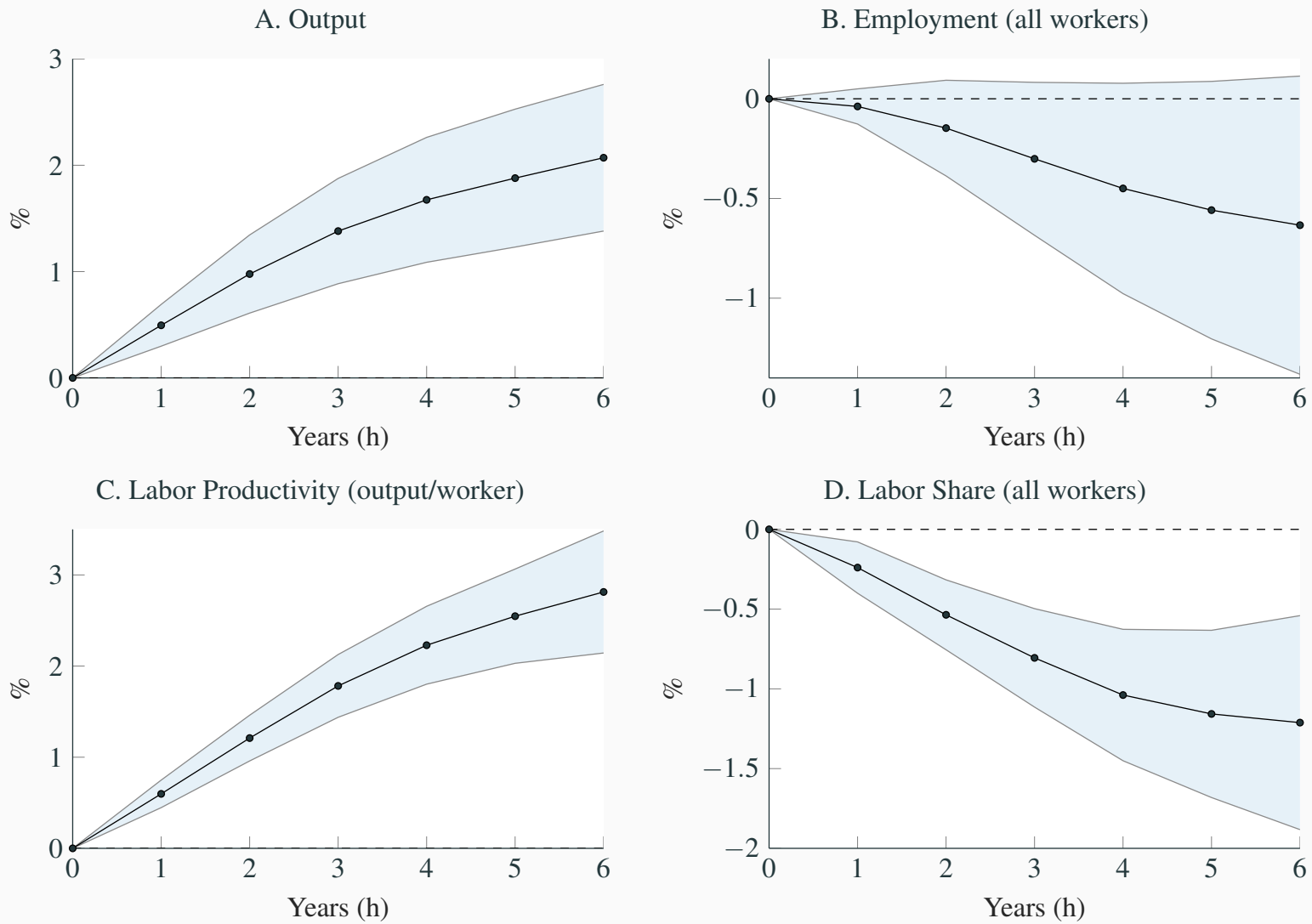
- Are distinct from previous patents but are related to subsequent patents (i.e., they are novel and impactful)
- Novelty and impact are computed based on the textual similarity between a given patent and prior and subsequent patents
- Breakthroughs: patents in the top 10 percent of the unconditional distribution of impact/novelty

Technology: # per-capital breakthroughs related to industry I

$$\psi_{I,t} = \frac{1}{\kappa_t} \sum_{p \in B_t} \alpha_{I,p}.$$


Furniture, Textiles, Apparel
Transportation Equipment
Machinery Manufacturing
Metal Manufacturing
Wood, Paper, Printing
Construction
Plastics, Rubber
Mineral Processing
Utilities
Mining, Extraction
Electrical Equipment
Chemical Manufacturing
Petroleum, Coal
Medical Equipment
Agriculture, Food
Computers, Electronics
1890
1940
1990
Wood, Paper, Printing
Agriculture, Food
Machinery Manufacturing
Transportation Equipment
Other
Electrical Equipment
Chemical Manufacturing
Plastics, Rubber
Computers, Electronics
1860
1880
1900
1920
1940
1960
1980
2000

Technology: Productivity vs Labor Share



Sample: Manufacturing, 1958–2018

Measuring Patent-Occupation Similarity

Using state of the art techniques in textual analysis we obtain a distance measure ρ between each *breakthrough* patent *p* and each occupation *i*

Patent



5,911,135

1

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 program 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

$\Leftrightarrow$

$\rho_{p,i}$

Occupation Task Description



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 an establishment.

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

Also see: Treasurers and Controllers, Investment Fund Managers

View report: Summary | Details | Custom | Easy Read | Veterans | Español

Tasks | Technology Skills | Tools Used | Knowledge | Skills | Abilities | Work Activities | Detailed Work Activities | Work Context | Job Zone | Credentials | Interests | Work Styles | Work Values | Related Occupations | Wages & Employment | Job Openings | Additional Information

Tasks

All 21 displayed

- Establish and maintain relationships with individual or business customers or provide assistance with problems these customers may encounter.
- Plan, direct, or coordinate the activities of workers in branches, offices, or departments of establishments, such as branch banks, brokerage firms, risk and 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 to procedures, 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.

Measuring Workers' Technology Exposure

Exposure of occupation i to technology at time t

$$\eta_{i,t} = \frac{1}{\kappa_t} \sum_{p \in B_t} \rho_{p,i}$$

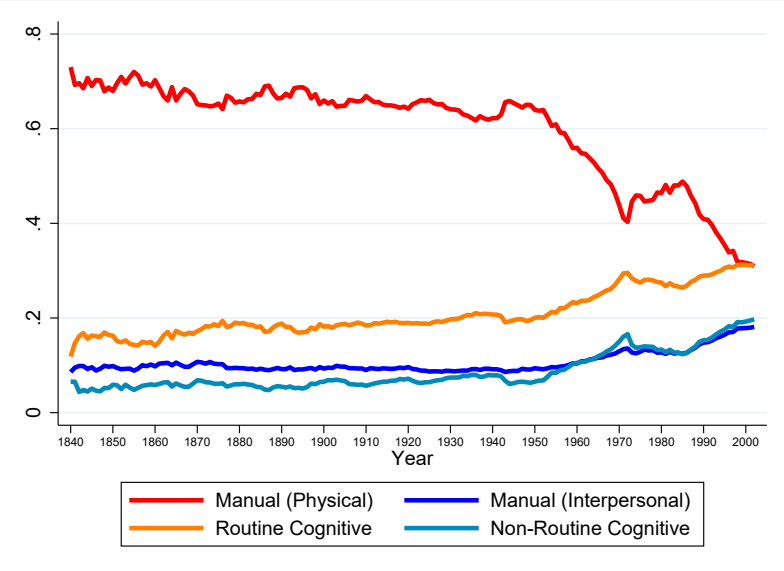
- Sum of breakthroughs related to the tasks occupation j performs
- Weights: textual similarity ρ between a given patent and occupation task descriptions (ONET/DOT)

Our prior: Since our approach is based on measuring task overlap, primarily identifies patents that substitute rather than complement worker tasks.

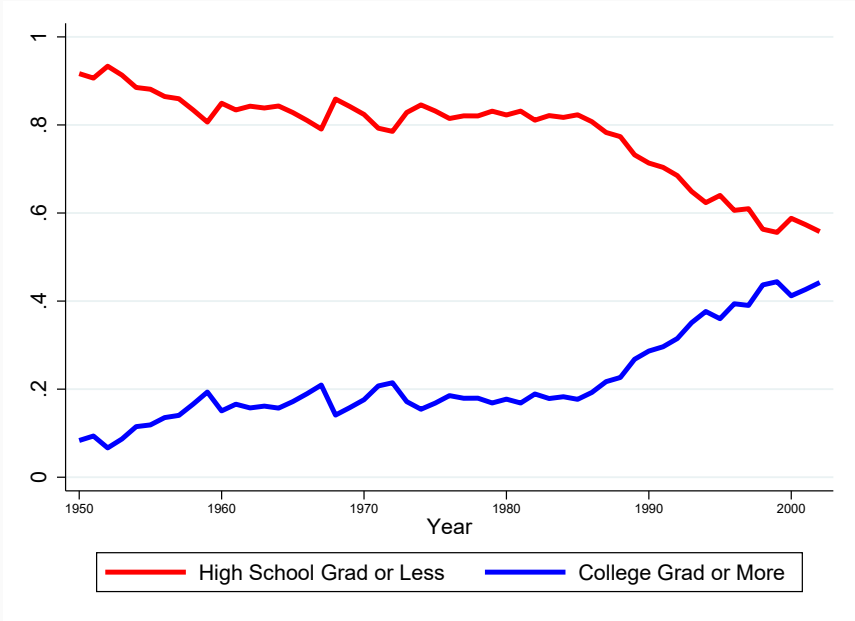
- We later verify this is the case by comparing our approach to a statistical factor constructed to maximize predictability of negative worker outcomes in sample.

White-collar occupations increasingly more exposed

A. Task Content

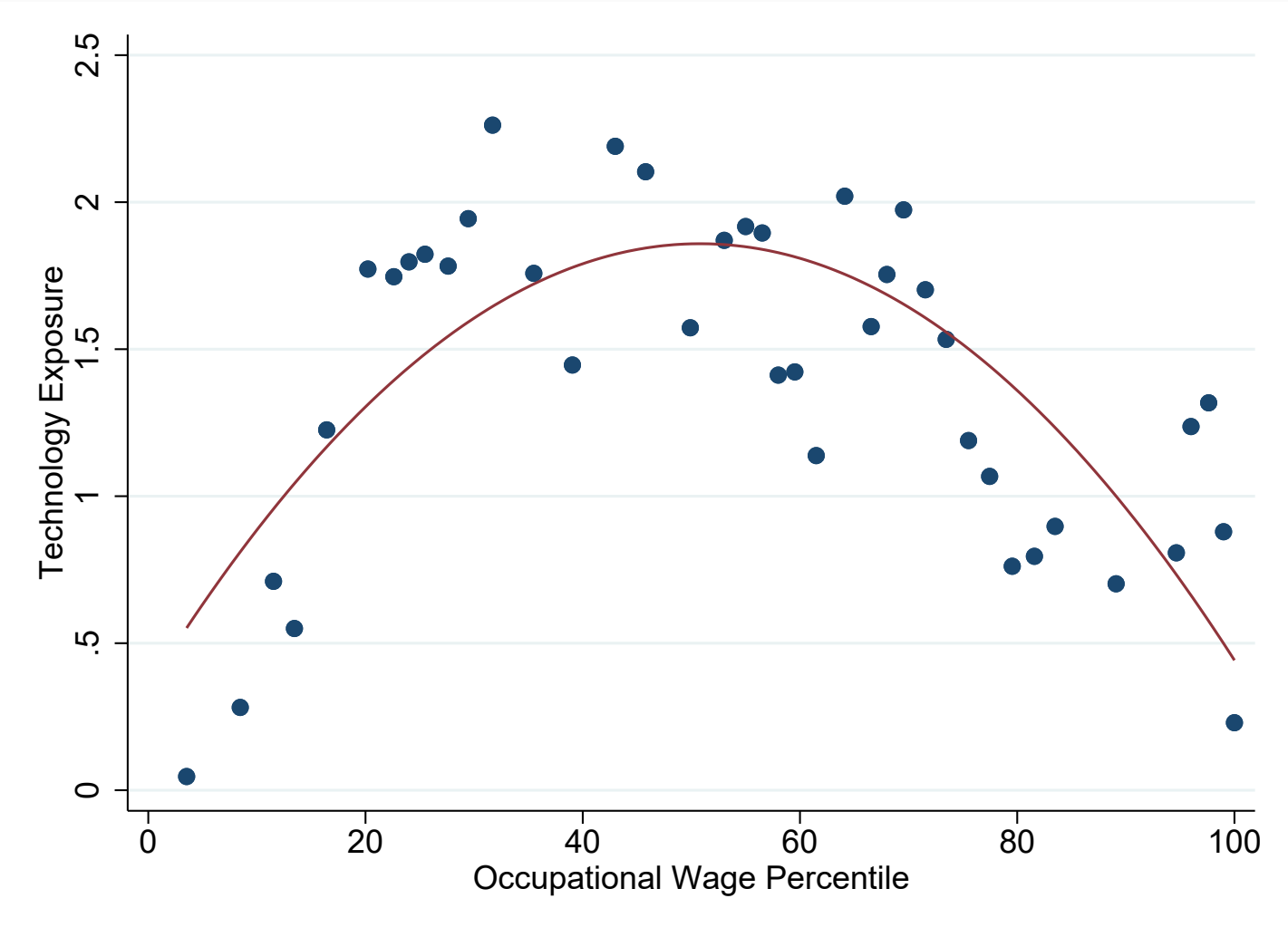


B. Education



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

Middle-skill occupations more exposed to technical change



- Workers in ccupations in the middle of the skill (=wage) distribution more highly exposed than top/bottom by 1 SD

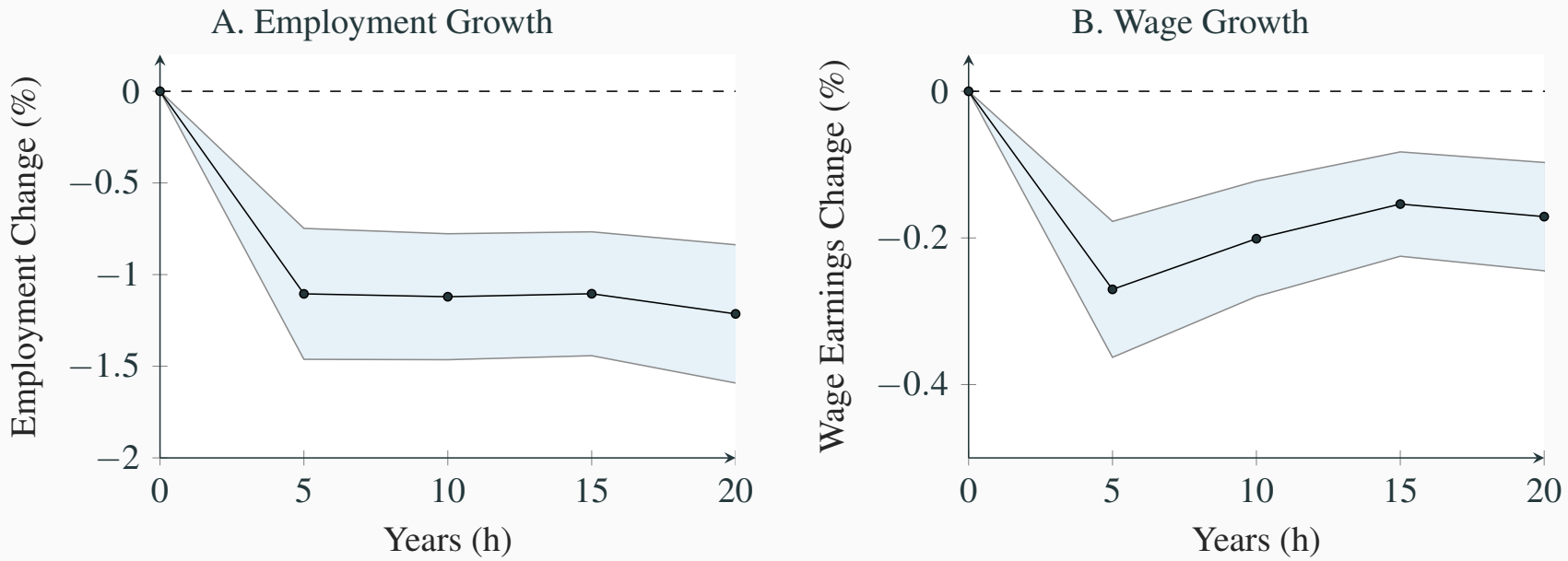
Employment and Technology Exposure (long run, 1850–present)

	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, $\eta_{i,t}$ (past decade average)	-0.48*** (-5.19)	-0.77*** (-6.84)	-0.37*** (-4.39)	-0.67*** (-6.93)	-0.56*** (-3.02)	-0.97*** (-3.92)	-0.60*** (-3.18)	-1.10*** (-4.33)
Observations	2,865	2,574	2,492	2,208	102,400	81,009	72,451	54,662
Controls								
Time FE	Y	Y	Y	Y				
Industry X Time FE					Y	Y	Y	Y
Lagged Dependent Variable			Y	Y			Y	Y

- Higher technology exposure predicts employment declines at the occupation level.
- Magnitudes: 1 SD followed by 0.5 to 1 percent annualized decline in employment

Employment, wage earnings and technology exposure

Recent period, 1980–present:



- Wage and employment declines at occupation level.
- 1 SD shock followed by 5% decline in average wages over next 20 years.

Impact of Innovation on Individual Workers

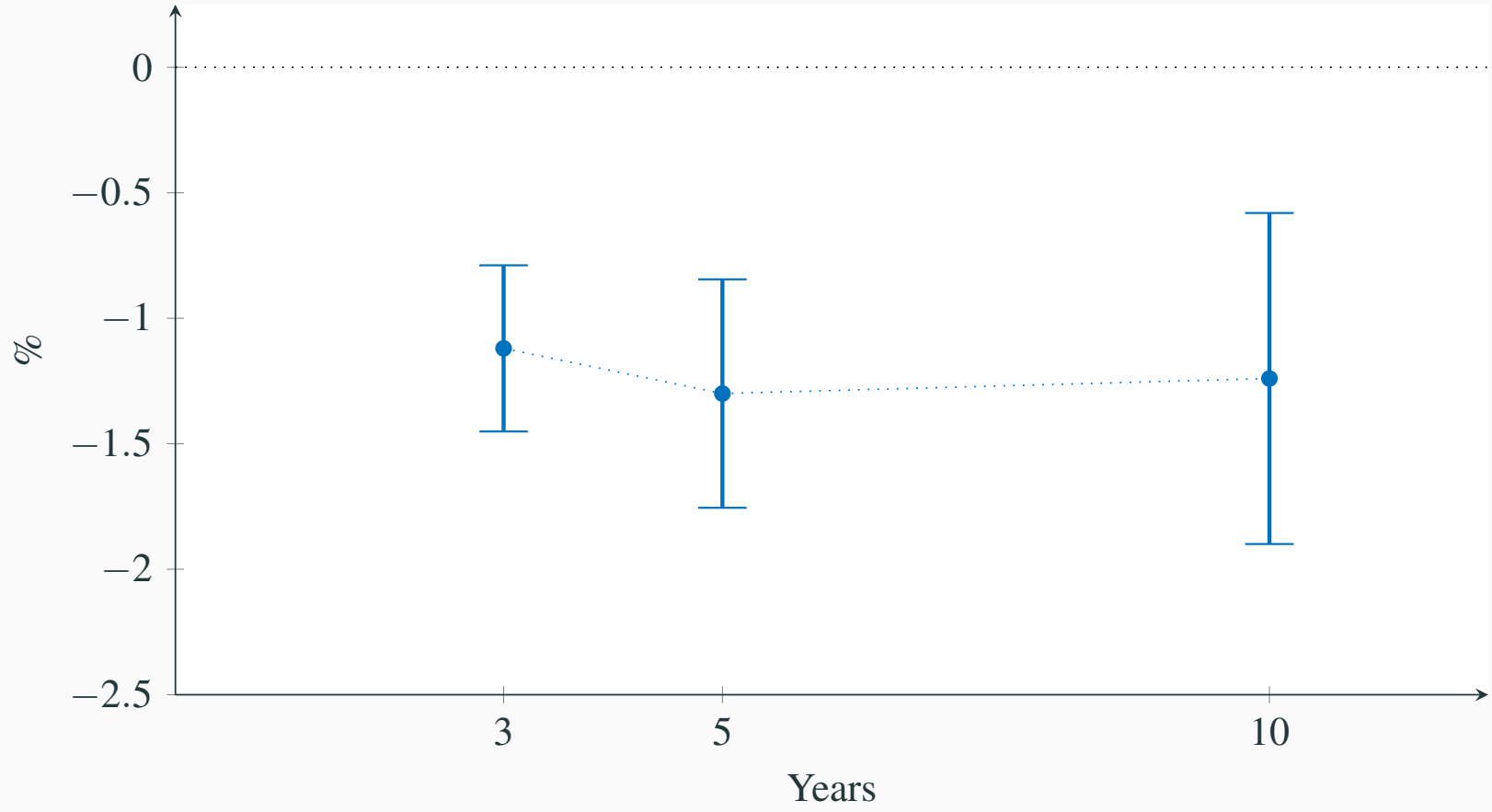
Track individual workers over time using a panel of individuals in the CPS linked with administrative tax data (DER).

Calculate growth in age-adjusted (cumulative) W2 earnings over the next 3-, 5-, and 10-year horizons

$$w_{i,t:t+h} \equiv \log\left(\frac{\sum_{j=0}^{h} \text{W2 wage}_{i,t+j}}{\sum_{j=0}^{h} D(\text{age}_{i,t+j})}\right)$$

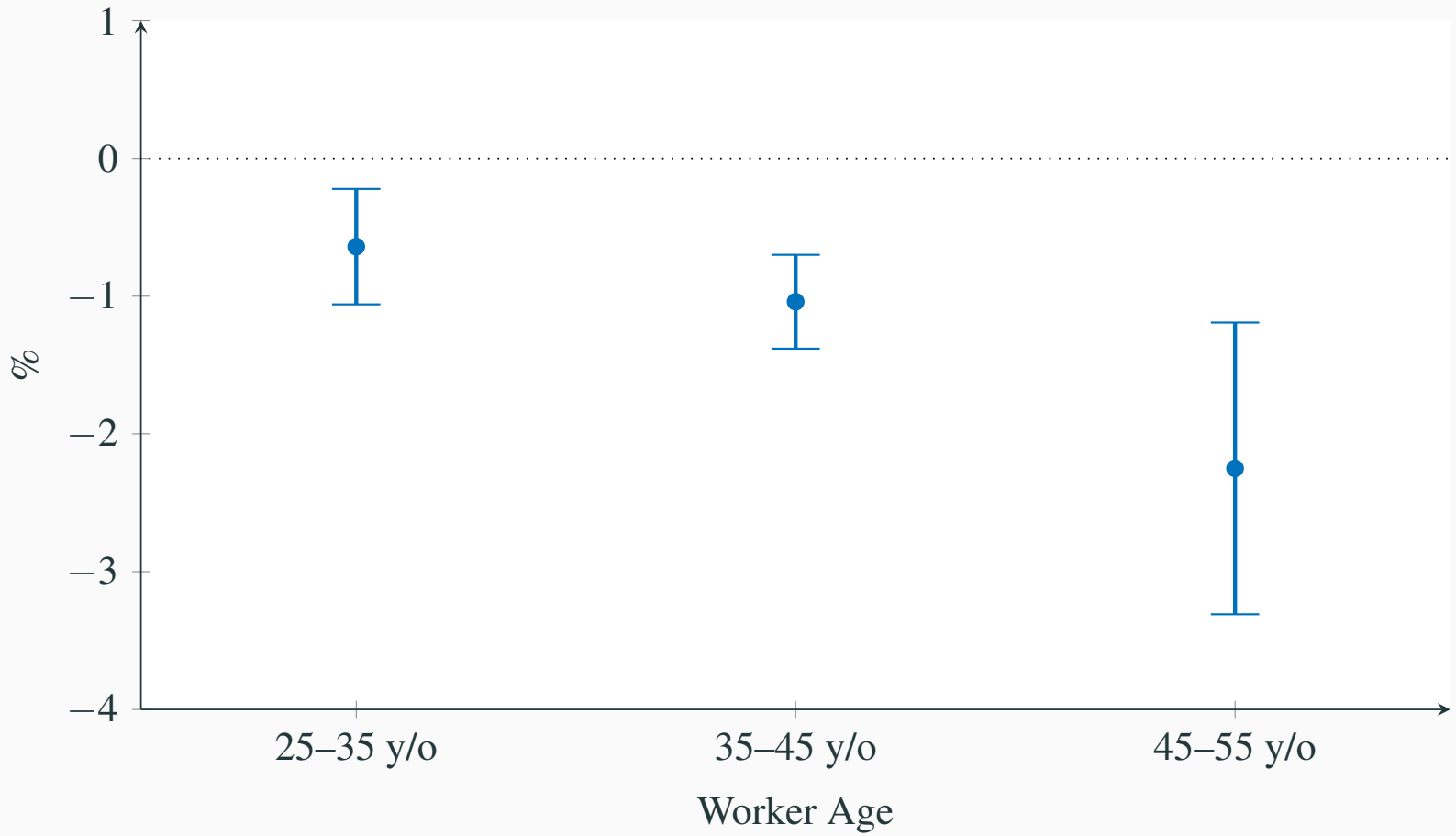
This specification emphasizes permanent income changes

Technology Exposure Predicts Earnings Declines



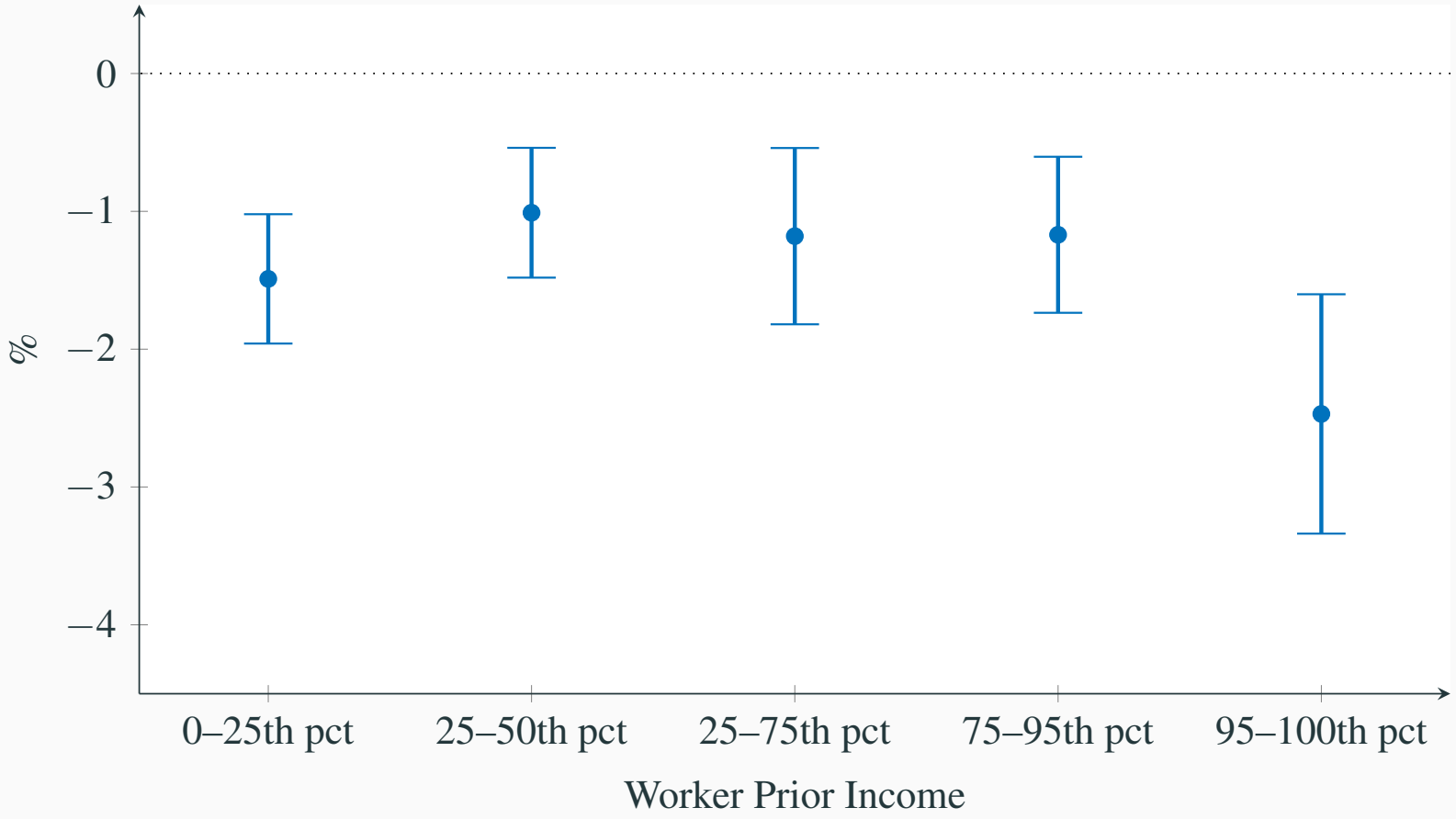
- Worker's cumulative earnings decline by 1–1.5 percentage points over the next five years in response to a 1-SD shock in tech exposure.

Magnitudes Larger For Older Workers



- Magnitude of the decline approximately 1.5x larger for older workers

Magnitudes larger for highly-paid workers

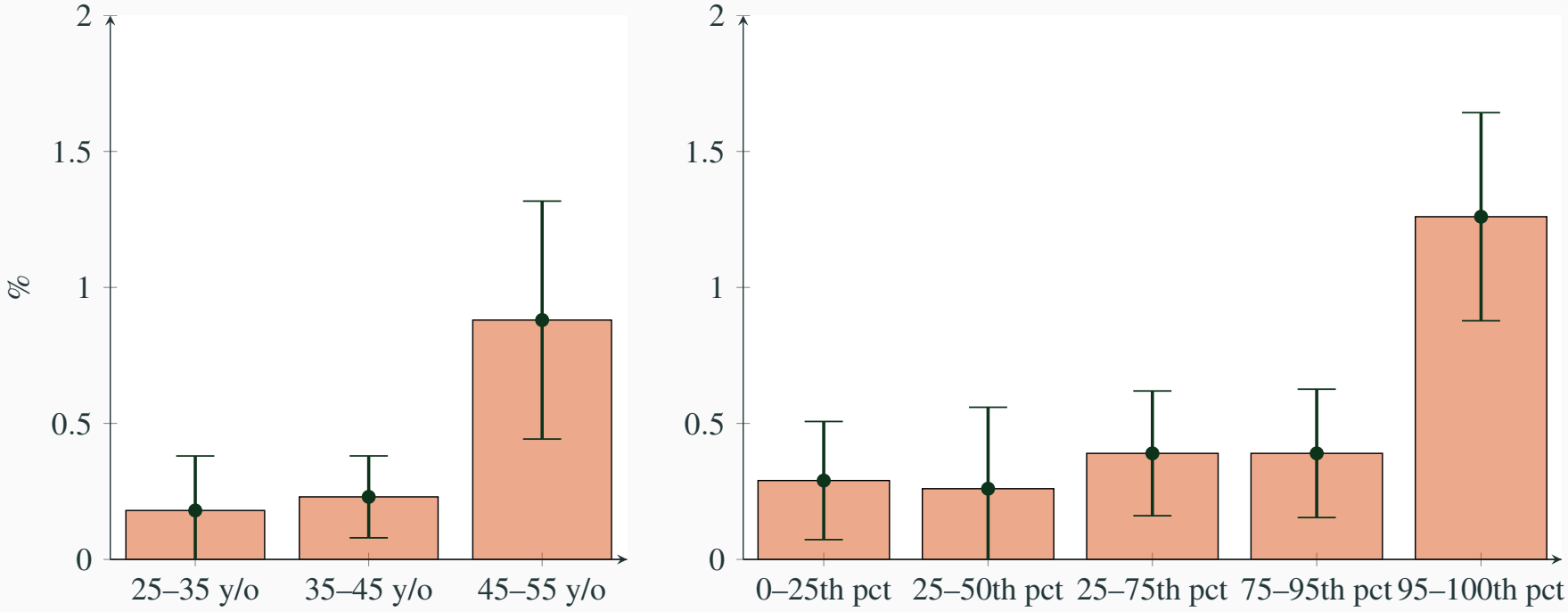


- Magnitude of the decline approximately 2x larger for highly-paid workers (relative to other workers in same occupation–industry cell)

Is technology complementary to skill?

- If technology is complementary to skill (and skill $\approx$ wage) we would expect to see that if two workers doing the same job experience the same degree of technology, wages of the high-skilled worker would decline by less (or even rise) relative to the low-skilled worker.
- We see the opposite. Why?
- One possibility: skilled workers as a group may benefit, yet individual workers may get left behind.
  - If so, these workers more likely to experience larger earnings declines.

Older and highly-paid workers face higher income risk



- 1 SD increase in exposure followed by higher likelihood of experiencing large declines— $P(\text{Earnings Growth} \leq \text{10-th percentile})$
- Increase in risk largest for older and more highly paid workers

Technology-Skill Complementarity

- Nested CES production in technology ξ, skilled H and unskilled L labor

$$Y_t = \left[\mu\left(H_t\right)^{\sigma} + (1-\mu)\left(\lambda\left(\xi_t\right)^{\rho} + (1-\lambda)\left(L_t\right)^{\rho}\right)^{\sigma/\rho}\right]^{1/\sigma}$$

- Technology frontier improves stochastically

$$d\xi_t = -g\,\xi_t\,dt + \kappa\,dN_t.$$

- Standard Assumption: Skilled labor more complementary to technology than unskilled labor: $\sigma < \rho < 1$
  - Skill premium $W_H - W_L$ increases with ξ

Skill Displacement

Skilled workers as a group may benefit, yet individual workers may get left behind since arrival of new technologies can render existing skills obsolete.

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

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

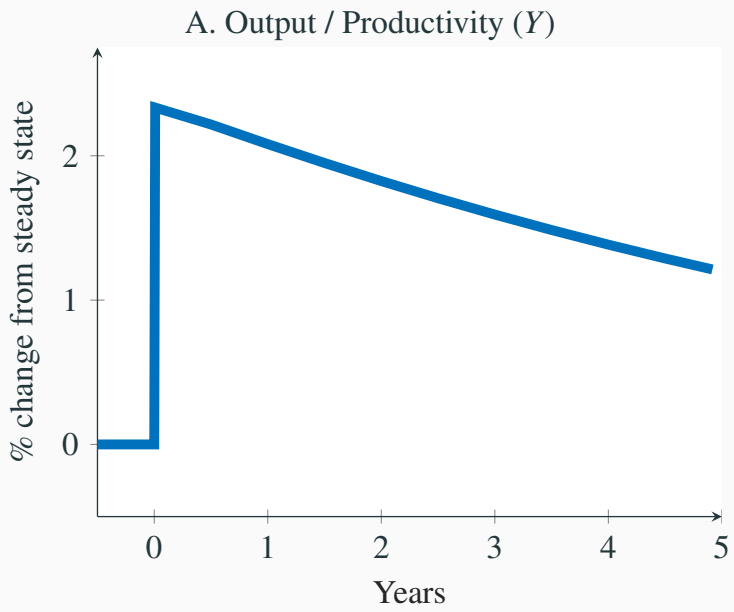
- With some probability θ_{it} falls as technology ξ improves

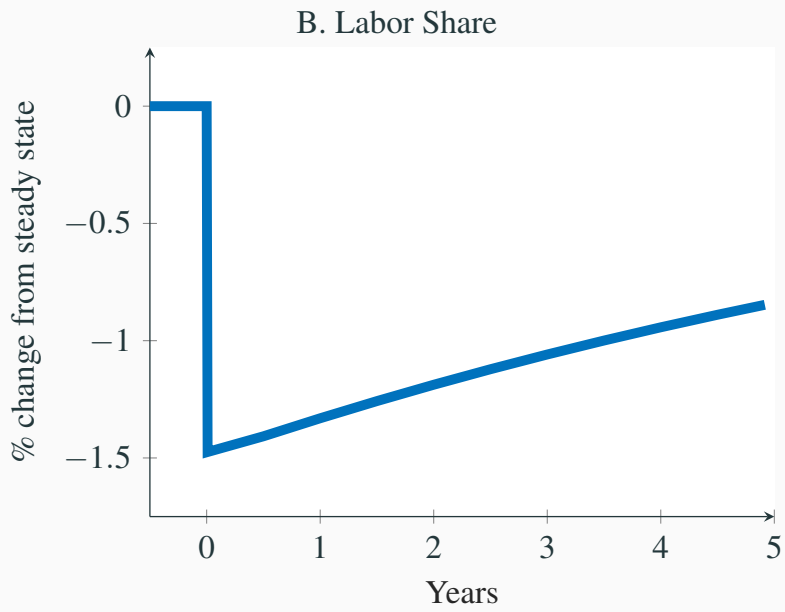
$$d\,\theta_{i,t} = m\,\theta_{i,t}\,dM_{i,t} - h\,\theta_{i,t}\,dN_{i,t},$$

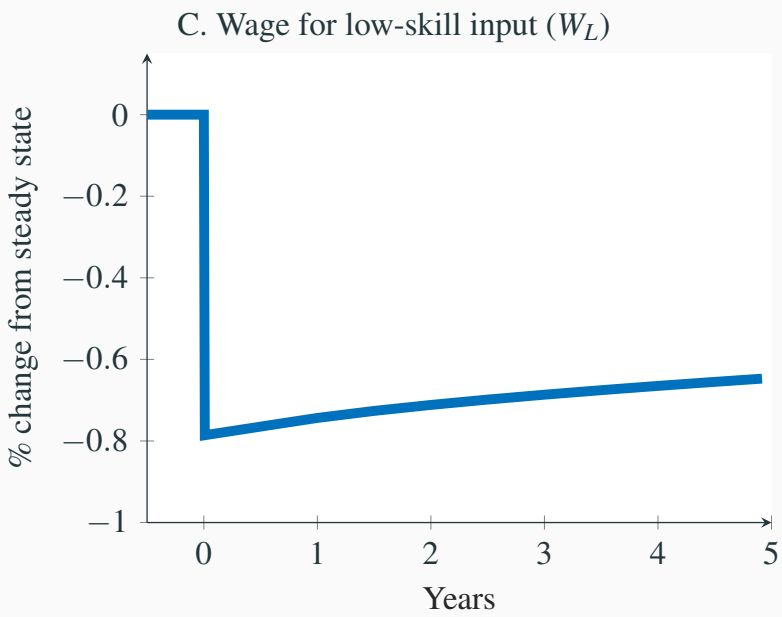
- Workers differentially exposed:

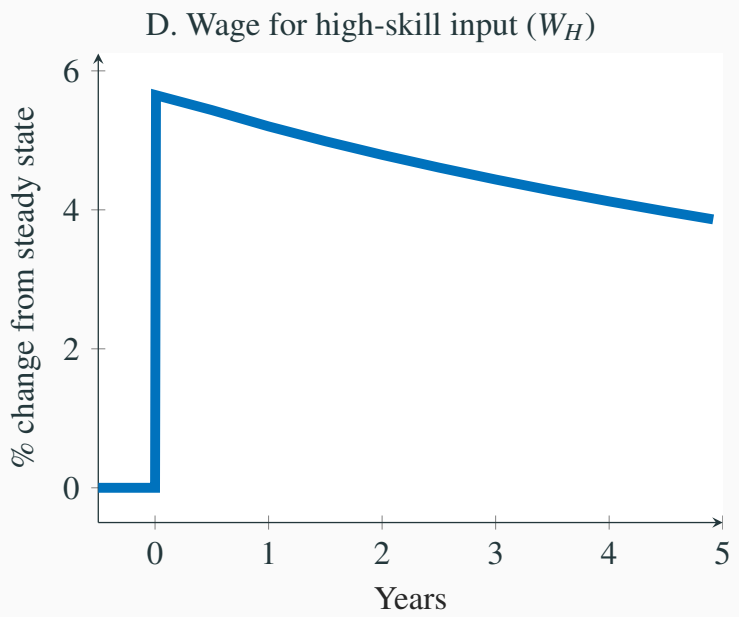
$$dN_{i,t} = d_{i,t}\,dN_t, \qquad d \in \{0,1\} \quad \text{i.i.d. with} \quad Prob(d=1) = \alpha$$

Model: Technology, Productivity and the Labor Share

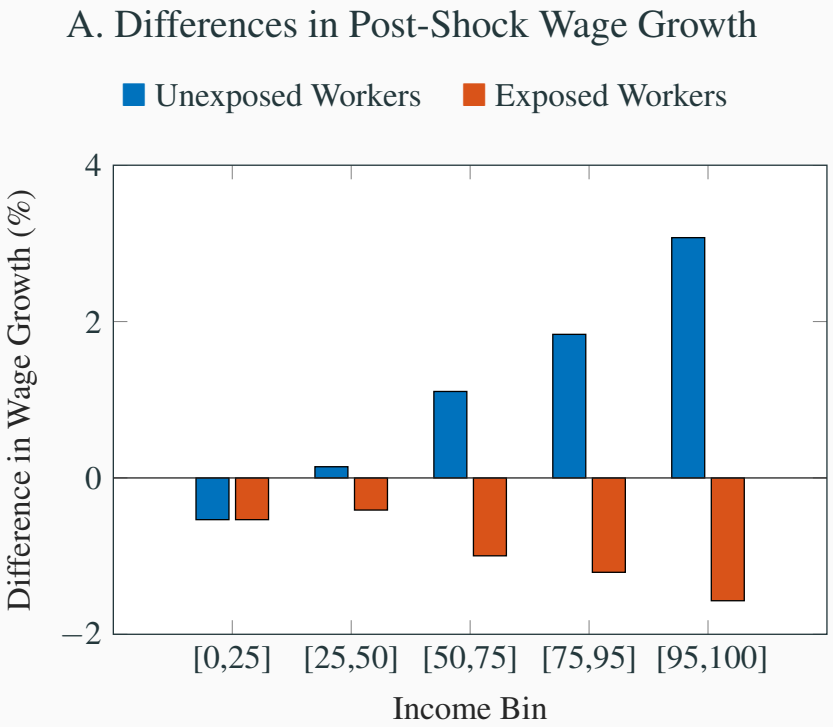


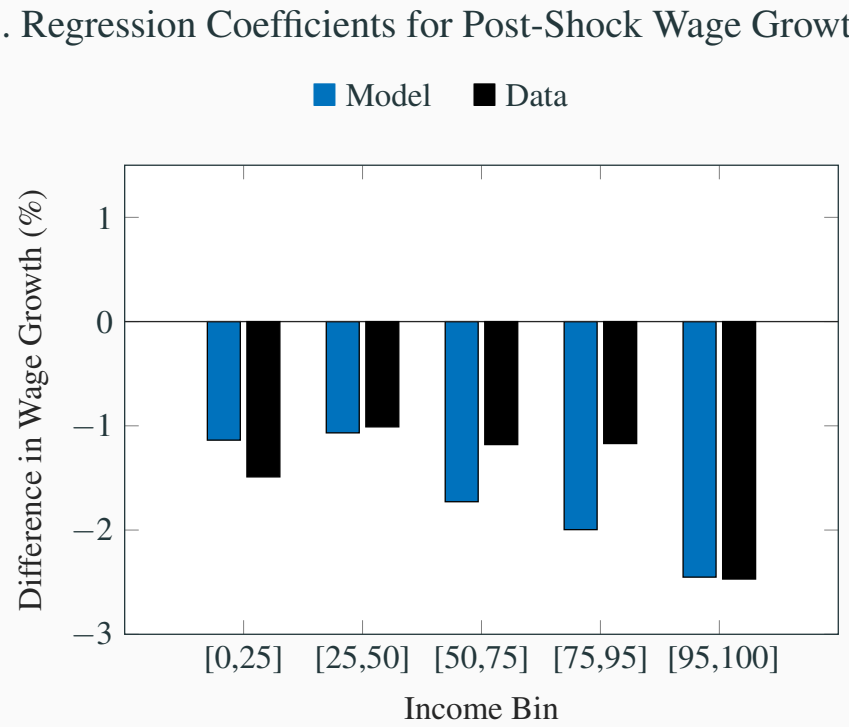






Model: Technology and Worker Earnings





Summary and Next Steps

- We construct direct measures of (labor-saving) technology exposure and find a robustly negative relation to worker outcomes (employment and wages)
  - Between occupation: Middle-skill occupations more highly exposed.
  - Within occupation: Magnitudes larger for (a) older, and (c) most highly-paid workers
- Allowing for skill displacement in the standard model of technology-skill complementarity helps interpret these findings
- Next steps:
  - Alternative measure based on knowledge spillovers
  - Implications for income inequality

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).

Additional Slides

Technology And Employment Over the Long Run (1850-2010)– Heterogenous effects by age

	A. Full Sample	B. Sub-samples		
		1850–1920	1930–1960	1970–1990
Age (20–29) × Technology Exposure, $\eta_{i,t}$	-0.78***	-1.95***	0.038	-0.77***
	(-3.66)	(-4.00)	(0.11)	(-2.69)
Age (30–39) × Technology Exposure, $\eta_{i,t}$	-0.67***	-1.48***	-0.051	-0.70***
	(-3.89)	(-3.25)	(-0.20)	(-2.96)
Age (40–49) × Technology Exposure, $\eta_{i,t}$	-1.26***	-1.88***	-0.54*	-1.39***
	(-6.94)	(-4.30)	(-1.92)	(-5.53)
Observations	6,512	2,232	1,989	2,291
R^2 (Within)	0.068	0.070	0.055	0.098
Controls				
Age Group X Year FE	Y	Y	Y	Y
Lagged Dependent Variable	Y	Y	Y	Y
P-val (40–49) - (20–29)	0.009	0.833	0.069	0.000