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 technology affect workers?

How:

- New measure of (labor-saving) technology exposure
- Worker-level data

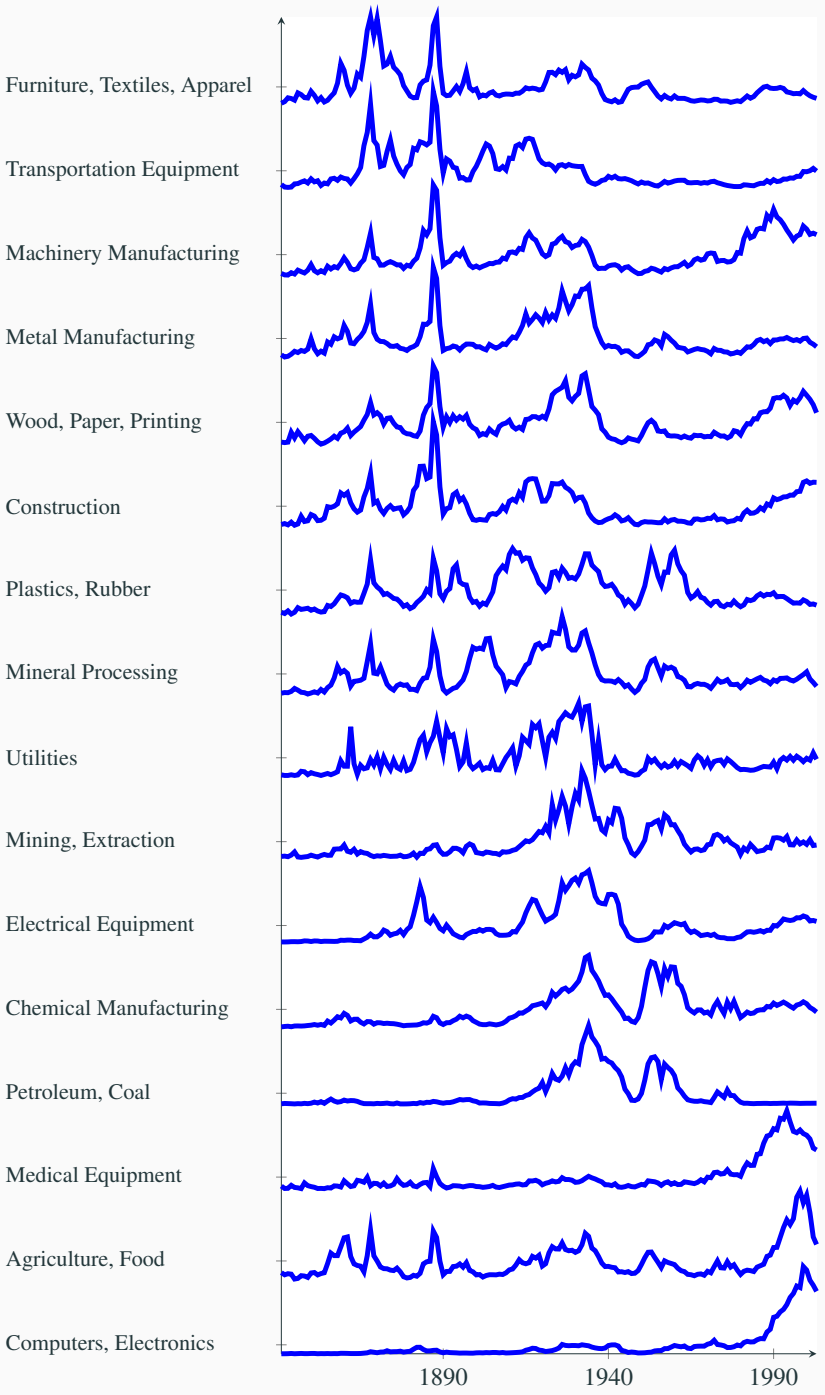
Answer:

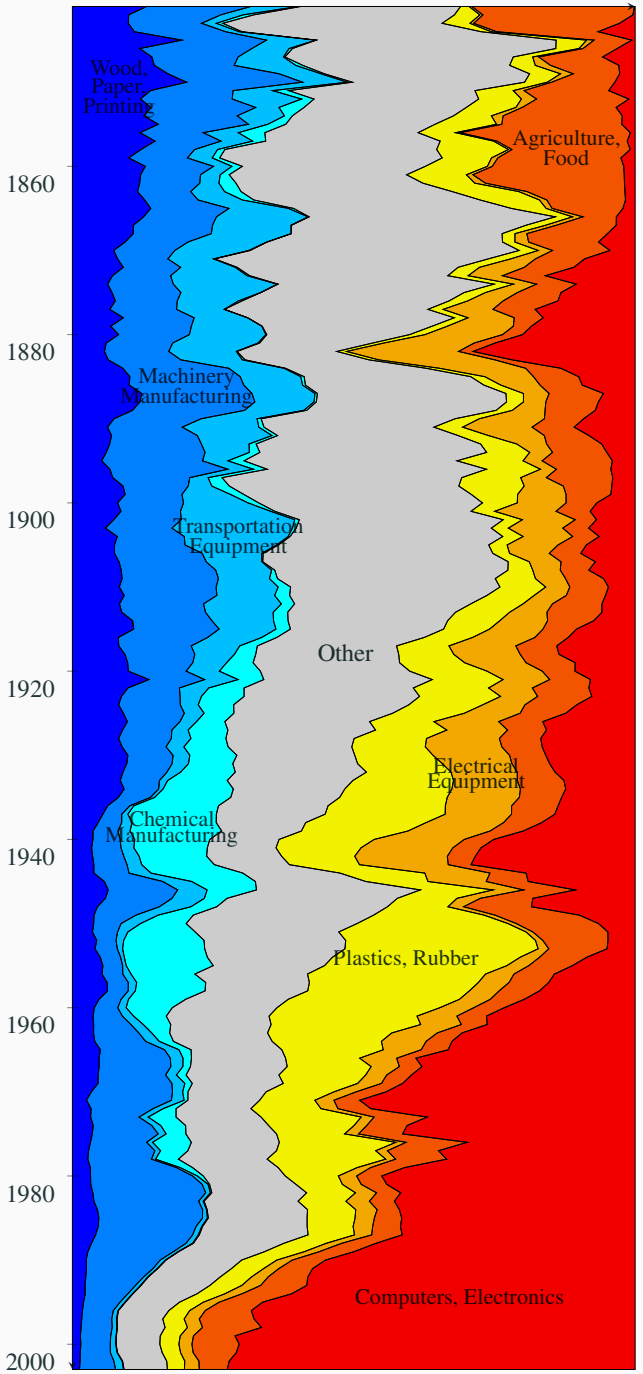
- Which occupations are most exposed has varied over time
- Exposed occupations experience declines in employment and wages
- Highest paid workers experience the largest declines in wage earnings

Measurement: Broad Idea

Use breakthrough patents to measure innovation. We follow Kelly, Papanikolaou, Seru, and Taddy (2021) and identify important patents as those that:

- Novel and impactful: are distinct from previous patents but are related to subsequent patents based on textual similarity
- Breakthroughs: patents in the top 10 percent of the unconditional distribution of impact/novelty


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


1860
1880
1900
1920
1940
1960
1980
2000
Wood, Paper, Printing
Agriculture, Food
Machinery Manufacturing
Transportation Equipment
Other
Electrical Equipment
Chemical Manufacturing
Plastics, Rubber
Computers, Electronics

Measuring patent-occupation similarity

Using textual analysis (word embeddings) we obtain a distance measure ρ between each *breakthrough* patent *p* and each occupation *i*

Patent

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 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

Bright Outlook

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

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

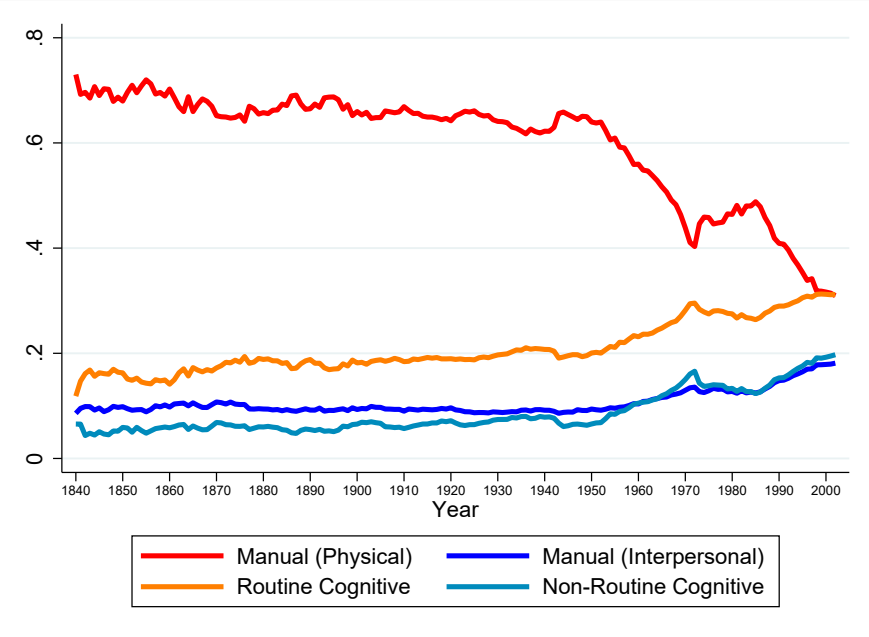
- Sum of breakthroughs related to the tasks occupation i performs
- Weights: textual similarity ρ between a given patent and occupation task descriptions (ONET/DOT)

Our approach is based on measuring overlap between innovations and tasks. Evidence suggests that it primarily identifies labor-saving innovations.

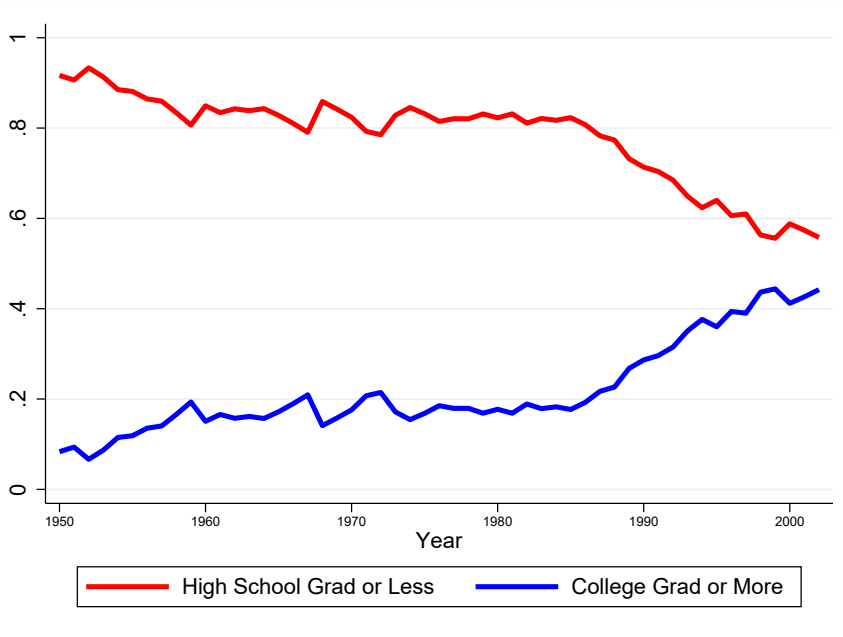
- A statistical factor constructed to maximize (in sample) predictability of negative worker outcomes delivers quantitatively similar results.

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-income occupations more exposed to technical change

Sample: post–1980

- Workers in occupations in the middle of the wage earnings distribution more highly exposed than top/bottom by 1/2 SD

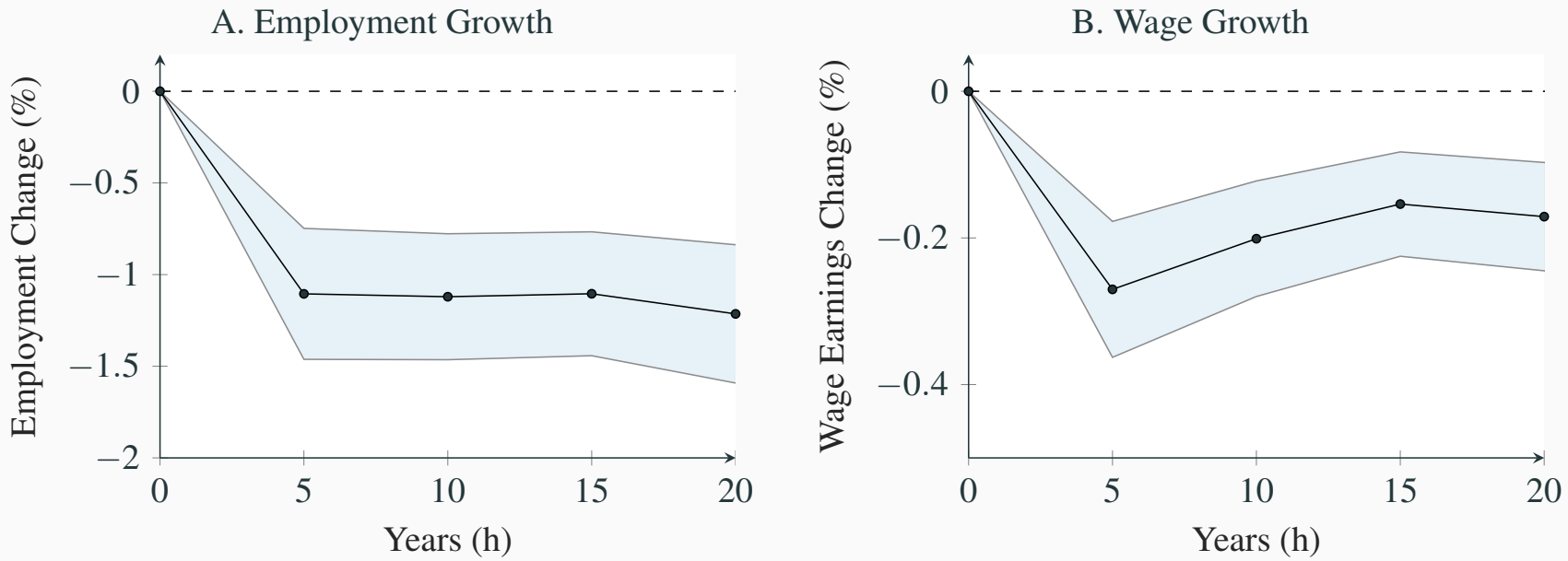
Employment and technology exposure (long run, 1850–present)

$\log \text{Empl}_{i,t+h} - \log \text{Empl}_{i,t}$	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 0.37 to 1.1 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 20% decline in employment and 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
- Perform analysis at occupation–industry cell (based on patent assignee)
- Include both occupation $\times$ year and industry $\times$ year dummies

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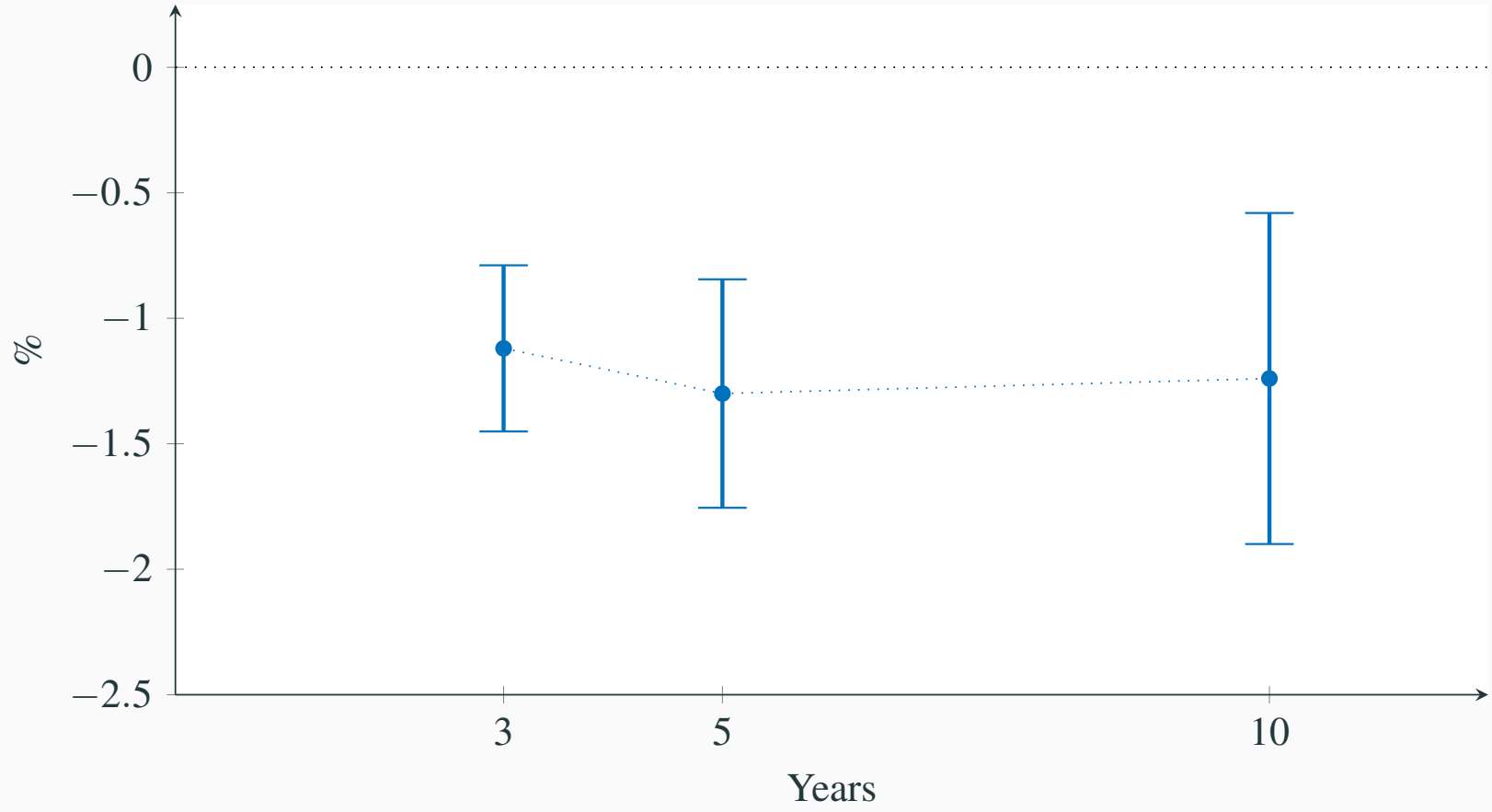
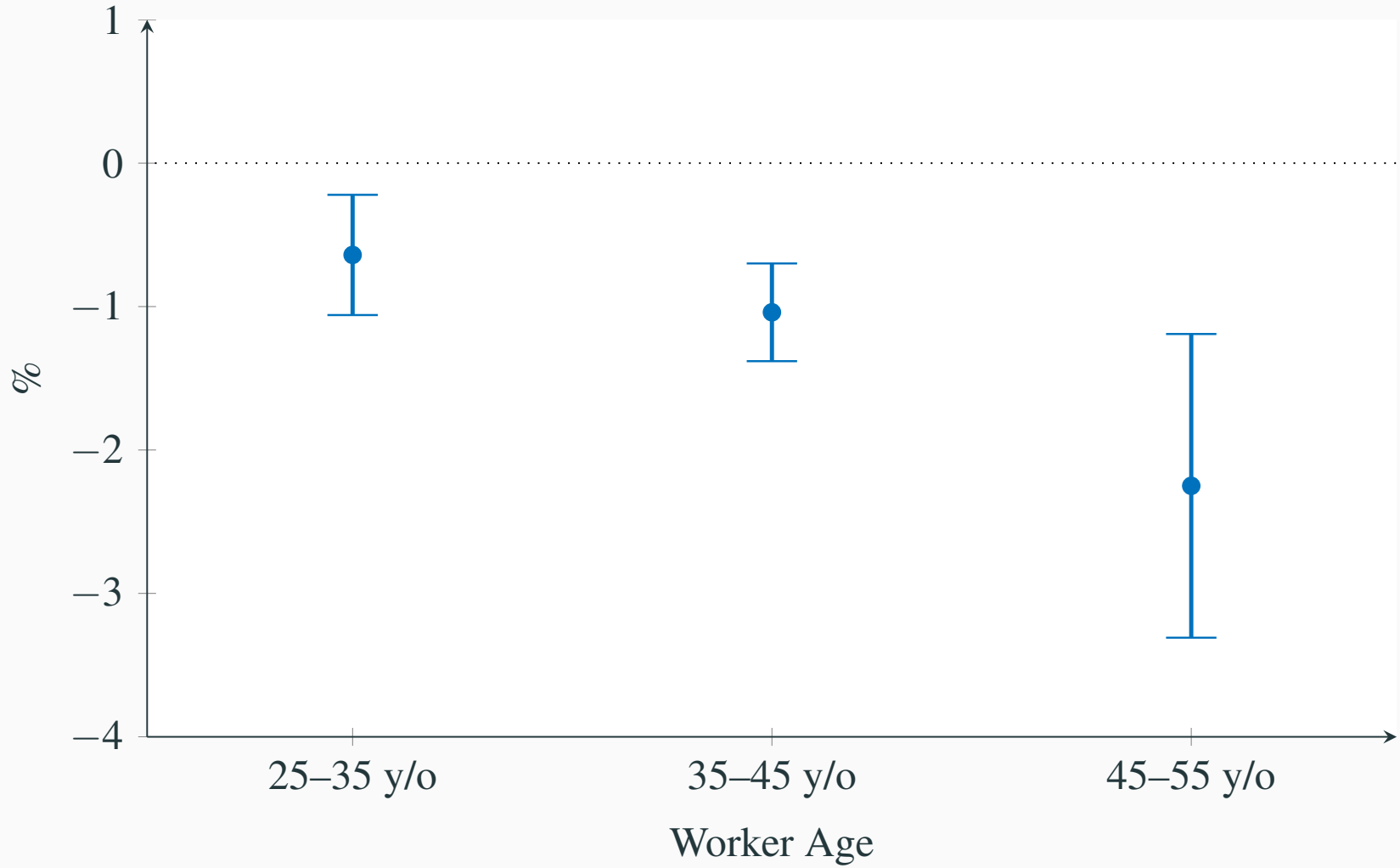
Technology Exposure Predicts Earnings Declines

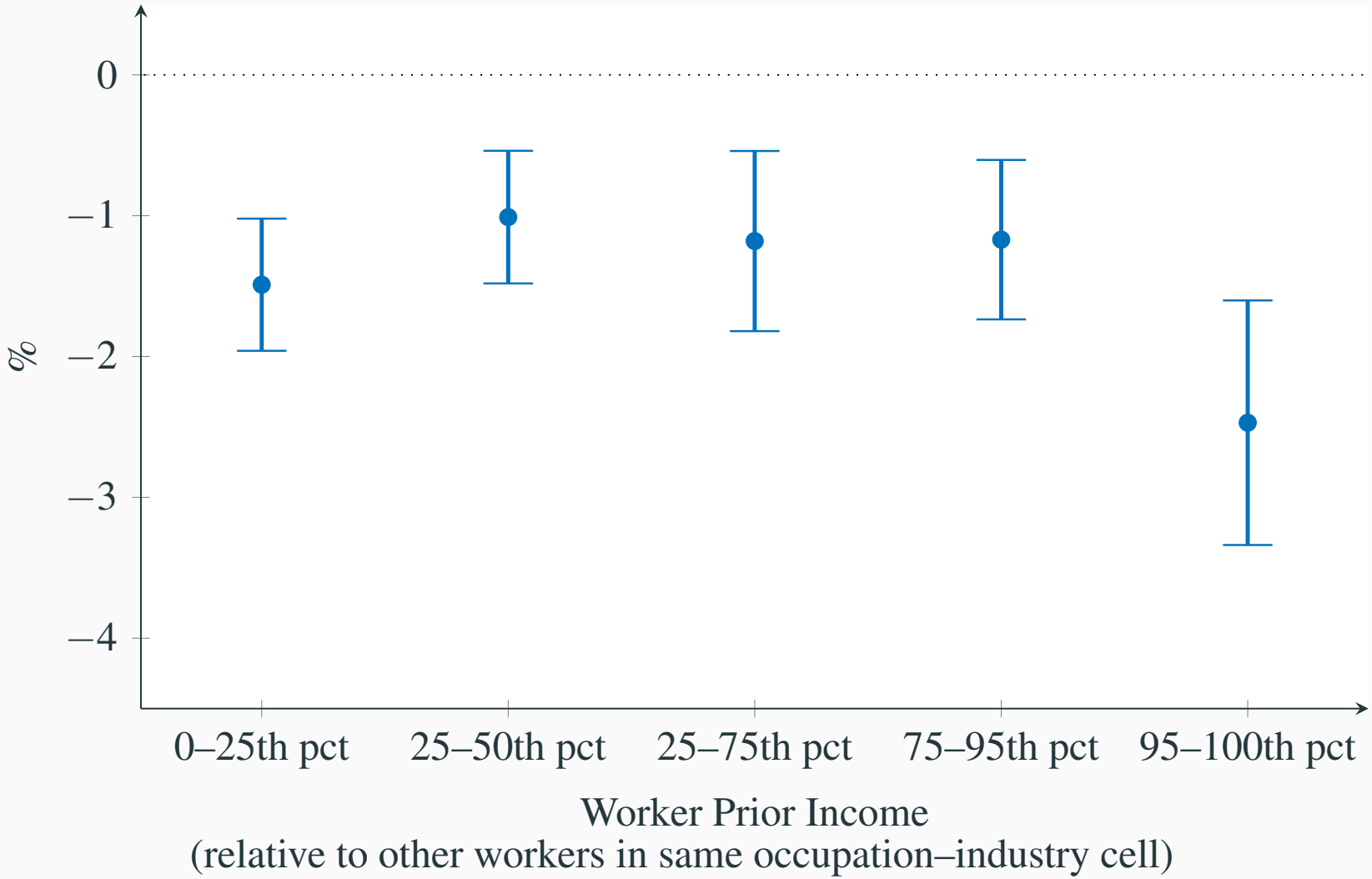


- Worker's cumulative earnings decline by 1–1.5 percentage points over the next five years in response to a 1-SD shock in tech exposure.

Magnitudes 1.5x larger for older workers



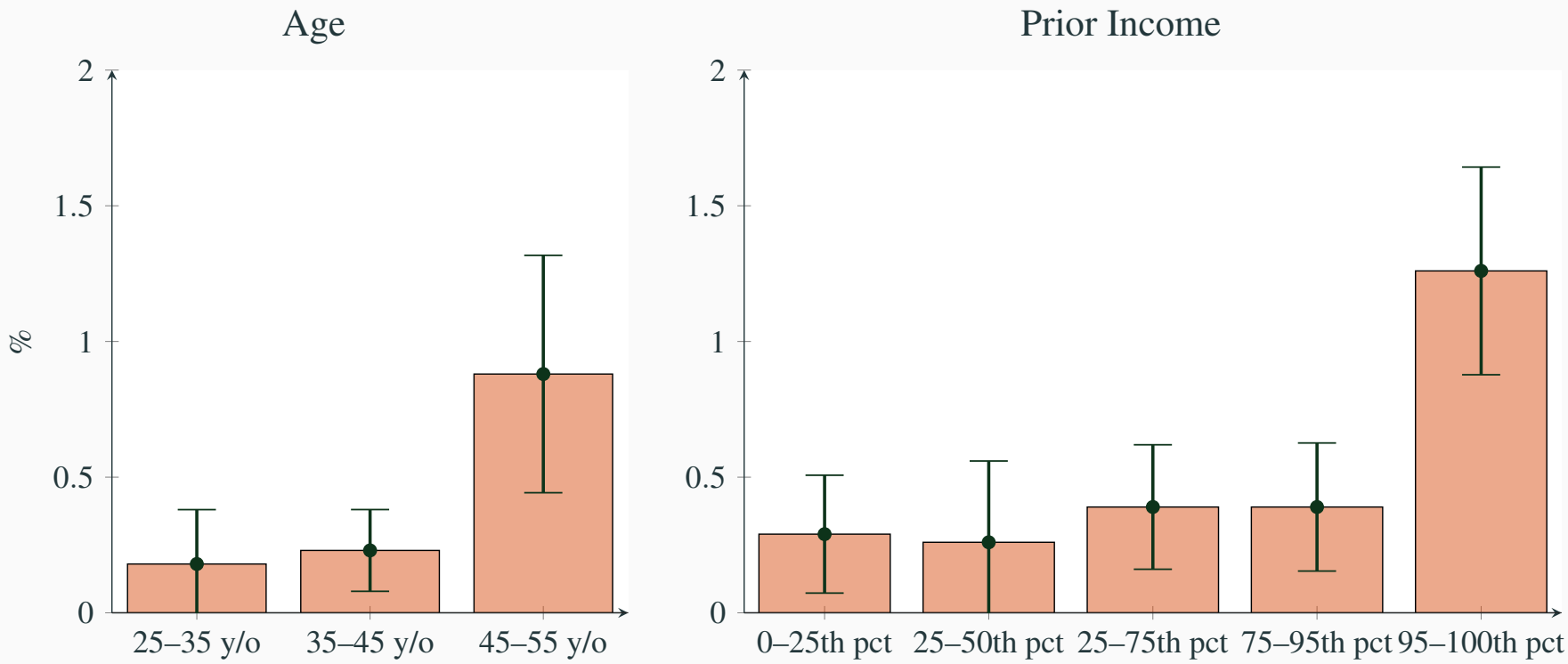
Magnitudes 2x larger for highly-paid workers



Is technology complementary to skill?

- If technology is complementary to skill (and skill $\approx$ wage)
  - Higher-paid workers should see a relative increase in wage earnings
- We see the opposite. Why?
- One possibility: skilled workers as a group may benefit, yet individual workers may get left behind if their skills are vintage-specific.
- If so, these workers more likely to experience larger earnings declines.

Older and highly-paid workers face higher income risk



- Dependent variable: $\mathbf{1}(\text{Earnings Growth} \leq \text{10-th percentile})$
- 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

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

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

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

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:

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

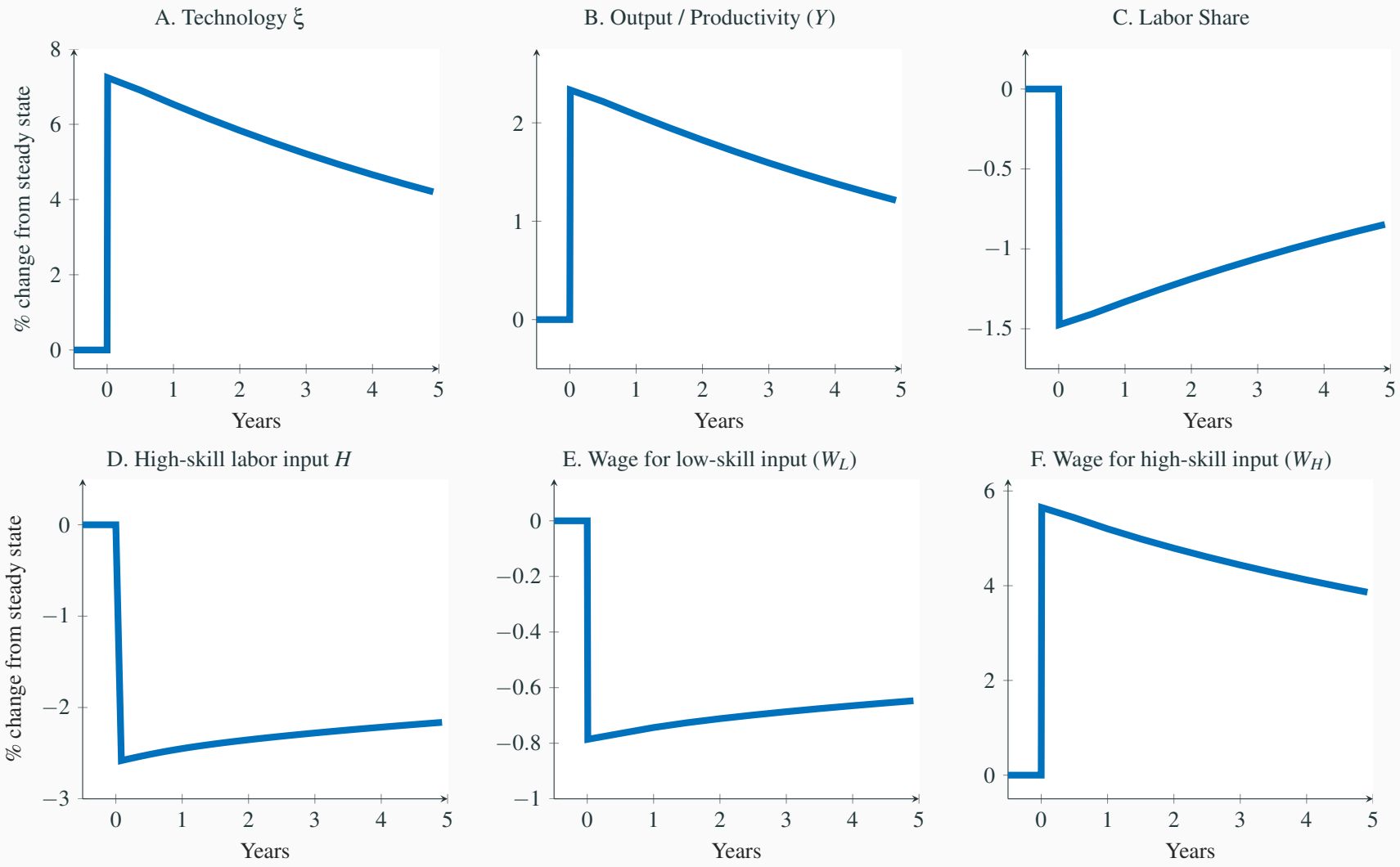
- With some probability θ_{it} falls as technology ξ improves

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

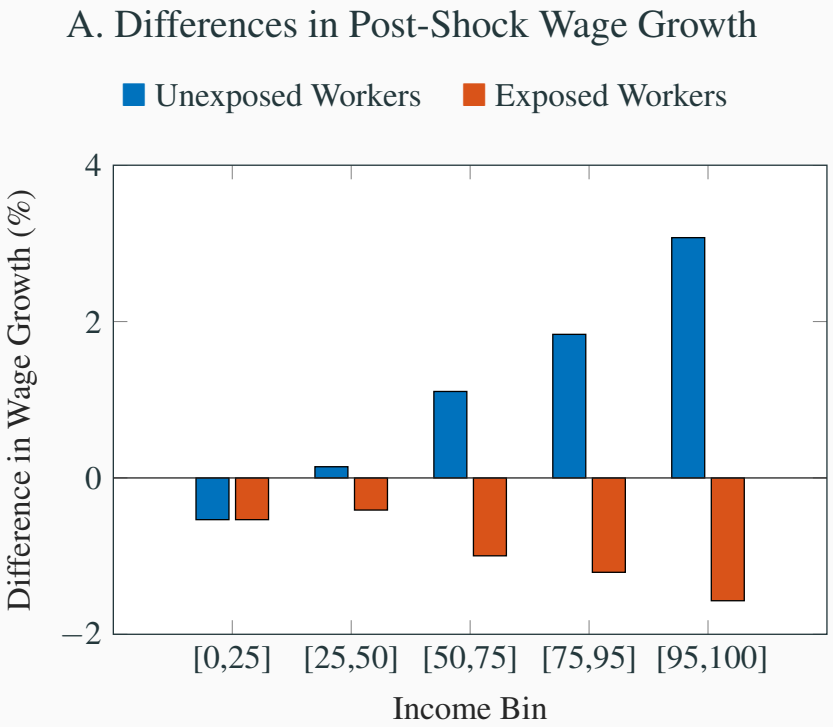
- Workers differentially exposed:

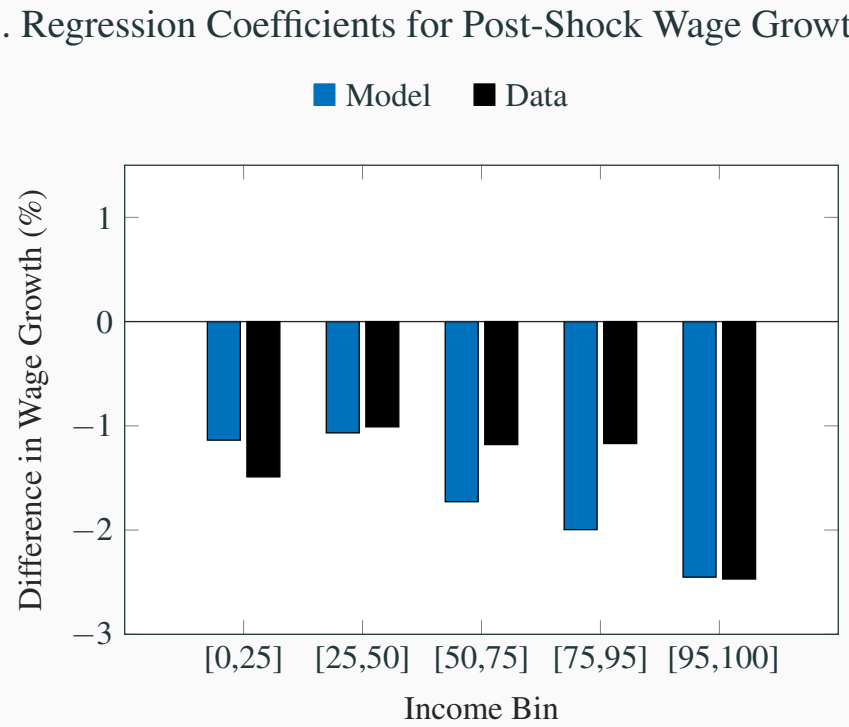
$$dN_{i,t} = d_{i,t}\,dN_t, \qquad d \in \{0,1\} \quad \text{i.i.d. with} \quad Prob(d=1) = \alpha$$

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
- 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
- Next steps:
  - Implications for income inequality
  - Alternative measure based on knowledge spillovers

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

Technology and Employment, by Decade

Patent/Occupation Similarity Examples

Top patents for occupations:

- Loan interviewers and clerks: Go
- Cashiers: Go
- Railroad conductors: Go
- Petroleum engineers: Go

Top occupations for patents:

- Knitting machine (1883): Go
- Metal wheel for vehicles (1922): Go
- System for managing financial accounts (1999): Go

Top Patents For Select Occupations: Loan Interviewers and Clerks

Loan Interviewers and Clerks (SOC Code 434131)

Patent Number	Title
6289319	Automatic business and financial transaction processing system
5611052	Lender direct credit evaluation and loan processing system
6233566	System, method and computer program product for online financial products trading
5940811	Closed loop financial transaction method and apparatus
5966700	Management system for risk sharing of mortgage pools

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Top Patents For Select Occupations: Cashiers

Cashiers (SOC Code 412011)

Patent Number	Title
5055657	Vending type machine dispensing a redeemable credit voucher upon payment interrupt
5987439	Automated banking system for making change on a card or user account
5897625	Automated document cashing system
6012048	Automated banking system for dispensing money orders, wire transfer and bill payment
5598332	Cash register capable of temporary-closing operation

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Top Patents For Select Occupations: Railroad Conductors

Railroad Conductors (SOC Code 534031)

Patent Number	Title
5828979	Automatic train control system and method
6250590	Mobile train steering
3944986	Vehicle movement control system for railroad terminals
6135396	System and method for automatic train operation
5797330	Mass transit system

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Top Patents For Select Occupations: Petroleum Engineers

Petroleum Engineers (SOC Code 172171)

Patent Number	Title
5117908	Method and equipment for obtaining energy from oil wells
4265309	Evaluation and production of attic oil
4031956	Method of recovering energy from subsurface petroleum reservoirs
5165235	System for using geopressured-geothermal reservoirs
4458945	Oil recovery mining method and apparatus

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Top Occupations For Select Patents

Knitting-machine (Patent No. 276146, Issued in 1883)

Occupation Title
Textile Knitting and Weaving Machine Setters, Operators, and Tenders
Sewing Machine Operators
Sewers, Hand
Fabric Menders, Except Garment
Textile Winding, Twisting, and Drawing Out Machine Setters, Operators, and Tenders

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Top Occupations For Select Patents: Metal Wheel for Vehicles

Metal wheel for vehicles (Patent No. 1405358, Issued in 1922)

Occupation Title
Automotive Service Technicians and Mechanics
Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic
Maintenance Workers, Machinery
Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic
Rolling Machine Setters, Operators, and Tenders, Metal and Plastic

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Top Occupations For Select Patents: System for Managing Financial Accounts

System for managing financial accounts by a priority allocation of funds among accounts (Patent No. 5911135, Issued in 1999)

Occupation Title
Financial Managers
Credit Analysts
Loan Interviewers and Clerks
Accountants and Auditors
Bookkeeping, Accounting, and Auditing Clerks

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