Divergent Transformation Paths: An Anatomy of the Baumol Cost Disease

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Motivation

Baumol's Cost Disease

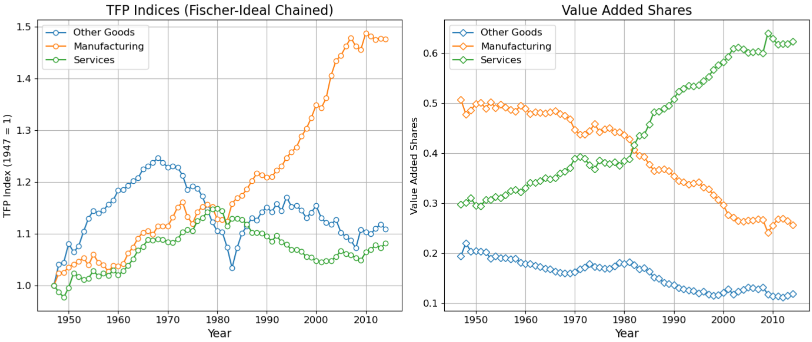
...the very progress of the technologically progressive sectors inevitably adds to the costs of the technologically unchanging sectors of the economy...

William Baumol *Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis* - AER,1967

Motivation

Sectoral TFP Growth and Structural Change in the US

- Structural Transformation $\leftrightarrow$ Productivity Slowdown
- Reallocation of economic activity
  - from dynamic ...
  - ...into less-dynamic sectors

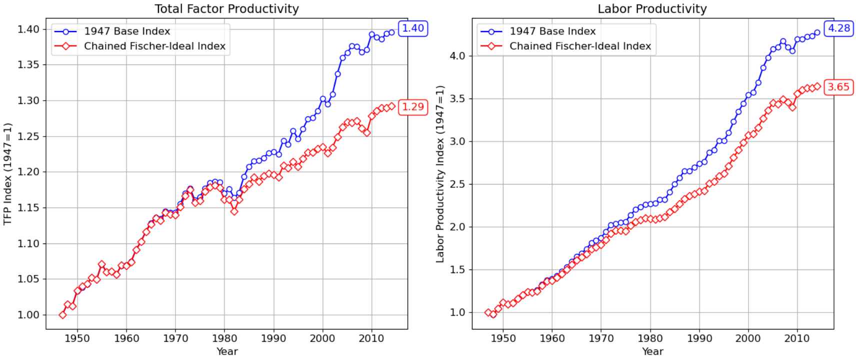


Source: Own calculations based on US KLEMS, March 2017 Release

Motivation

Main Implication

- Lower measured TFP growth due to compositional effects



Source: Own calculations based on US KLEMS, March 2017 Release

Motivation

Structural Change, Innovation, and Growth

- Sectoral productivity growth is not fixed
- The state and structure of the economy also affect
  - Incentives to innovate
  - Allocation of R&D resources
- Shaping sectoral and aggregate productivity growth
- This paper studies:
  - The determinants of the sectoral allocation of R&D
  - How they vary with structural change and development
  - Implications for sectoral and aggregate TFP growth

Introduction

Contribution and Findings

1. New Evidence on Innovation and Struct. Transformation (ST)
   - ST in **innovation** from manufacturing to services
   - Divergent Transformation Paths
     - Research activity moves to **high R&D** services
     - Production shifts to **low R&D** services
2. We build quantitative theory of ST and Innovation and study
   - Mechanisms driving the sectoral allocation of RD
   - Implications for sectoral and aggregate productivity growth
   - Potential role for policy interventions
3. Quantitative Findings; (US 1947-2014)
   - ST contributed to TFP slowdown (-2.0 p.p; vs. 11.0 p.p.)
   - Similar quant. effect as pop. growth slowdown (-2.8 p.p.)
   - Market power and markups hindered TFP growth (-7.8 p.p.)
   - Cross-sector spillovers helped sustain TFP growth (+10.2 p.p.)

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Related Literature

Empirical Facts

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Conclusion

Appendix

Related Literature

1. **Drivers of Secular Stagnation**
   - **Demographics** Abiry et al. (2016); Eggertsson et al. (2019)
   - **Productivity growth slowdown** Bergeaud et al. (2018); Platzer & Peruffo (2022); Liu et al. (2022)

   We study the role of SC in driving growth slowdown

2. **Causes & Consequences of Structural Change**
   - **Documenting structural change** Stigler et al. (1956); Kuznets, (1957); Fuchs et al. (1968); Herrendorf et al. (2014)
   - **Causes of structural change** Ngai & Pissarides (2007); Kongsamut et al. (2001); Boppart (2014); Comin et al. (2021)
   - **Heterogeneous services** Buera & Kaboski (2012); Duernecker et al. (2024)

   i) document SC in innovation ii) endogenise sectoral prod. growth

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Data

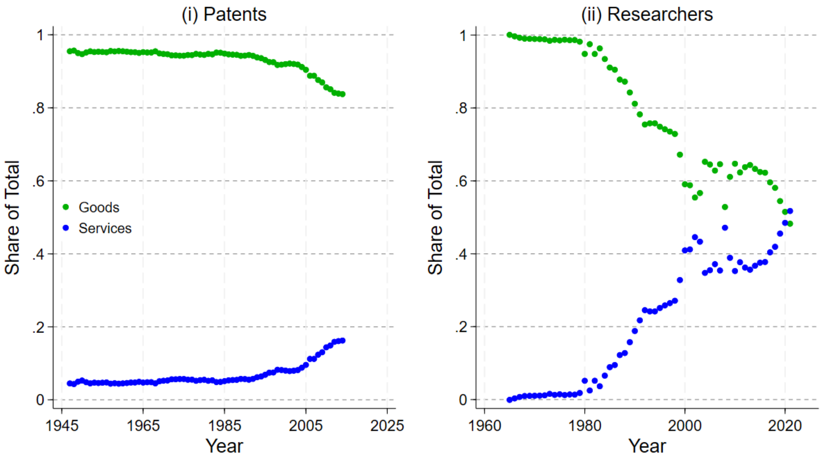
We merge several data sources together:

Variable	Source
Scientists	National Science Foundation (BERD survey)
Patents[1]	US Patent & Trademark Office (PTO)
Cross-citations	OECD Citations Database
VA, TFP, Lab. Prod.	World KLEMS (March 2017 release)

[1] USPC-industry crosswalk from (Goldschlag, et al., 2019)

Structural Change in Innovation

From Manufacturing/Goods to Services

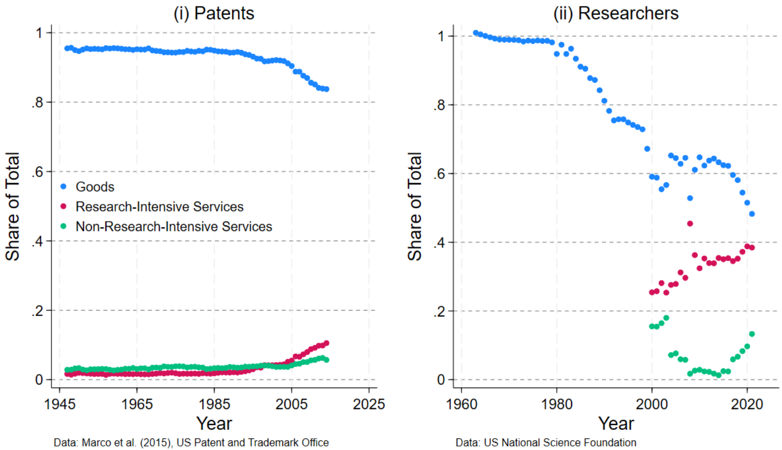


Data: Marco et al. (2015), US Patent and Trademark Office

Data: US National Science Foundation

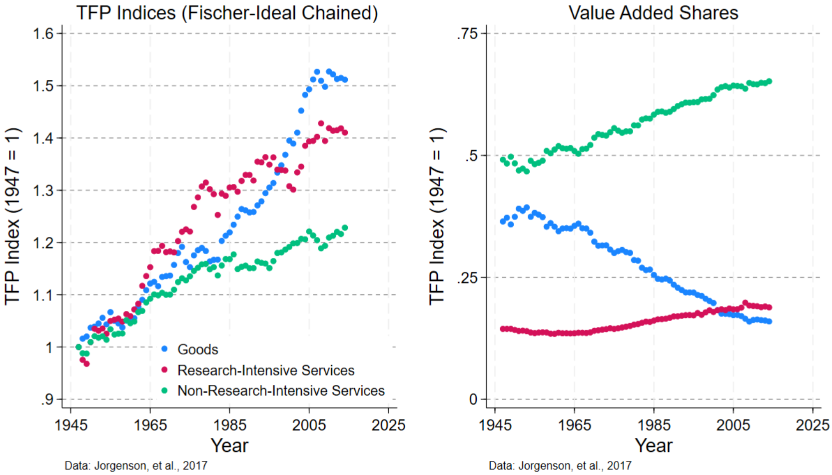
Structural Change in Innovation

More Prominent Towards High R&D Services



▸ Services Split ▸ OECD

Driving Heterogeneous Productivity Paths



Rich Structure of Cross-Sector Knowledge Spillovers

Manufacturing ideas have a relevant effect on services

		Citing Setor		
		MFG	RI-SERV	NRI-SERV
Cited Sector	MFG	0.93	0.62	0.82
	RI-SERV	0.03	0.32	0.05
	NRI-SERV	0.03	0.06	0.13

▸ Robustness

Plan

Key Model Features

- Traditional representative household structure
- Standard ST model via:
    1. relative price effects
    2. income effects
- Endogenous sector-level prod. growth à la Acemoglu (2002)
- With innovation incentives shaped by
    1. price effect
    2. market size effect
    3. knowledge spillovers
    4. marginal costs/markups

Household Preferences & Demographic Structure

- Continuum of homogeneous workers of mass $L(t)$
- Labor force grows at (time-variant) rate $n(t)$

- Workers can work in:
  - The production sector ($L^P(t)$), making wages $w_l(t)$
  - The R&D sector ($L^S(t)$), making wages $w_s(t)$
  - $L^P(t) + L^S(t) = L(t)$
- In per-capita terms: $s(t) = \frac{L^S(t)}{L(t)}, \quad l(t) = \frac{L^P(t)}{L(t)}$

- Standard CRRA preferences (χ), given by

$$U\left(c(t), L(t)\right) = \int_0^\infty e^{-\rho t} L(t) \left(\frac{c(t)^{1-\chi} - 1}{1 - \chi} \right) dt$$

Production Technologies

- Three-sector economy
- Nested non-homothetic CES structure
- Final good: composite of $Y_m(t)$ and $Y_s(t)$ output

$$\left[\theta_m^{\frac{1}{\sigma}} \left(Y(t)^{-\zeta_m} Y_m(t)\right)^{\left(\frac{\sigma-1}{\sigma}\right)} + \theta_s^{\frac{1}{\sigma}} \left(Y(t)^{-\zeta_s} Y_s(t)\right)^{\left(\frac{\sigma-1}{\sigma}\right)}\right]^{\left(\frac{\sigma}{\sigma-1}\right)} = 1$$

- Services: composite of $Y_{rs}(t)$ and $Y_{ns}(t)$ output

$$\left[\psi_{rs}^{\frac{1}{\epsilon}} \left(Y_s(t)^{-\zeta_{rs}} Y_{rs}(t)\right)^{\left(\frac{\epsilon-1}{\epsilon}\right)} + \psi_{ns}^{\frac{1}{\epsilon}} \left(Y_s(t)^{-\zeta_{ns}} Y_{ns}(t)\right)^{\left(\frac{\epsilon-1}{\epsilon}\right)}\right]^{\left(\frac{\epsilon}{\epsilon-1}\right)} = 1$$

Sectoral Technologies

- Sectoral output produced according to

$$Y_j(t) = \left(\frac{1}{1-\beta}\right) X_j(t)^{1-\beta} \left(B_j(t) L_j^P(t)\right)^{\beta} \quad \text{for} \quad j \in \{m, rs, ns\}$$

- With
  - L_j^P: production labor in j
  - B_j: labor-augmenting technology in j
  - X_j: aggregate machine input in j
- X_j is defined by the CES aggregator

$$X_j(t) = \left(\int_0^{N_j(t)} x_j(\nu, t)^{\mu_j} d\nu\right)^{(1/\mu_j)}$$

  - $x_j(\nu, t)$ is the quantity of machines of type ν in time t
  - $N_j(t)$ is the measure of machine varieties

Machine Producers' Technologies

- Each variety ν is produced by an intermediate goods producer
- Technology given by

$$x_j(\nu, t) = a_j(t) y_j^x(\nu, t)$$

  - $y_j^x(\nu, t)$ are units of the final good used in $x_j(\nu, t)$
  - $a_j(t)$ is the sector-specific productivity of machine producers

Research & Development (R&D)

- Directed innovation
  - Large number of research labs
  - Create *new* machine variety blueprints
  - R&D efforts directed to a specific sector
  - Successful innovators obtain fully-enforced perpetual patents
  - Machines fully depreciate after one period
  - Patents can be sold to machine produces at price $V_j(t)$

- Aggregate research efforts yield the following flow of ideas

$$\dot{N_j}(t) = \eta_j \Lambda_j(t)^{\gamma} L_j^S(t)^{(1-\alpha)}$$

  - η_j exogenous arrival rate of ideas in j
  - $L^S(t)$: R&D workers in j
  - $\Lambda_j(t) = N_j(t)^{\delta_{jj}} N_i(t)^{\delta_{ji}} N_k(t)^{\delta_{jk}}$ ideas aggregator

Market Value of Patents

- Value of owning a patent of type ν in sector j is

$$V_j(\nu, t) = \int_{s=t}^{\infty} e^{-\int_{s'=0}^{s} r(s')ds'} \pi_j(\nu, s)ds$$

- The corresponding Hamilton-Jacobi-Bellman equation is

$$r(t)V_j(\nu, t) = \pi_j(\nu, t) + \dot{V}_j(\nu, t)$$

  - $\pi_j(\nu, t)$: profits for a machine variety producer
  - $r(t)$: real interest rate

Equilibrium Characterization

Sectoral Output Demand

- Sectoral output demands are

$$Y_m(t) = \frac{e_m(t)Y(t)}{p_m(t)}$$

$$Y_k(t) = (1 - e_m(t))\frac{e_k(t)Y(t)}{p_k(t)} \quad k \in \{rs, ns\}$$

- With sectoral output shares given by

$$e_m(t) = \theta_m Y(t)^{(\zeta_m - 1)(1-\sigma)} p_m(t)^{1-\sigma}$$

$$e_k(t) = \theta_k \left(\frac{p_k(t)}{p_s(t)}\right)^{1-\epsilon} Y_s(t)^{(\zeta_k - 1)(1-\epsilon)}$$

Equilibrium Characterization

Markups, Profits & Output

- Machine producers in each sector face (inverse) demand

$$p_j^x(\nu,t) = \left(\frac{p_j(t)Y_j(t)}{X_j(t)}\right)\left(\frac{X_j(t)}{x_j(\nu,t)}\right)^{(1-\mu_j)}$$

- Optimal pricing of machine producers in each sector

$$p_j^x(\nu,t) = \frac{1}{\mu_j}\frac{p(t)}{a_j(t)}$$

- Profits for each sector's machine producers are

$$\pi_j(\nu,t) = \left(\frac{1-\mu_j}{\mu_j}\right)\frac{p(t)x_j(\nu,t)}{a_j} \quad \text{where} \quad x_j(\nu,t) = \frac{\alpha p_j(t)Y_j(t)a_j(t)}{N_j(t)}$$

- Output is

$$Y_j(t) = C_j(\beta,\mu_j)N_j(t)^{\left(\frac{1-\beta}{\beta}\right)\left(\frac{1-\mu_j}{\mu_j}\right)}(p_j(t)a_j(t))^{\left(\frac{1-\beta}{\beta}\right)}B_j(t)L_j^P(t)$$

Equilibrium Characterization

Drivers of Directed Technical Change

- Profits for machine producers drive incentives to innovate
- Directed technical change (Acemoglu, 2002)

$$\pi_j^{DTC}(\nu, t) = \beta p_j(t)^{1/\beta} L_j^P(t)$$

  - sector size effect and relative price effect key $\rightarrow$ ST

- Here we get

$$\pi_j(\nu, t) = (1-\mu_j)\left(\frac{1}{1-\beta}\right)^{\frac{1}{\beta}} N_j(t)^{\frac{1-\mu_j-\beta}{\mu_j\beta}} (\mu_j a_j(t))^{\frac{1-\beta}{\beta}} \frac{B_j(t)\pi_j^{DTC}}{\beta}$$

  - Heterogenous sectoral trends in machine productivity $\rightarrow$ different marginal costs in each sector $\rightarrow$ influence sector profits

Equilibrium Characterization

Innovation Dynamics and Wages

- Free entry into the innovation sector yields

$$\dot{N_j}(t)V_j(t) = w_s(t)L_j^S(t) \quad \text{for} \quad j \in \{m, rs, ns\}$$

- Implying that the wage for scientists is

$$\eta_j \Lambda_j(t)^{\gamma} L_j^S(t)^{-\alpha} V_j(t) = w_s(t)$$

- Free labor mobility between production and innovation

$$w_s(t) = w_l(t)$$

Equilibrium Characterization

Sectoral Allocations for Workers and Scientists

- Employment shares equal output shares

$$\frac{L_j^P(t)}{L(t)} = e_j(t) \quad j \in \{m, rs, ns\}$$

- Sectoral R&D employment is given by

$$S_m(t) = \frac{S(t)}{\left[1 + \left(\frac{\eta_{rs}\Lambda_{rs}(t)^\gamma V_{rs}(t)}{\eta_m\Lambda_m(t)^\gamma V_m(t)}\right)^{1/\alpha} + \left(\frac{\eta_{ns}\Lambda_{ns}(t)^\gamma V_{ns}(t)}{\eta_m\Lambda_m(t)^\gamma V_m(t)}\right)^{1/\alpha}\right]}$$

$$S_i(t) = S_m(t)\left(\frac{\eta_i\Lambda_i(t)^\gamma V_i(t)}{\eta_m\Lambda_m(t)^\gamma V_m(t)}\right)^{1/\alpha} \quad i \in \{rs, ns\}$$

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Externally Calibrated Parameters

Parameter	Description	Value	Source
β	labor intensity	0.65	macro literature
χ	intertemporal elasticity of sub.	1.50	macro literature
ρ	discount factor	0.05	macro literature
δ_{mm}	knowledge spillover intensity MFG to MFG	0.92	authors calc.
δ_{rm}	knowledge spillover intensity MFG to RI-S	0.57	authors calc.
δ_{nm}	knowledge spillover intensity MFG to NRI-S	0.72	authors calc.
δ_{mr}	knowledge spillover intensity RI-S to MFG	0.04	authors calc.
δ_{rr}	knowledge spillover intensity RI-S to RI-S	0.27	authors calc.
δ_{nr}	knowledge spillover intensity RI-S to NRI-S	0.10	authors calc.
δ_{mn}	knowledge spillover intensity NRI-S to MFG	0.05	authors calc.
δ_{rn}	knowledge spillover intensity NRI-S to RI-S	0.16	authors calc.
δ_{nn}	knowledge spillover intensity NRI-S to NRI-S	0.18	authors calc.
γ	spillover elasticity	0.50	robustness checks
$1-\alpha$	scientist elasticity	0.35	robustness checks

Structurally Estimated Parameters

Via Simulated Method of Moments

Parameter	Interpretation	Value
σ	elasticity of sub. b/w MFG and SERV	0.05
ϵ	elasticity of sub. b/w RI-S and NRI-S	1.07
ζ_m	MFG non-homotheticity parameter	0.51
ζ_{rs}	RI-S non-homotheticity parameter	1.00
ζ_{ns}	NRI-S non-homotheticity parameter	1.25
η_m	MFG arrival rate of innovation	0.036
η_{rs}	RI-S arrival rate of innovation	0.005
η_{ns}	NRI-S arrival rate of innovation	0.001
$g_{b,m}$	growth in MFG labor-augmenting technology	0.0138
$g_{b,rs}$	growth in RI-S labor-augmenting technology	0.0129
$g_{b,ns}$	growth in NRI-S labor-augmenting technology	0.0103
θ_m	MFG sector weight (1947)	0.596
θ_{rs}	RI-S sector weight (1947)	0.236
θ_{ns}	NRI-S sector weight (1947)	0.749

▸ Data Moments ▸ Income Elasticities

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Counterfactual TFP Growth

		Aggregate TFP Growth (2010-1947, %)	Difference w.r.t Benchmark (p.p.)
Panel A. Benchmark Value		***29.9***	
Panel B. Drivers of Structural Change in Production			
B.1	*No Income Effects*	*31.4*	*+1.5*
B.2	*No Income and Substitution Effects*	*31.9*	*+2.0*
Panel C. Other Drivers of Sectoral Innovation			
C.2	*No Change in Markups*	*37.7*	*+7.8*
C.1	*No Cross-Sector Spillovers*	*19.7*	*-10.2*
Panel D. No Population Growth Slowdown		*32.7*	*+2.8*

▸ $\gamma = 0.30$ ▸ $\gamma = 0.70$

Productivity Growth in the Future

Model's Predicted Structural Change in Employment and Innovation

Variable	1947 (-67 years)	2014	2081 (+67 years)	p.p. Δ (2081-2014)
$e_m(t)$	0.598	0.338	0.197	-14.1
$e_{ns}(t)$	0.764	0.758	0.754	-0.4
$e_{rs}(t)$	0.236	0.242	0.246	+0.4
$L_m^S(t)/L^S(t)$	0.947	0.866	0.483	-38.4
$L_{rs}^S(t)/L^S(t)$	0.016	0.078	0.358	+28.0
$L_{ns}^S(t)/L^S(t)$	0.037	0.056	0.160	+10.4

- Structural change out of manufacturing predicted to continue
- Stable shares within services
    - income and substitution effects offset each other
- Scientists continue moving to RIS (markups!)

Productivity Growth in the Future

Model's Predicted Sectoral and Aggregate TFP Growth

Variable	**1947**	**2014**	**2075**	x_{2075}/x_{2010}
$y(t)$	1.00	3.03	6.14	2.02
$N_m(t)$	1.00	1.44	2.04	1.49
$N_{ns}(t)$	1.00	1.21	1.66	1.37
$N_{rs}(t)$	1.00	1.29	2.14	1.66
$TFP(t)$	1.00	1.30	1.91	1.47

- Re-allocation hinders output growth (lab. prod)
- TFP growth speeds up in services
  - Scientists drive TFP growth in NRIS
- Scientists continue moving into RIS

Plan

Conclusion

1. Document divergence in structural change patterns in innovation and and production employment/VA
2. Built a theory that rationalises these trends
   - Feedback between direction of tech. change and ST
   - Sectoral allocation of R&D activity depends on ST, spillovers and markups
3. Main results
   - Markpus main force behind divergent transformation paths
   - ST contributed to TFP slowdown (-2.0 p.p)
   - Market power and markups hindered TFP growth (-7.8 p.p.)
   - Cross-sector spillovers helped sustain TFP growth (+10.2 p.p.)

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Services Split By Research-Intensity

		Patents per Hour		
Industry	Description	Av. ('63-'14)	Initial ('63)	Sector
51	Information	0.522	0.063	RI-Serv.
48-49	Transportation & Warehousing	0.130	0.089	RI-Serv.
54	Prof., Scientific & Technical Serv.	0.115	0.017	RI-Serv.
52	Finance & Insurance	0.104	0.062	NRI-Serv.
621-623	Healthcare and Social Assistance	0.058	0.056	NRI-Serv.
NA	Others	0.050	0.040	NRI-Serv.
55	Management of Comp. & Enterp.	0.042	0.021	NRI-Serv.
44-45	Retail Trade	0.034	0.005	NRI-Serv.
53	Real Estate, Rental & Leasing	0.002	0.002	NRI-Serv.
42	Wholesale Trade	0.001	0.000	NRI-Serv.

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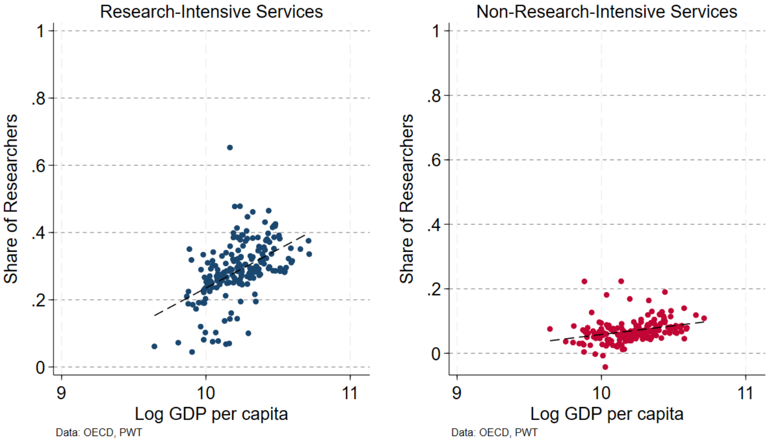
Post-Industrial Economies Observe Similar Trends



Countries included: Australia, Austria, Belgium, China, Czechia, Spain, Estonia, France, Greece, Hungary, Iceland, Italy, Korea, Mexico, the Netherlands, Norway, Poland, Portugal, Singapore, Slovakia, Slovenia, USA

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Conditional Probabilities Robust To Different Specs.

- Cited Conditional Probabilities (has X)

		Citing Setor		
		MFG	RI-SERV	NRI-SERV
	MFG	0.92	0.56	0.72
Cited Sector	RI-SERV	0.03	0.27	0.10
	NRI-SERV	0.05	0.17	0.19

- Cited Conditional Probabilities (has XY)

		Citing Setor		
		MFG	RI-SERV	NRI-SERV
	MFG	0.92	0.57	0.73
Cited Sector	RI-SERV	0.03	0.26	0.10
	NRI-SERV	0.05	0.16	0.17

- Cited Conditional Prob (has X only)

		Citing Setor		
		MFG	RI-SERV	NRI-SERV
	MFG	0.91	0.55	0.70
Cited Sector	RI-SERV	0.04	0.27	0.10
	NRI-SERV	0.05	0.17	0.19

Conditional Probabilities Robust To Different Years

- Cited Probability (> 2000)

		Citing Setor		
		MFG	RI-SERV	NRI-SERV
	MFG	0.92	0.56	0.72
Cited Sector	RI-SERV	0.03	0.27	0.10
	NRI-SERV	0.05	0.17	0.18

- Cited Probability (> 2010)

		Citing Setor		
		MFG	RI-SERV	NRI-SERV
	MFG	0.92	0.55	0.73
Cited Sector	RI-SERV	0.03	0.28	0.10
	NRI-SERV	0.05	0.17	0.18

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Matching Behavior of US Economy

Sectoral Data Aggregates: 1947-2014

	2014 TFP (1947 = 1)			2014 Relative Prices (1947 = 1)		
	MFG	**RI-S**	**NRI-S**	**MFG**	**RI-S**	**NRI-S**
Moment	1.48	1.32	1.23	0.93	0.97	1.08

	2014 Output Shares			2000 Scientist Shares		
	MFG	**RI-S**	**NRI-S**	**MFG**	**RI-S**	**NRI-S**
Moment	0.33	0.16	0.51	0.59	0.25	0.16

	1947 Output Shares			2014 Output p. w. (1947 = 1)
	MFG	**RI-S**	**NRI-S**	**Aggregate**
Moment	0.60	0.09	0.031	3.18

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Income Elasticity Computations

Income elasticities according to CLM specification (2021) are

$$\Omega_i \equiv \frac{\partial \log Y_i}{\partial \log Y} = \sigma + (1-\sigma)\frac{\zeta_i}{\bar{\zeta}} \quad \forall i = m, s$$

$$\Omega_k \equiv \frac{\partial \log Y_k}{\partial \log p_s Y_s} = \epsilon + (1-\epsilon)\frac{\zeta_k}{\bar{\zeta}_s} \quad \forall k = rs, ns$$

where

$$\bar{\zeta} = \sum_i e_i \zeta_i \quad \text{and} \quad \bar{\zeta}_s = \sum_k \frac{e_k}{e_s}\zeta_k$$

Calibrated non-homotheticity parameters imply income elasticities

	MFG	RI-S	NRI-S
1947 shares	0.67	1.01	1.00
2014 shares	0.55	1.01	1.00

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TFP Growth Counterfactuals

Robustness ($\gamma = 0.30$)

		Aggregate TFP Growth (2010-1947, %)	**Difference w.r.t Benchmark (p.p.)**
Panel A. Benchmark Value		***29.9***	
Panel B. Drivers of Structural Change in Production			
B.1	*No Income Effects*	*31.6*	*+1.7*
B.2	*No Income and Substitution Effects*	*32.0*	*+2.1*
Panel C. Other Drivers of Sectoral Innovation			
C.2	*No Change in Markups*	*38.1*	*+8.2*
C.1	*No Cross-Sector Spillovers*	*20.7*	*-9.2*
Panel D. No Population Growth Slowdown		*32.7*	*+2.8*

Back to Benchmark Counterfactuals

TFP Growth Counterfactuals

Robustness ($\gamma = 0.70$)

		Aggregate TFP Growth (2010-1947, %)	Difference w.r.t Benchmark (p.p.)
Panel A. Benchmark Value		***29.9***	
Panel B. Drivers of Structural Change in Production			
B.1	*No Income Effects*	*31.5*	*+1.6*
B.2	*No Income and Substitution Effects*	*31.9*	*+2.0*
Panel C. Other Drivers of Sectoral Innovation			
C.2	*No Change in Markups*	*37.9*	*+8.0*
C.1	*No Cross-Sector Spillovers*	*20.1*	*-9.8*
Panel D. No Population Growth Slowdown		*32.8*	*+2.9*

Back to Benchmark Counterfactuals