Technical and Structural Change

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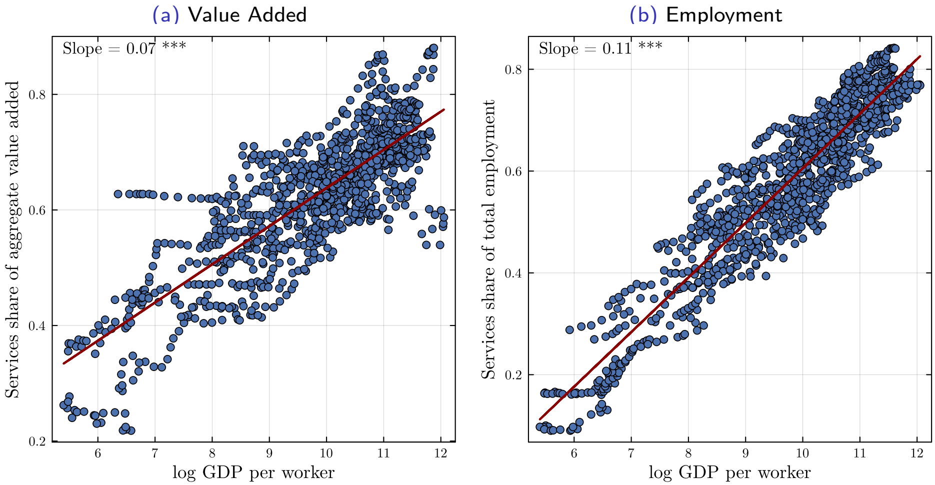
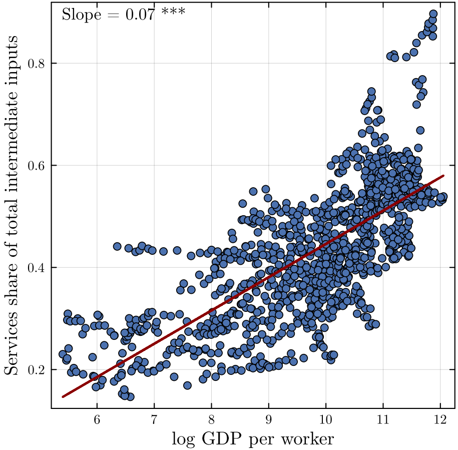
Motivation: Structural Change



- As countries develop, economic activity moves toward services.

Motivation: Structural Change in Intermediate Inputs



- As countries develop, the services share of total intermediates rises.

U.S. Data

Motivation: Structural Change in Intermediate Inputs

- Use of services intermediates affects aggregate growth, comparative advantage, etc. (e.g., Sposi, 2019, Acemoglu and Azar, 2020, Baqaee and Farhi, 2020)
- Question: What explains the rise of service intermediates?
- Standard explanation from the literature: **substitution** effect via relative prices. (e.g., Valentinyi, 2021 and Gaggl et al., 2023)
- In this work:
  - Substitution does not fully account for the rise of services intermediates.
  - New mechanism: **biased technical change**.

Motivation: Bias in Technical Change

- Technology is often incorporated into intermediates (e.g., Acemoglu and Azar, 2020).
  - e.g., better software, higher-quality materials, etc.
- $\Rightarrow$ Technical change affects **input composition**.
- Example – the production function of an economist in:
  - 1965: research $= f_{1965}$(paper, chalk, physical journals, ...)
  - 2025: research $= f_{2025}$(MATLAB license, journal subscription, ...)
- Has technical change driven intermediate demand toward services?
  ($\Leftrightarrow$ Is technical change **service-biased**?)

This Paper

- **Methodology**:
  1. Cross-country evidence (WIOD Input-Output data, 40 countries over 1965–2014)
  2. Quantitative model (calibrated using U.S. data, 1965–2014)
- **Preview of the results**:
  1. Technical change is biased in the services-producing, neutral in the goods-producing sector.
  2. Bias drives structural change across all metrics:
     - 2.1 $\sim$ 40% of the service share of aggregate intermediates
     - 2.2 $\sim$ 50% of the service share of total employment
     - 2.3 $\sim$ 30% of the service share of aggregate value-added
     - 2.4 $\sim$ 25% of the service share of final consumption
  3. Bias slows down aggregate GDP growth:
     - 3.1 Main driver of stagnation of services labor productivity
     - 3.2 Reduces real GDP growth by $\sim$ 25%

Contributions to the Literature

1. Sectoral composition of input-output linkages
   Berlingieri (2013); Sposi (2019); Valentinyi (2021); Gaggl et al. (2023)
   - Rise of service intermediates is driven by within sub-sector changes.
2. Mechanisms of structural transformation
   Kongsamut et al. (2001); Ngai and Pissarides (2007); Herrendorf et al. (2014)
   - New mechanism: **biased technical change**.
3. Biased technical change
   Acemoglu (2002); León-Ledesma et al. (2010)
   - Technical change in **intermediates** (literature: technical change in **factors**).
4. Productivity propagation via input-output linkages
   Acemoglu et al. (2012); Baqaee and Farhi (2019); Baqaee and Rubbo (2023)
   - Propagation of **intermediate-specific** productivities (literature: propagation of TFPs).

Roadmap

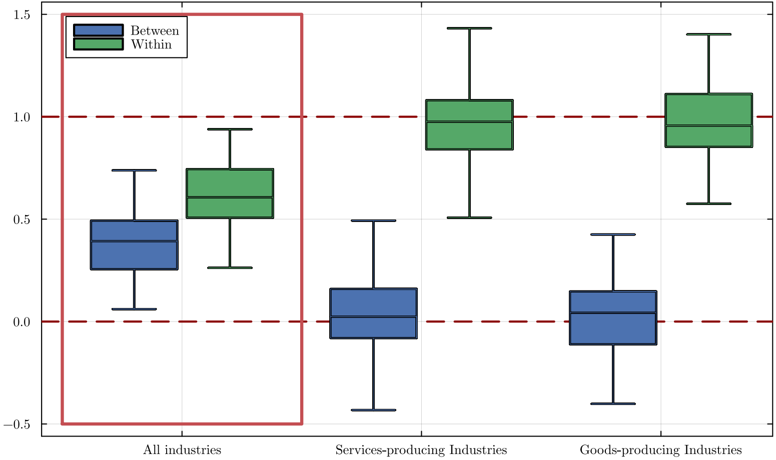
- Empirical Evidence
- Model
- Estimation
- Counterfactual

Empirical Evidence

Empirical Evidence – Data and Objectives

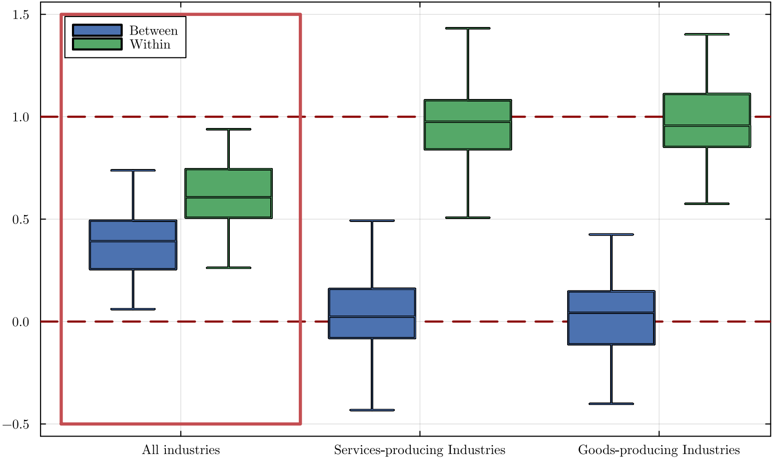
- **Data**: World Input-Output Database (WIOD) Details
  - 11 industries, 40 countries, 1965–2014
  - Industries grouped into two broad sectors (goods- and services-producing)
- **Objectives**:
  1. Is structural change in intermediates driven by
     1.1 Industries becoming more service-intensive (**within**)?
     1.2 Reallocation of output toward service-intensive industries (**between**)?
  2. Does the demand for services differ between industries?
  3. How well can relative prices "explain" the rise of services intermediates?

Empirical Evidence – Shift-Share Decomposition 1 Methodology



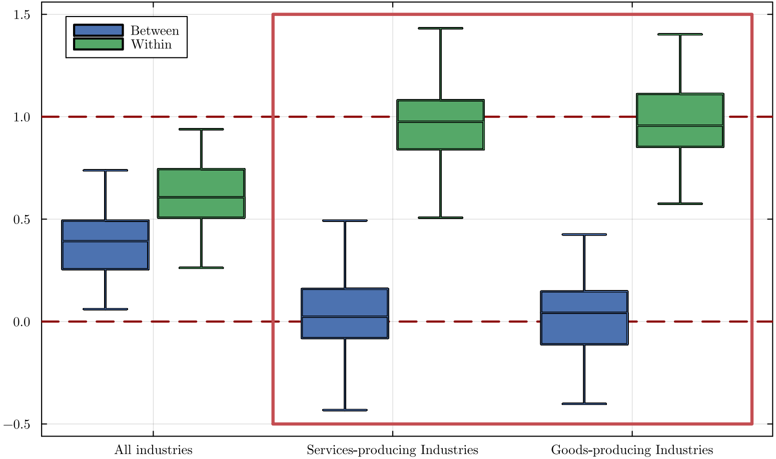
- Growth of services share of **aggregate** intermediates driven by both mechanisms.

Empirical Evidence – Shift-Share Decomposition 1 Methodology



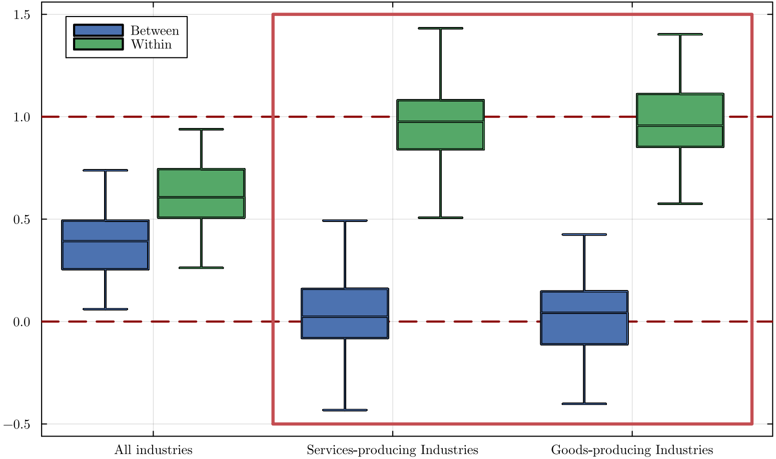
- Growth of services share of **aggregate** intermediates driven by both mechanisms.
- $\Rightarrow$ Growth of services share is also driven by reallocation between industries.

Empirical Evidence – Shift-Share Decomposition 2 Methodology



- Growth of services share of **sectoral** intermediates driven mostly by the "within" margin.

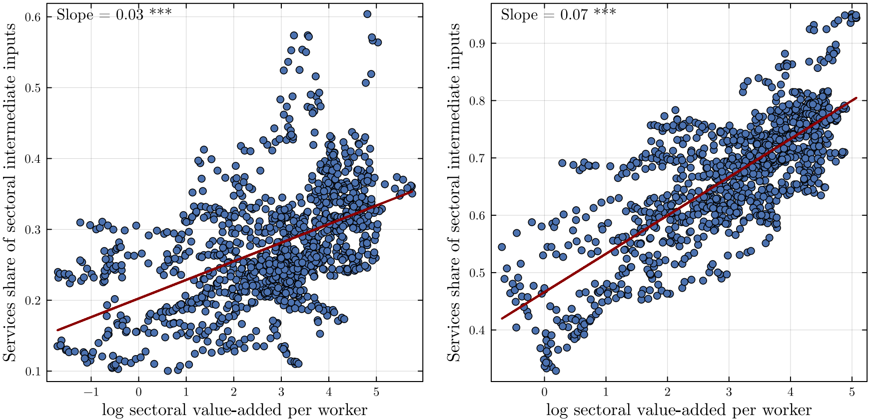
Empirical Evidence – Shift-Share Decomposition 2 Methodology



- Growth of services share of **sectoral** intermediates driven mostly by the "within" margin.
- $\Rightarrow$ Two-sector framework captures most of the reallocation.

Empirical Evidence – Services Shares of Intermediates, by Broad Sector

(a) Goods (b) Services



- Services-producing sector is more **services-intensive**.
- The services share **rises faster** with income in the services-producing sector.

Empirical Evidence – Do Prices Explain SC in Intermediates?

Sector:	Goods			Services		
	Services share of sectoral inputs (log)					
	(1)	(2)	(3)	(4)	(5)	(6)
Relative Prices (log, Services/ Goods)	0.213***	0.216***	0.191***	0.138***	0.112***	0.100***
	(0.020)	(0.022)	(0.023)	(0.012)	(0.013)	(0.012)
GDP per worker (log)		-0.004			0.022***	
		(0.008)			(0.005)	
Sect. value added per worker (log)			0.025*			0.072***
			(0.011)			(0.006)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	1,181	1,181	1,181	1,181	1,181	1,181
R^2	0.924	0.924	0.924	0.925	0.926	0.933
Within-R^2	0.091	0.091	0.095	0.112	0.127	0.215

- After controlling for prices, **correlation with sectoral value-added remains significant.**
- **Controlling for sectoral value-added improves fit** (within R^2).

Corr. Plot U.S. Data

Empirical Evidence – Summary of Results

1. Structural change in intermediates is
   - Driven by an increase in service intensity within **industries**
   - Reallocation between **sectors**
2. Sectors are heterogeneous in services intensity.
3. Controlling for prices shows **residual correlation** between services use and value-added:
   - $\Rightarrow$ **Relative prices do not fully explain structural change in intermediates**.

Model

Model Outline

- Two sectors: "g" and "s."
- **Input-output network**: sectoral output can be used
  1. For final consumption by households
  2. As an intermediate for any sector
- **Biased technical change**: heterogeneous intermediate-specific productivities.
- Productivities are exogenous.
- Standard representative household ("c") (homothetic CES preferences)

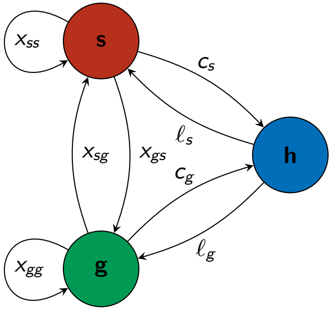


Figure: Graph of the input-output structure

Model: Technology

- **Sectoral production function**:

$$y_{i,t} = A^{go}_{i,t} \cdot M_{i,t}\left(\mathbf{a}_{i,t} \circ \mathbf{x}_{i,t}\right)^{\alpha} \left(\ell_{i,t}\right)^{1-\alpha}, \qquad \forall i \in [g, s].$$

where:

  - $A^{go}_{i,t}$ is (gross-output) *sectoral TFP*.
  - $\mathbf{a}_{i,t} = [a_{ig,t}, a_{is,t}]$ is a vector of *input-specific productivities*.
  - $\mathbf{x}_{i,t} = [x_{ig,t}, x_{is,t}]$ is a vector of *intermediate inputs*.

- **Intermediate aggregator**:

$$M\left(\mathbf{a}_{i,t} \circ \mathbf{x}_{i,t}\right) = \left[\gamma_i (a_{ig,t} x_{ig,t})^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - \gamma_i)(a_{is,t} x_{is,t})^{\frac{\sigma_i - 1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i - 1}}, \quad \forall i \in [g, s].$$

Model: Structural Change in Intermediates

- The (log) sectoral relative share of services intermediates:

$$\ln \frac{p_{is,t} x_{is,t}}{p_{ig,t} x_{ig,t}} = \sigma_i \ln \left(\frac{1-\gamma_i}{\gamma_i} \right) + \underbrace{(1-\sigma_i)(\ln a_{ig,t} - \ln a_{is,t})}_{\text{Bias in technical change } = \phi_{i,t}} + \underbrace{(1-\sigma_i)(\ln p_{is,t} - \ln p_{ig,t})}_{\text{Substitution effect}}, \quad \forall i \in [g, s].$$

- If intermediates are gross complements ($\sigma_i < 1$), intermediate shares move toward:
  1. The **more expensive** intermediate.
  2. The **least productive** intermediate.

Model: Value-Added

- Sectoral value-added (VA):

$$Y_{i,t} = \underbrace{\left[A^{go}_{i,t} \cdot \theta^{\alpha}_{i,t} \cdot \left(\phi^{\chi_{is,t}}_{i,t} \right)^{-\alpha} \right]^{\frac{1}{1-\alpha}}}_{A^{va}_{i,t}} \cdot \ell_{i,t}.$$

- Aggregate value-added (GDP) in terms of the numeraire – consumer price index:

$$Y_t = \underbrace{\mathcal{C}^Y \left[\sum_{j \in [g,s]} \eta_j^{\sigma_c} \left(\frac{(\mathcal{P}^M_{j,t}(\mathbf{A}, \phi))^{\alpha}}{A^{go}_{j,t}} \right)^{1-\sigma_c} \right]^{\frac{1}{(1-\sigma_c)(1-\alpha)}}}_{\mathcal{A}_t} \cdot L_t.$$

- **Takeaway**: biased technical change ($\phi_{i,t} \neq 1$) affects:
  1. Sectoral VA via services' intermediate shares.
  2. Aggregate VA via intermediate price indexes.

Model: Role of I–O Structure and Bias upon TFP

- **Input-output network**: if $\alpha = 0$ (no intermediates), then

$$\mathcal{A}_t = \left[\sum_{j \in [g,s]} \eta_j^{\sigma_c} \left(A_{j,t}\right)^{1-\sigma_c} \right]^{\frac{1}{\sigma_c - 1}} \qquad \Longrightarrow \text{ Aggr. TFP} = \text{CES mean of sectoral TFPs.}$$

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- **Bias in technical change**: if $\phi_s = \phi_g$, $\forall i \in [g,s]$,

$$\mathcal{A}_t = \left[\sum_{j \in [g,s]} \eta_j \left(\frac{A_{j,t}}{\bar{A}_t^{\frac{\alpha}{1-\alpha}}} \right)^{\sigma_c - 1} \right]^{\frac{1}{\sigma_c - 1}},$$

where $\bar{A}_t$ is a (biased) CES of sectoral productivities:

$$\bar{A}_t \equiv \frac{1}{\theta} \left[\gamma^{\sigma} \left(A_{g,t} \right)^{\sigma - 1} + \phi (1-\gamma)^{\sigma} \left(A_{s,t} \right)^{\sigma - 1} \right]^{\frac{1}{\sigma - 1}}.$$

Model: (First-Order) Aggregate Dynamics

- Growth rate of aggregate TFP:

$$\Delta \ln \mathcal{A}_t \approx \underbrace{\sum_{i\in[g,s]} \lambda_{i,t} \left(\Delta \ln A^{go}_{i,t} + \alpha \Delta \ln \theta_{i,t} \right)}_{\text{TFP component}} - \underbrace{\sum_{i\in[g,s]} s_{i,t} \Delta \ln \phi_{i,t}}_{\text{Bias component}}, \qquad \lambda_{i,t}, s_{i,t} > 0, \quad \forall i, t.$$

$\Rightarrow$ **Aggregate TFP is declining in the bias term.**

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$\Rightarrow$ **Aggregate TFP is declining in the bias term.**

- Evolution of relative prices:

$$\Delta \ln p_{i,t} \approx \overbrace{\sum_{j\in[g,s]} \hat{\Omega}_{ij,t} \Omega_{is,t} \Delta \ln \phi_{j,t}}^{\text{Bias component}} - \overbrace{\sum_{j\in[g,s]} \hat{\Omega}_{ij,t} (\Delta \ln A^{go}_{j,t} + \alpha \Delta \ln \theta_{i,t})}^{\text{TFP component}} - \overbrace{\Delta \ln Y_t}^{\text{Numeraire adjustment}} \qquad .$$

$\Rightarrow$ **Sectoral prices are increasing in the bias term.**

Model: Structural Transformation

- Sectoral intermediate:

$$\Delta \ln \frac{\text{Share}_{i,s}}{\text{Share}_{i,g}} = \phi_i + (1 - \sigma_i)\Delta \ln \hat{P}(\phi).$$

$\Rightarrow$ Service share of intermediates depends on ϕ both directly and via relative prices ($\hat{P}$).

- Final demand:

$$\Delta \ln \frac{\text{Share}_{C,s}}{\text{Share}_{C,g}} = (1 - \sigma_C)\Delta \ln \hat{P}(\phi).$$

$\Rightarrow$ Service share of final expenditure depends on ϕ via relative prices ($\hat{P}$).

Model: Asymptotic Aggregate Balanced Growth Path

- Assumptions:
  1. Productivities grow at constant, heterogeous rates.
  2. TFP grows faster in the goods-producing sector.
  3. Technical change is not increasingly goods-biased.
- Asymptotic Aggregate Balanced Growth Path (AABGP):

$$\lim_{t\to\infty} \Delta \ln \mathcal{A}_t = \lim_{t\to\infty} \Delta \ln A^{va}_{s,t} \qquad (\Rightarrow \textbf{Service sector takes over the economy})$$
$$= \frac{1}{1-\alpha} \cdot \left(\Delta \ln A^{go}_{s,t} + \alpha \Delta \ln \theta_{s,t}\right) - \underbrace{\frac{\alpha}{(1-\sigma_s)(1-\alpha)}}_{>1} \cdot \Delta \ln \phi_{s,t},$$

$\Rightarrow$ **Bias in technical change slows down asymptotic growth.**

Estimation

Estimation: Measuring Bias in Technical Change

- Sectoral ES (σ) and ϕ must be jointly estimated:
  - Not accounting for technical change biases σ toward unity (Antras, 2004).
  - **Here**: joint GMM estimation using lagged inputs as instruments (León-Ledesma et al., 2010; Lashkari et al., 2024).
- Cannot jointly estimate σ and ϕ without assuming a functional form for ϕ (Diamond et al., 1978).
  - **Here**: sectoral ϕ modeled as a random walk with drift.
- Estimation with U.S. data (WIOD and NIPA).
- Finite-sample performance: Monte Carlo simulation details & results.

detailed methodology

Estimation: Measuring Bias in Technical Change

methodology

	σ	$\Delta \ln \phi$
Goods	0.001 (0.008)	0.001 (0.005)
Services	0.002 (0.002)	0.012** (0.004)

- Intermediates are perfect complements ($\Leftrightarrow$ intermediates aggregator is Leontief).
- Technical change is:
  - **Neutral** in the goods sector.
  - **Services-biased** in the services sector.

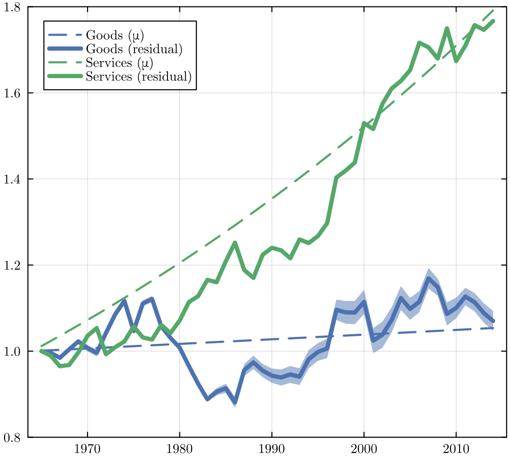


Figure: Evolution of residual ϕ by sector

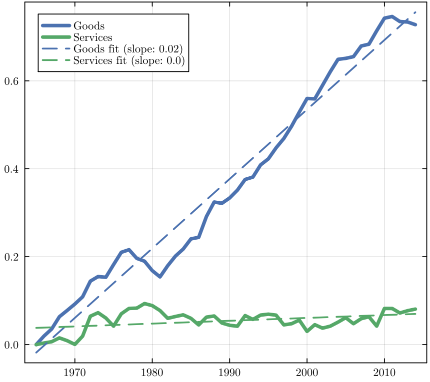
Estimation - Parameters Table

Parameter	Value	Source
α_G	0.52	Average intermediate share of nominal output (1965–2014, WIOD)
α_S	0.27	Average intermediate share of nominal output (1965–2014, WIOD)
Γ_G	0.77	Goods share of nominal output (1965, WIOD)
Γ_S	0.41	Goods share of nominal output (1965, WIOD)
Γ_C	0.79	Goods share of nominal final household expenditure (1965, WIOD)
σ_G	0.00	Estimated via GMM
σ_S	0.00	Estimated via GMM
σ_C	0.17	Estimated via OLS

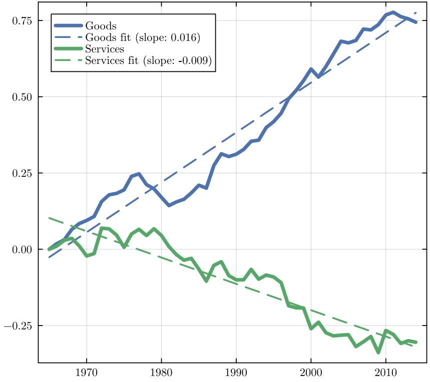
Table: Calibrated parameters

Estimation: Growth Accounting

(a) (Gross-output) productivity ($\ln A^{go}$)



(b) (Value-added) labor productivity ($\ln A^{va}$)



Estimation: Decomposition of Sectoral Value-Added Labor Productivity

- Why is value-added labor productivity declining in the services-producing sector?

$$\Delta \ln A^{VA} = \underbrace{\frac{\Delta \ln A^{go}_{i,t}}{1-\alpha_i}}_{\text{Gross-output TFP}} + \underbrace{\frac{\alpha_i \Delta \ln \theta_{i,t}}{1-\alpha_i}}_{\text{Total intermediate}} - \underbrace{\frac{\alpha_i \chi_{is,t} \Delta \ln \phi_{i,t}}{1-\alpha_i}}_{\text{Bias}}$$

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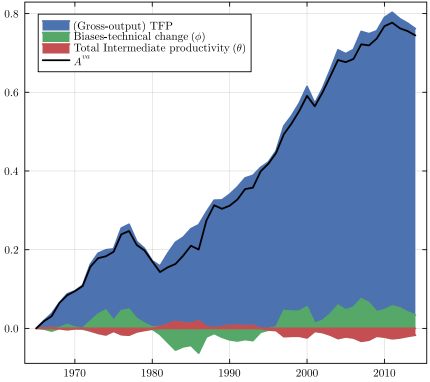
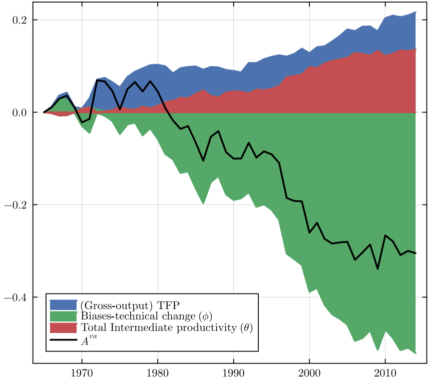
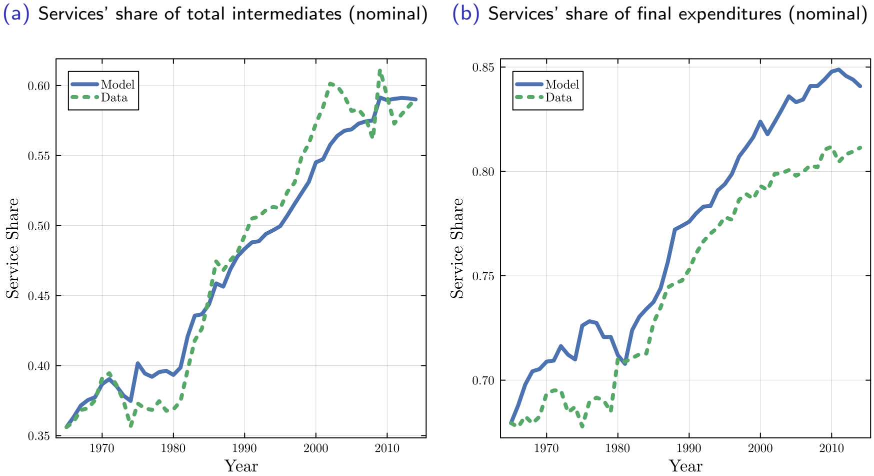


(a) Goods



(b) Services

Estimation - Model Fit



- Leontief $M \Rightarrow$ intermediates quantity $\propto \phi$: model captures relative prices well!
- Missing mechanism in final expenditure (non-homothetic preferences).

Counterfactuals

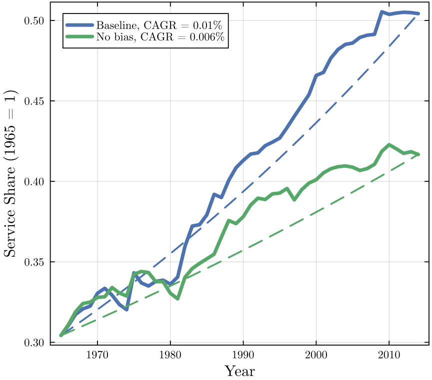
Counterfactual Exercise

- Objective:
  1. How much of the rising share of service intermediates is driven by biased technical change?
  2. Does it affect other measures of structural change?
  3. What is its contribution to aggregate GDP growth?
- Strategy: solve the model twice:
  1. With estimated ϕ ("baseline")
  2. With $\phi = 1$ for all sectors ("counterfactual").

     $\Rightarrow$ **Unbiased technical change**.

Counterfactual Exercise - Structural Change in Intermediates

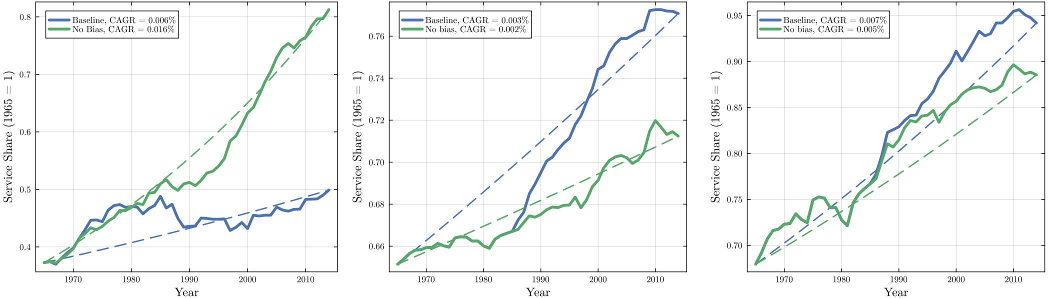
(a) Services' share of total intermediates



- Biased technical change accounts for $\sim 50\%$ of the rise in the **services' share of total intermediates** in the U.S. between 1965–2014.

Counterfactual Exercise - Structural Change

(a) Value-added (services' share) (b) Employment (services' share) (c) Final exp. (services' share)

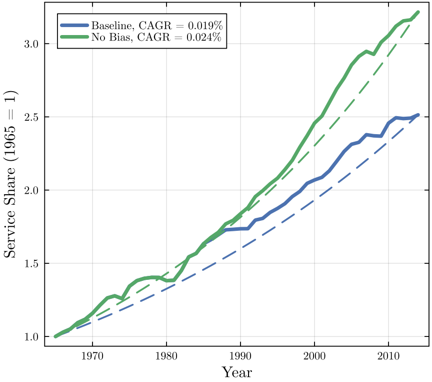


- Biased technical change accounts for:
    1. $\sim$ 30% of the change in the service share of **aggregate value-added**.
    2. $\sim$ 50% of the change in the service share of **aggregate employment**.
    3. $\sim$ 20% of the change in the service share of **final expenditures**.

  in the U.S. between 1965 and 2014.

Counterfactual Exercise (GDP per Capita)

(a) Aggregate real value-added



- Biased technical change slows down **real GDP growth** by $\sim 25\%$.

Conclusion

Conclusion

- **Main finding:**
  - Biased technical change **drives structural change and aggregate growth**.
  - Technical change was
    1. **services-biased** in the services-producing sector, and
    2. **neutral** in the goods-producing sector,

    in the U.S. between 1965 and 2014.
- **Quantitative implications:**
  - Biased technical change explains $\sim 40\%$ of the rise in the services' share of intermediates.
  - Accounts for ~ 25–50% of strutural transformation across standard measures.
  - Slows aggregate **real GDP growth** by $\sim 25\%$ relative to the unbiased counterfactual.
- **Takeaway:** Bias in technical change is a **central mechanism** behind postwar structural transformation and aggregate growth.

Thank you!

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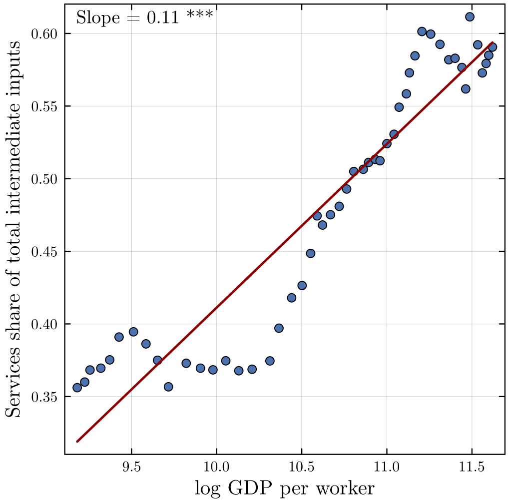
Appendix

Appendix: Structural Transformation in the U.S.



back

Appendix: Data 1

- Source: Harmonized WIOD (40 countries, 12 industries)
- Aggregated into two sectors: **goods** vs **services**
- Abstract from trade: use total inputs by country–sector
- Consistent growth rates via chain-linking across WIOD vintages
- Deflation with sectoral price indices (normalized to 1965)
- Final series: nominal & real inputs/outputs + deflators

Back

Appendix: Data 2

ISIC3 code	Broad sector	Description
AtB	Goods	Agriculture, hunting, forestry, and fishing
C	Goods	Mining and quarrying
D	Goods	Total manufacturing
E	Goods	Electricity, gas and water supply
F	Goods	Construction
G	Services	Wholesale and retail trade
H	Services	Hotels and restaurants
I	Services	Transport, storage, post and telecommunications
J	Services	Financial intermediation
K	Services	Real estate, renting and business activities
LtQ	Services	Community social and personal services

Table: WIOD sector classification

Back

Appendix: Shift-Share Decomposition

- Structural change in intermediates might be driven by
  1. Sectors becoming more service intensive (**within**).
  2. Reallocation of output toward service-intensive sectors (**between**).
- The services share of aggregate intermediates (S_{ct}) is

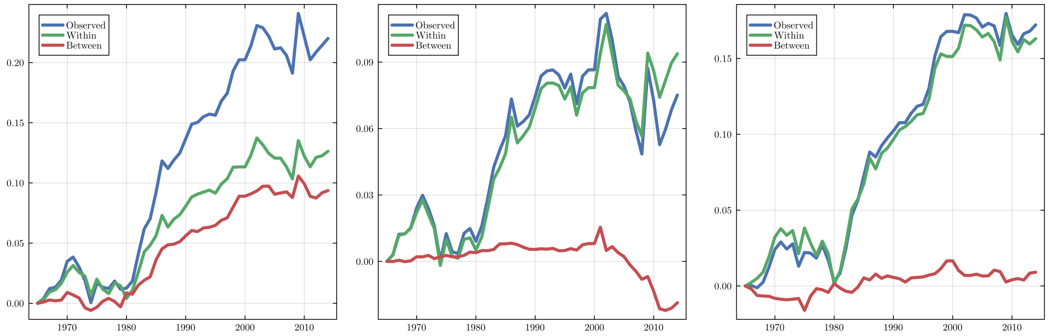
$$\Delta \ln S_{ct} \approx \underbrace{\sum_j \bar{\omega}_{jct} \Delta \chi_{jct}}_{\text{"Within"}} + \underbrace{\sum_j \bar{\chi}_{jct} \Delta \omega_{jct}}_{\text{"Between"}}$$

where

- ω_{jct}: industry's share of total sectoral intermediate inputs
- χ_{jct}: service share of industry's intermediates

back

Appendix: Shift-Share Decomposition (USA)



(a) All sub-sectors (b) Goods (c) Services

back

Appendix: Residual Correlation (Methodology)

- For each sector $s \in \{\text{Goods}, \text{Services}\}$ and country c, retrieve residuals $\hat{\varepsilon}_{cst}$ from:

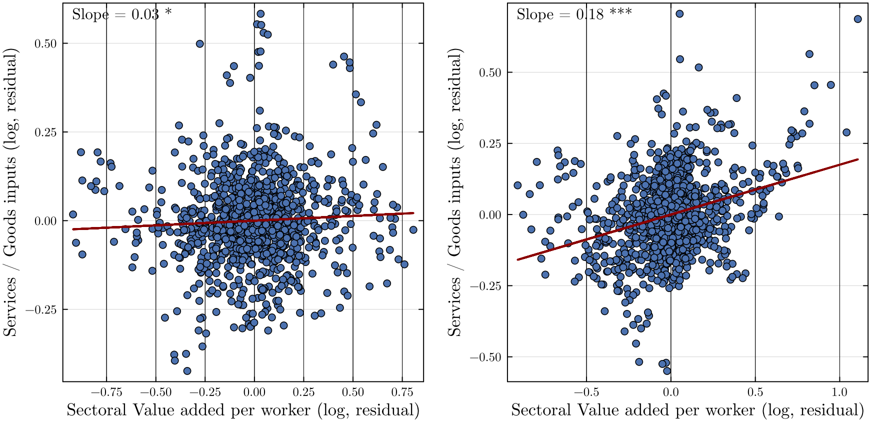
$$\log \frac{\text{input}_{cst}^{serv.}}{\text{input}_{cst}^{goods}} = \beta_s \, \text{RelPrice}_{cst} + \gamma_{cs} + \varepsilon_{cst}, \qquad \forall s \in [goods, services].$$

- Similarly I obtain fitted residuals $\hat{\varepsilon}_{cst}$ from

$$\log(\text{Value-added})_{cst} = \beta_s^Y \, \text{RelPrice}_{cst} + \gamma_{cs}^Y + \varepsilon_{cst}^Y, \qquad \forall s \in [goods, services].$$

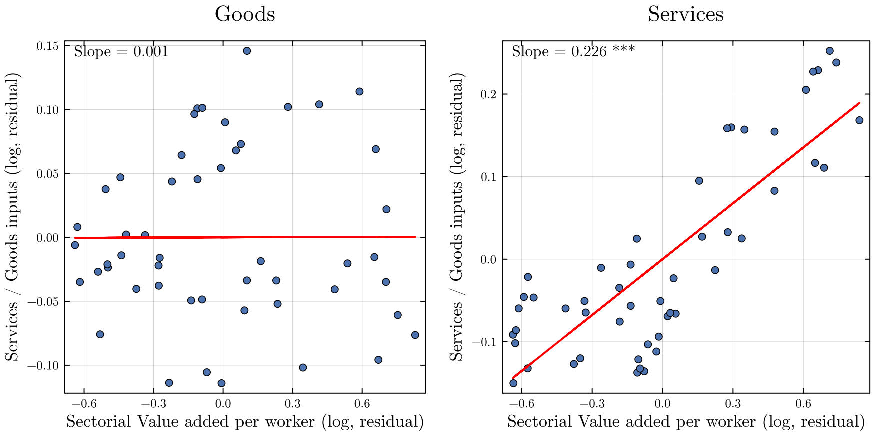
back

Appendix: Residual Correlation (all countries)



- After partialling-out prices, **residual correlation remains significant**.
- Correlation is stronger in the services-producing sector.

Appendix: Residual Correlation (USA)



back

Appendix: Estimation Methodology - 1

- Due to the role of complementarity, bias and σ must be jointly estimated.
- **Re-parametrization**:

$$\exp\phi_{i,t} = \frac{a_{is,t}}{a_{ig,t}} \qquad \text{and} \qquad \exp\theta_{i,t} = a_{ig,t}\cdot C_{i,t}, \qquad \forall i \in [g,s].$$

- **Normalized intermediates aggregator** (Klump et al., 2012):

$$\bar{M}_{i,t} = \theta_{i,t}\cdot\left[\Gamma_{i,t}\cdot\bar{x}_{ig,t}^{\frac{\sigma_i-1}{\sigma_i}} + (1-\Gamma_{i,t})(\exp(\bar{\phi}_{i,t})\bar{x}_{is,t})^{\frac{\sigma_i-1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i-1}},$$

where $\bar{x}_{i,t} \equiv x_{i,t}/x_{i0}$ and

$$\Gamma_{i,t} \equiv \frac{p_{g,0}x_{ig,0}}{p_{g,0}x_{ig,0} + p_{s,0}x_{is,0}}$$

back

Appendix: Estimation Methodology - 2

- **Bias terms solve:**

$$\begin{cases} \phi_{i,t} = (\ln \bar{p}_{is,t} - \ln \bar{p}_{ig,t}) - \frac{1}{1-\sigma_i} \cdot \ln \frac{\bar{p}_{s,t}\bar{x}_{is,t}}{\bar{p}_{g,t}\bar{x}_{ig,t}} \\ \theta_{i,t} = \ln \bar{M}_{i,t} - \ln \left\{ \left[\Gamma_{i,t}\bar{x}_{ig,t}^{\frac{\sigma_i-1}{\sigma_i}} + (1-\Gamma_{i,t})(\exp(\phi_{i,t}(\bar{\mathbf{p}}_{i,t}, \bar{\mathbf{x}}_{i,t})) \cdot \bar{x}_{is,t})^{\frac{\sigma_i-1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i-1}} \right\} \end{cases}$$

- **Assumption**:

$$\phi_{ij,t} = \phi_{ij,t-1} + \mu_{ij}^{\phi} + \epsilon_{ij,t}^{\phi} \qquad j \in [g, s]$$
$$\theta_{ij,t} = \theta_{ij,t-1} + \mu_{ij}^{\theta} + \epsilon_{ij,t}^{\theta} \qquad j \in [g, s]$$

- This system can be solved using GMM (Wooldridge, 2009, Lashkari et al., 2024)

back

Appendix: Monte Carlo 1

- **Data generation** (León-Ledesma et al., 2010):
  1. Technology processes:

     $$\ln \tilde{\psi}_t = \ln \tilde{\psi}_{t-1} + \mu^{\psi} + \epsilon_{\psi,t}, \quad \ln \theta_t = \ln \theta_{t-1} + \mu^{\theta} + \epsilon_{\theta,t}$$

     with shocks $\epsilon \sim \mathcal{N}(0, \sigma)$.
  2. Input series:

     $$z_{i,t} = z_{i,t-1} \exp(\mu^{z} + \epsilon_{z,t}), \quad z \in \{x_g, x_s\}.$$

  3. Equilibrium output & prices: solved from CES production function and FOCs.

- **Estimation:**
  - Parameters $(\sigma, \mu^{\phi}, \mu^{\theta})$ estimated over **5,000 replications**, each with 50 observations.
  - Shocks: $\{\epsilon_{\phi,t}, \epsilon_{\theta,t}, \epsilon_{x_g,t}, \epsilon_{x_s,t}\}$.
  - Variances: $[\sigma_{\phi}, \sigma_{g}, \sigma_{x_g}, \sigma_{x_s}] = [0.025, 0.015, 0.1, 0.2]$.
  - Performance assessed via bias, RMSE, and convergence frequencies.

back

Appendix: Monte Carlo 2

Parameter	True	Mean	Std	Bias	RMSE	Conv Rate
σ	0.600	0.597	0.038	-0.003	0.038	1.00
μ_ϕ	0.020	0.020	0.008	-0.000	0.008	1.00
μ_θ	0.010	0.010	0.003	0.000	0.003	1.00

Table: Monte Carlo Results (N=50, Sims=5000)

back