Intermediates-Specific Technical Change, Structural Transformation, and Growth

Davide Marco Difino

Goethe University Frankfurt

October 31, 2025

Motivation: Structural Change

- **Structural change**: as countries develop, economic activity shifts toward services.
  - Measures: value added, employment, expenditures, investment.

Evidence

Motivation: Structural Change

- **Structural change**: as countries develop, economic activity shifts toward services.
  - Measures: value added, employment, expenditures, investment. Evidence
- **This work**: as economies grow, they use more services as **intermediates**. Evidence
  - Intermediates: goods and services used in the production process.
    (e.g., ingredients in a restaurant, cloud services for online retail, etc.)

Motivation: Structural Change

- **Structural change**: as countries develop, economic activity shifts toward services.
  - Measures: value added, employment, expenditures, investment. Evidence
- **This work**: as economies grow, they use more services as **intermediates**. Evidence
  - Intermediates: goods and services used in the production process.
    (e.g., ingredients in a restaurant, cloud services for online retail, etc.)
- **Why it matters**: comparative advantage, supply-chain shocks, aggregate growth.
  (e.g., Sposi, 2019; Acemoglu and Azar, 2020; Baqaee and Farhi, 2020)
- **Research question**: what drives the rise of service intermediates?

Motivation: What Drives the Rise of Service Intermediates?

- Standard mechanism from the literature: changes in **relative prices**.
  (e.g., Valentinyi, 2021, Gaggl et al., 2023)

Motivation: What Drives the Rise of Service Intermediates?

- Standard mechanism from the literature: changes in **relative prices**.
  (e.g., Valentinyi, 2021, Gaggl et al., 2023)
- Relative prices:
  - Capture **supply-side** mechanisms (differences in *producers'* productivities, markups, etc.)
  - Drive reallocation via **substitution**.

Motivation: What Drives the Rise of Service Intermediates?

- Standard mechanism from the literature: changes in **relative prices**.
  (e.g., Valentinyi, 2021, Gaggl et al., 2023)
- Relative prices:
  - Capture **supply-side** mechanisms (differences in *producers'* productivities, markups, etc.)
  - Drive reallocation via **substitution**.
- This work documents that:
  1. Relative prices do not fully account for the rise of service intermediates.
  2. More **productive** sectors use more services after controlling for relative prices.

Motivation: What Drives the Rise of Service Intermediates?

- Standard mechanism from the literature: changes in **relative prices**.
  (e.g., Valentinyi, 2021, Gaggl et al., 2023)
- Relative prices:
  - Capture **supply-side** mechanisms (differences in *producers'* productivities, markups, etc.)
  - Drive reallocation via **substitution**.
- This work documents that:
  1. Relative prices do not fully account for the rise of service intermediates.
  2. More **productive** sectors use more services after controlling for relative prices.
- **RQ**: does technology ($\sim$ productivity) drive the demand for service intermediates?

  $\Leftrightarrow$ Is sector-specific 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 **service-biased** in the services-producing sector.
  2. Technical change is **neutral** in the goods-producing sector.
  3. Service-biased technical change drives structural change across all metrics.
  4. Service-biased technical change slows down aggregate GDP growth:
     - Main driver of the stagnation of services' labor productivity.
     - 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)
   - The rise of service intermediates is driven by within-subsector changes.
2. Mechanisms of structural transformation.
   Kongsamut et al. (2001); Ngai and Pissarides (2007); Herrendorf et al. (2014)
   - New mechanism: biased, **intermediate-specific 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.
- Counterfactuals.

Empirical Evidence

Empirical Evidence – Three Stylized Facts

- **Data**: World Input-Output Database (WIOD) Details
  - 11 industries, 40 countries, 1965–2014.
  - Industries grouped into two broad sectors (goods- and services-producing).
- **Three stylized facts**:
  1. Structural change in **aggregate** intermediates is driven by both:
     - 1.1 Industries becoming more service-intensive.
     - 1.2 Reallocation of output toward the service-intensive sector.
  2. For both sectors, service intensity is correlated with (labor) productivity.
  3. After controlling for prices, the correlation persists.

SF1 – Industries Drive the Intensive Margin, Sectors the Reallocation Margin

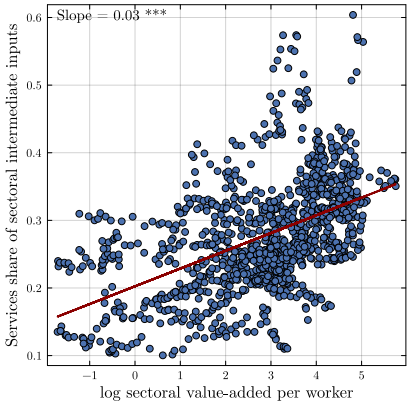
- Is structural change in aggregate intermediates driven by:
  1. Industries (i.e., sub-sectors) becoming more service-intensive?
  2. Reallocation of output toward service-intensive industries?
- **Methodology**: shift-share decomposition. Details
- **Results**:
  1. Structural change in **aggregate** intermediates is driven by both mechanisms. Result

     $\Rightarrow$ Industries become more service-intensive.
  2. Structural change in **sectoral** intermediates is driven only by the intensive margin. Result

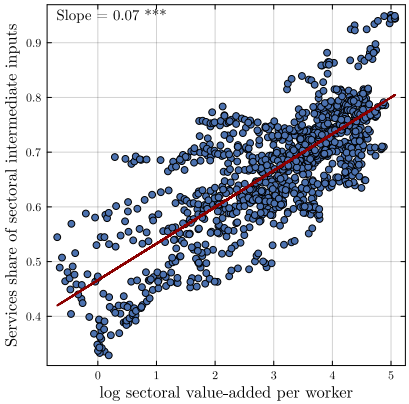
     $\Rightarrow$ There is **no reallocation** within sectors (goods- and services-producing).

Therefore, reallocation occurs entirely between broad sectors.

SF2 – Service Intensity Is Correlated with Productivity



(a) Goods-producing sector



(b) Services-producing sector

SF3 – Prices Do Not Fully Capture Structural Change 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, the **correlation with sectoral value added remains significant**.
- **Controlling for sectoral value added improves the fit** (within R^2).

Corr. Plot U.S. Data

Empirical Evidence – Why We Need a Model

- **Research question**: does technology ($\sim$ productivity) drive the rising demand for service intermediates?
- Empirical evidence: structural change in intermediates is driven by:
  1. Reallocation of output between **sectors** (= structural change).
  2. Sectoral service intensity is correlated with their productivity.
- However, structural change is endogenous to changes in productivities.
  (e.g., productivity $\uparrow \Rightarrow$ service intermediates $\uparrow \Rightarrow$ output of services-producing sectors $\uparrow$)
- To disentangle structural change and service-biased productivities, **we need a model**.

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 ("h") with homothetic CES preferences.

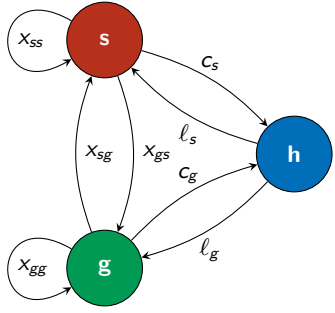


Figure: Graph of the input-output structure.

Model: Technology

- **Sectoral production function**:

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

  where:

  - $A_{i,t}^{go}$ is the sector-specific (gross-output) *TFP*.
  - $\phi_{i,t}$ is a sector-specific, *services-enhancing productivity* (a.k.a. **bias**).
  - $\mathbf{x}_{i,t} = [x_{ig,t}, x_{is,t}]$ is a vector of *intermediate inputs*.

- **Intermediate aggregator**:

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

- There are four (exogenous) productivity terms: $A_{g,t}^{go}$, $A_{s,t}^{go}$, $\phi_{g,t}$, and $\phi_{s,t}$.

Model: Structural Change in Intermediates

- Standard optimization $\Rightarrow$ relative demand for service intermediates:

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

- $\Rightarrow$ Intermediate-specific productivities reallocate demand across intermediates.

Model: (First-Order) Aggregate Dynamics

- Growth rate of aggregate TFP (Real $GDP_t = \mathcal{A}_t \cdot L_t$):

$$\Delta \ln \mathcal{A}_t \approx \underbrace{\sum_{i \in [g,s]} \frac{p_{i,t} \cdot y_{i,t}}{GDP_t} \cdot \Delta \ln A_{i,t}^{go}}_{\text{TFP component}} - \underbrace{\sum_{i \in [g,s]} \frac{p_{i,t} \cdot x_{is,t}}{GDP_t} \cdot \Delta \ln \phi_{i,t}}_{\text{Bias component}}, \qquad \lambda_{i,t}, s_{i,t} > 0, \quad \forall i, t.$$

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

Model: (First-Order) Aggregate Dynamics

- Growth rate of aggregate TFP (Real $GDP_t = \mathcal{A}_t \cdot L_t$):

$$\Delta \ln \mathcal{A}_t \approx \underbrace{\sum_{i \in [g,s]} \frac{p_{i,t} \cdot y_{i,t}}{GDP_t} \cdot \Delta \ln A^{go}_{i,t}}_{\text{TFP component}} - \underbrace{\sum_{i \in [g,s]} \frac{p_{i,t} \cdot x_{is,t}}{GDP_t} \cdot \Delta \ln \phi_{i,t}}_{\text{Bias component}}, \qquad \lambda_{i,t}, s_{i,t} > 0, \quad \forall i, t.$$

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

- Evolution of relative prices:

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

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

Model: Structural Transformation

- Sectoral intermediates:

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

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

Model: Structural Transformation

- Sectoral intermediates:

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

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

- Final demand:

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

$\Rightarrow$ The 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, heterogeneous rates.
  2. TFP grows faster in the goods-producing sector.
  3. Technical change is not increasingly goods-biased.

- **Asymptotic Aggregate Balanced Growth Path**:

$$\lim_{t\to\infty} \Delta \ln \mathcal{A}_t = \underbrace{\frac{\Delta \ln A_s^{go}}{1-\alpha}}_{\text{TFP component}} - \underbrace{\overbrace{\frac{\alpha}{(1-\sigma_s)(1-\alpha)}}^{>1} \cdot \Delta \ln \phi_{s,t}}_{\text{Bias component}},$$

$\Rightarrow$ **Services-bias in technical change slows long-run 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 is 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-producing sector.
  - **Services-biased** in the services-producing sector.

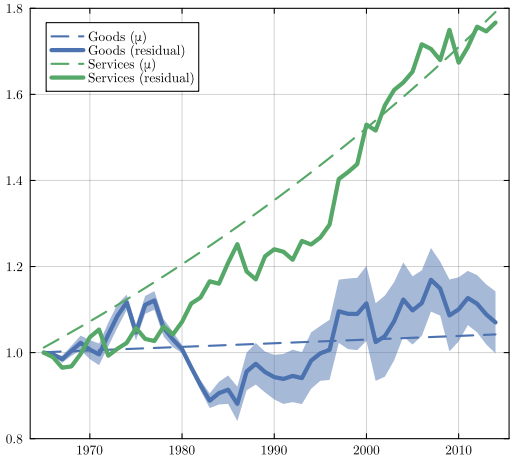


Figure: Evolution of residual ϕ by sector.

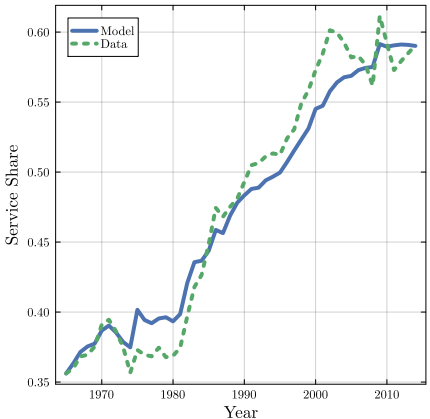
Estimation: Parameters Table

Parameter	Description	Value	Source
α_G	Intermediates intensity (goods-producing)	0.52	Avg. intermediate share of nominal output (19
α_S	Intermediates intensity (services-producing)	0.33	Avg. intermediate share of nominal output (19
Γ_G	Normalized goods-intermediate intensity (goods-producing)	0.77	Goods share of nominal output (1965, WIOD)
Γ_S	Normalized goods-intermediate intensity (services-producing)	0.41	Goods share of nominal output (1965, WIOD)
Γ_C	Normalized goods-intensity (consumers)	0.79	Goods share of nominal final demand (1965, W
σ_G	ES (goods-producing sector)	0.00	Estimated via GMM
σ_S	ES (services-producing sector)	0.00	Estimated via GMM
σ_C	ES (consumers)	0.17	Estimated via OLS

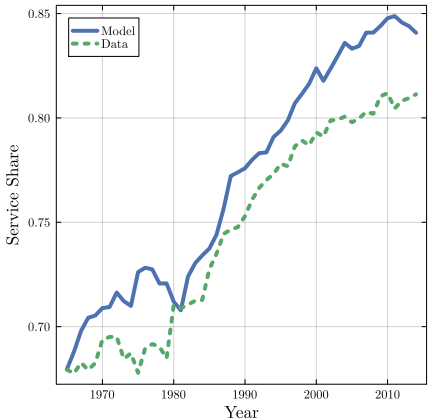
Table: Calibrated parameters.

Estimation: Model Fit

(a) Services' share of total intermediates (nominal)



(b) Services' share of final expenditures (nominal)



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

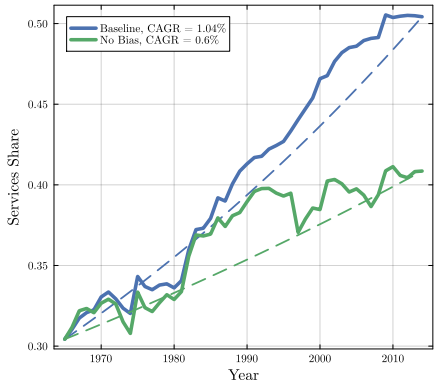
Counterfactuals

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

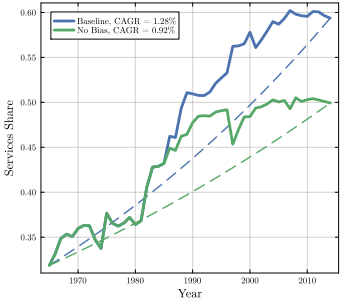
(a) Services' share of total intermediates.



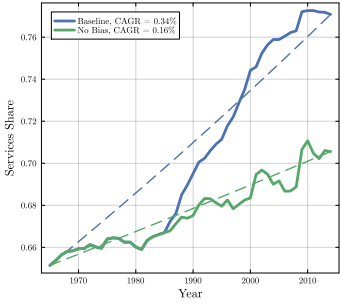
- Biased technical change accounts for $\sim 50\%$ of the rise in the **services' share of total intermediates** in the U.S. between 1965–2014.

Counterfactual Exercise: Structural Change

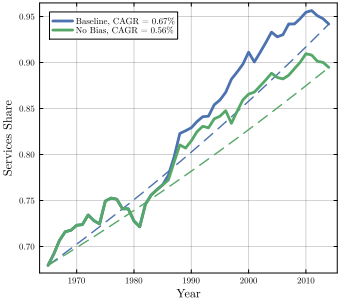
(a) Value-added (services' share)



(b) Employment (services' share)



(c) Final expenditure (services' share)

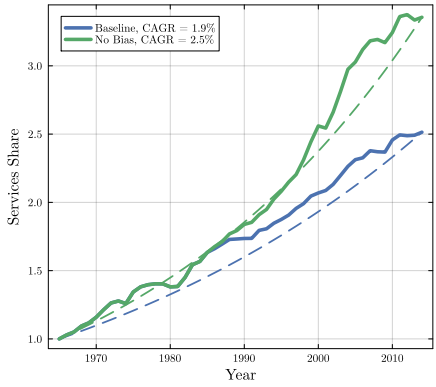


- Biased technical change accounts for:
  1. $\sim$ 30% of the change in the service share of **aggregate value-added**.
  2. $\sim$ 50% of the change in the service share of **aggregate employment**.
  3. $\sim$ 20% of the change in the service share of **final expenditures**.

  in the U.S. between 1965 and 2014.

Counterfactual Exercise: GDP per Worker

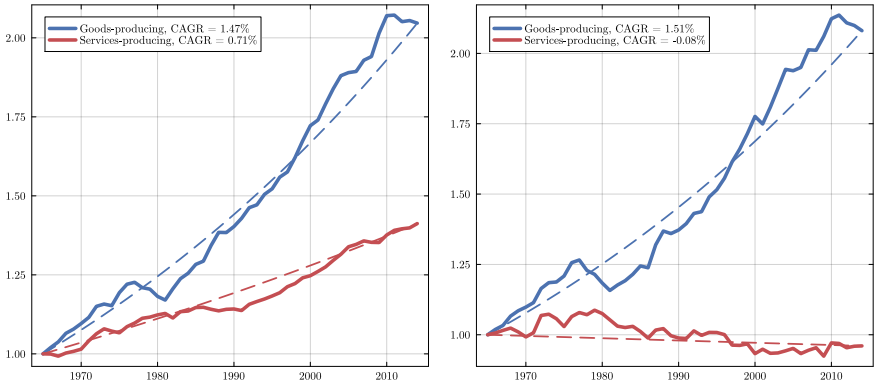
(a) Aggregate real value-added.



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

Counterfactual Exercise: What Drives the Slowdown of GDP?

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



- (Gross-output) TFP has grown in both sectors.
- But (real value-added) TFP has been stagnating in the services-producing sector.

Counterfactual Exercise: Decomposition of Value-Added Productivity

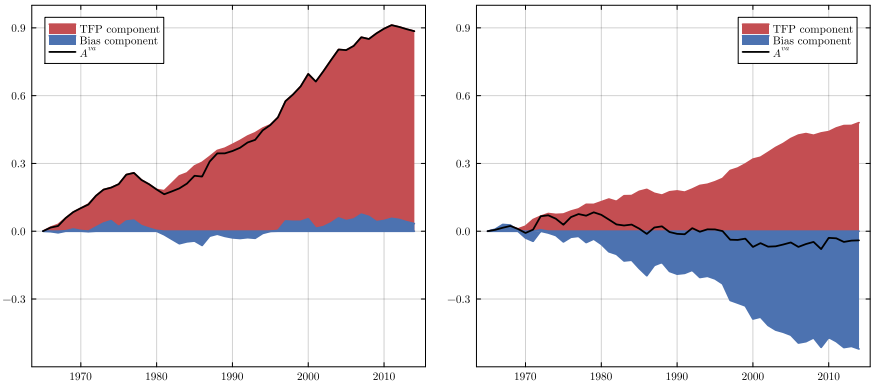
- Why is value-added labor productivity stagnating in the services-producing sector?

$$\Delta \ln A_{i,t}^{va} = \underbrace{\frac{\Delta \ln A_{i,t}^{go}}{1-\alpha_i}}_{\text{TFP component}} - \underbrace{\frac{\alpha_i \chi_{is,t} \Delta \ln \phi_{i,t}}{1-\alpha_i}}_{\text{Bias component}}.$$

Counterfactual Exercise: Decomposition of Value-Added Productivity

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

$$\Delta \ln A_{i,t}^{va} = \underbrace{\frac{\Delta \ln A_{i,t}^{go}}{1-\alpha_i}}_{\text{TFP component}} \underbrace{- \frac{\alpha_i \chi_{is,t} \Delta \ln \phi_{i,t}}{1-\alpha_i}}_{\text{Bias component}}.$$



(a) Goods-producing sector (b) Services-producing sector

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 $\sim$ 20–50% of structural 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 structural transformation and aggregate growth.

Thank you!

Daron Acemoglu. Directed technical change. *The review of economic studies*, 69(4):781–809, 2002.

Daron Acemoglu and Pablo D Azar. Endogenous production networks. *Econometrica*, 88(1): 33–82, 2020.

Daron Acemoglu, Vasco M Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi. The network origins of aggregate fluctuations. *Econometrica*, 80(5):1977–2016, 2012.

Pol Antras. Is the us aggregate production function cobb-douglas? new estimates of the elasticity of substitution. *Contributions in Macroeconomics*, 4(1):20121005, 2004.

David Baqaee and Elisa Rubbo. Micro propagation and macro aggregation. *Annual Review of Economics*, 15(1):91–123, 2023.

David Rezza Baqaee and Emmanuel Farhi. The macroeconomic impact of microeconomic shocks: Beyond hulten's theorem. *Econometrica*, 87(4):1155–1203, 2019.

David Rezza Baqaee and Emmanuel Farhi. Productivity and misallocation in general equilibrium. *The Quarterly Journal of Economics*, 135(1):105–163, 2020.

Giuseppe Berlingieri. Outsourcing and the rise in services. 2013.

Peter Diamond, Daniel McFadden, and Miguel Rodriguez. Measurement of the elasticity of factor substitution and bias of technical change. In *Contributions to economic analysis*, volume 2, pages 125–147. Elsevier, 1978.

Paul Gaggl, Aspen Gorry, and Christian Vom Lehn. Structural change in production networks and economic growth. 2023.

Berthold Herrendorf, Richard Rogerson, and Akos Valentinyi. Growth and structural transformation. *Handbook of economic growth*, 2:855–941, 2014.

Rainer Klump, Peter McAdam, and Alpo Willman. The normalized ces production function: theory and empirics. *Journal of Economic surveys*, 26(5):769–799, 2012.

Piyabha Kongsamut, Sergio Rebelo, and Danyang Xie. Beyond balanced growth. *The Review of Economic Studies*, 68(4):869–882, 2001.

Danial Lashkari, Arthur Bauer, and Jocelyn Boussard. Information technology and returns to scale. *American Economic Review*, 114(6):1769–1815, 2024.

Miguel A León-Ledesma, Peter McAdam, and Alpo Willman. Identifying the elasticity of substitution with biased technical change. *American Economic Review*, 100(4):1330–1357, 2010.

L Rachel Ngai and Christopher A Pissarides. Structural change in a multisector model of growth. *American economic review*, 97(1):429–443, 2007.

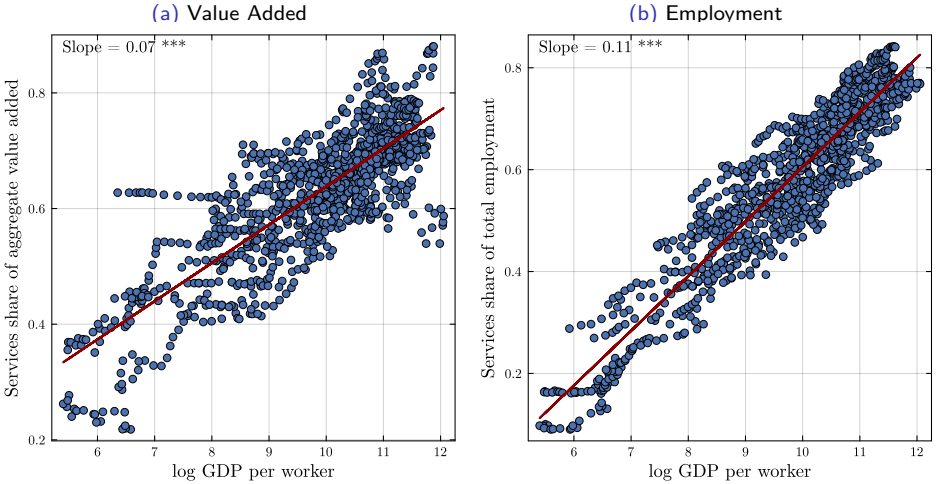
Michael Sposi. Evolving comparative advantage, sectoral linkages, and structural change. *Journal of Monetary Economics*, 103:75–87, 2019.

Akos Valentinyi. Structural transformation, input-output networks, and productivity growth. *Structural Transformation and Economic Growth (STEG) Pathfinding paper*, 2021.

Jeffrey M Wooldridge. On estimating firm-level production functions using proxy variables to control for unobservables. *Economics letters*, 104(3):112–114, 2009.

Appendix

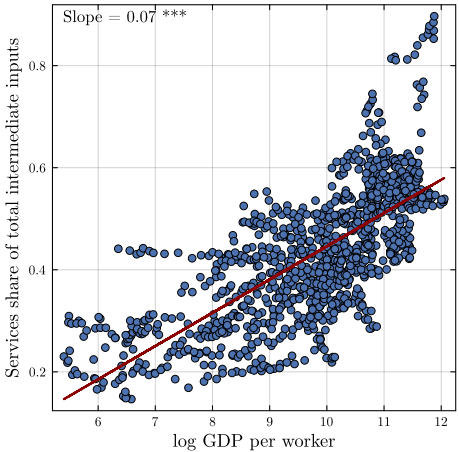
Motivation: Structural Change



- As countries develop, economic activity moves toward services.

back

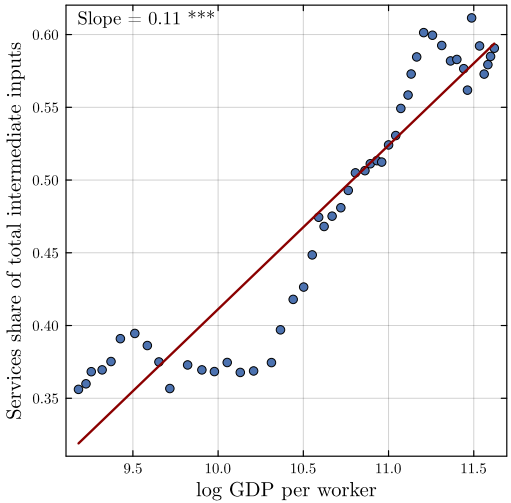
Motivation: Structural Change in Intermediate Inputs



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

back

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

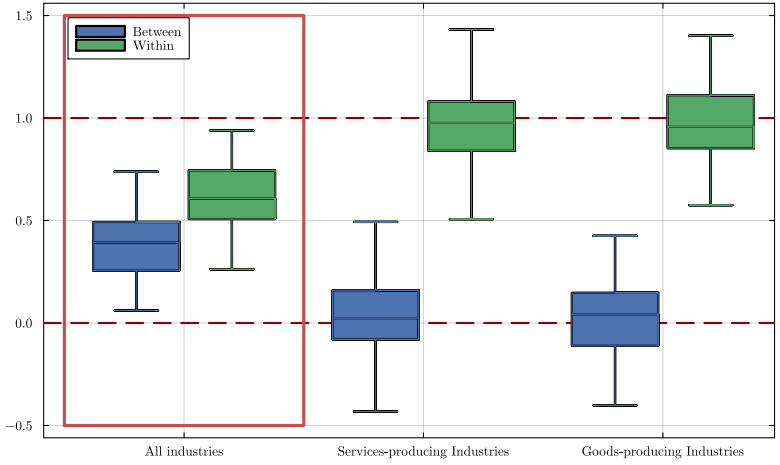
$$\Delta \ln S_{ct} \approx \underbrace{\sum_j \bar{\omega}_{jct} \Delta \chi_{jct}}_{\text{"Within"}} + \underbrace{\sum_j \bar{\chi}_{jct} \Delta \omega_{jct}}_{\text{"Between"}}$$

where

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

back

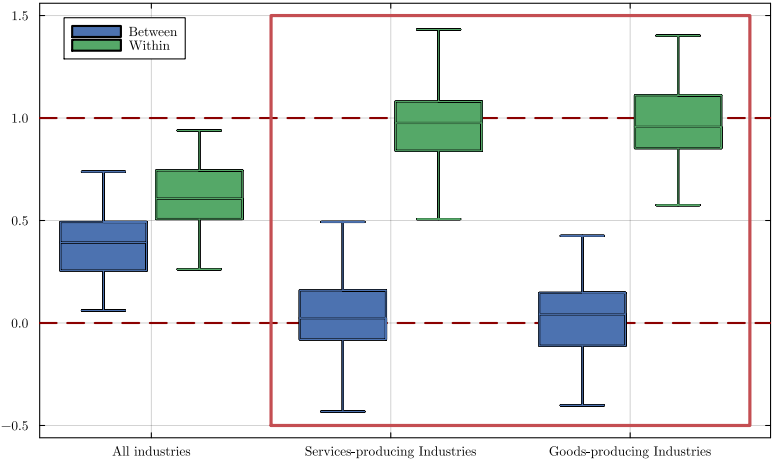
Appendix: Shift-Share Decomposition 2



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

back

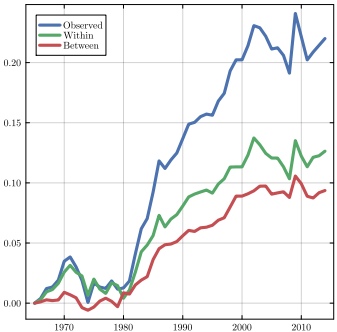
Appendix: Shift-Share Decomposition 3



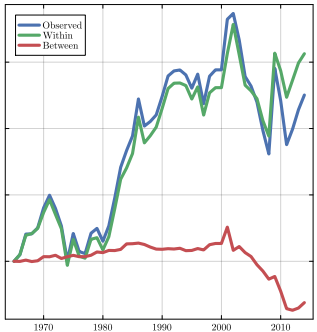
- Growth of services share of **sectoral** intermediates driven mostly by the "within" margin.
- $\Rightarrow$ Two-sector framework captures most of the reallocation.

back

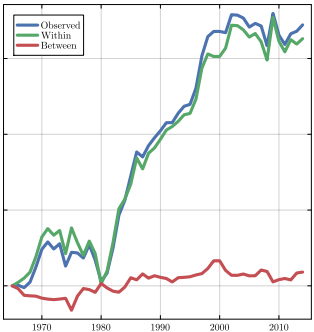
Appendix: Shift-Share Decomposition (USA)



(a) All sub-sectors



(b) Goods-producing



(c) Services-producing

back

Appendix: Residual Correlation (Methodology)

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

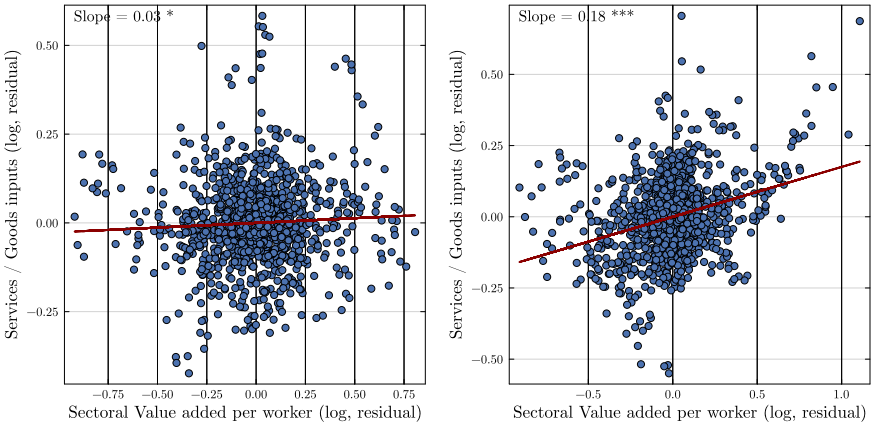
$$\log \frac{\text{input}_{cst}^{serv.}}{\text{input}_{cst}^{goods}} = \beta_s \, \text{RelPrice}_{cst} + \gamma_{cs} + \varepsilon_{cst}, \qquad \forall s \in [goods, services].$$

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

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

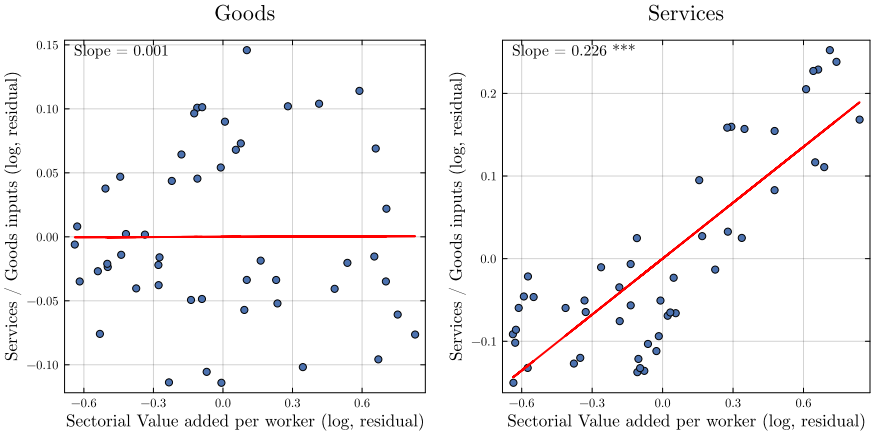
back

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