Capital-Embodied Structural Change

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Introduction

- The study of the process of structural change has focused almost exclusively on sector-specific factor-neutral technical change.

- But factor-augmenting (investment-specific) technological change accounts for more than half of overall output growth. (Greenwood, et. al. 1997).

- We study sector-specific factor-augmenting technological change → embodied in capital.

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- We study sector-specific factor-augmenting technological change → embodied in capital.

  - Disembodied technology: shifts output for given capital stock(s).
  - Embodied technology: shifts the marginal cost of producing investment relative to consumption.

What is the role capital embodied technical change (CETC) for structural change?

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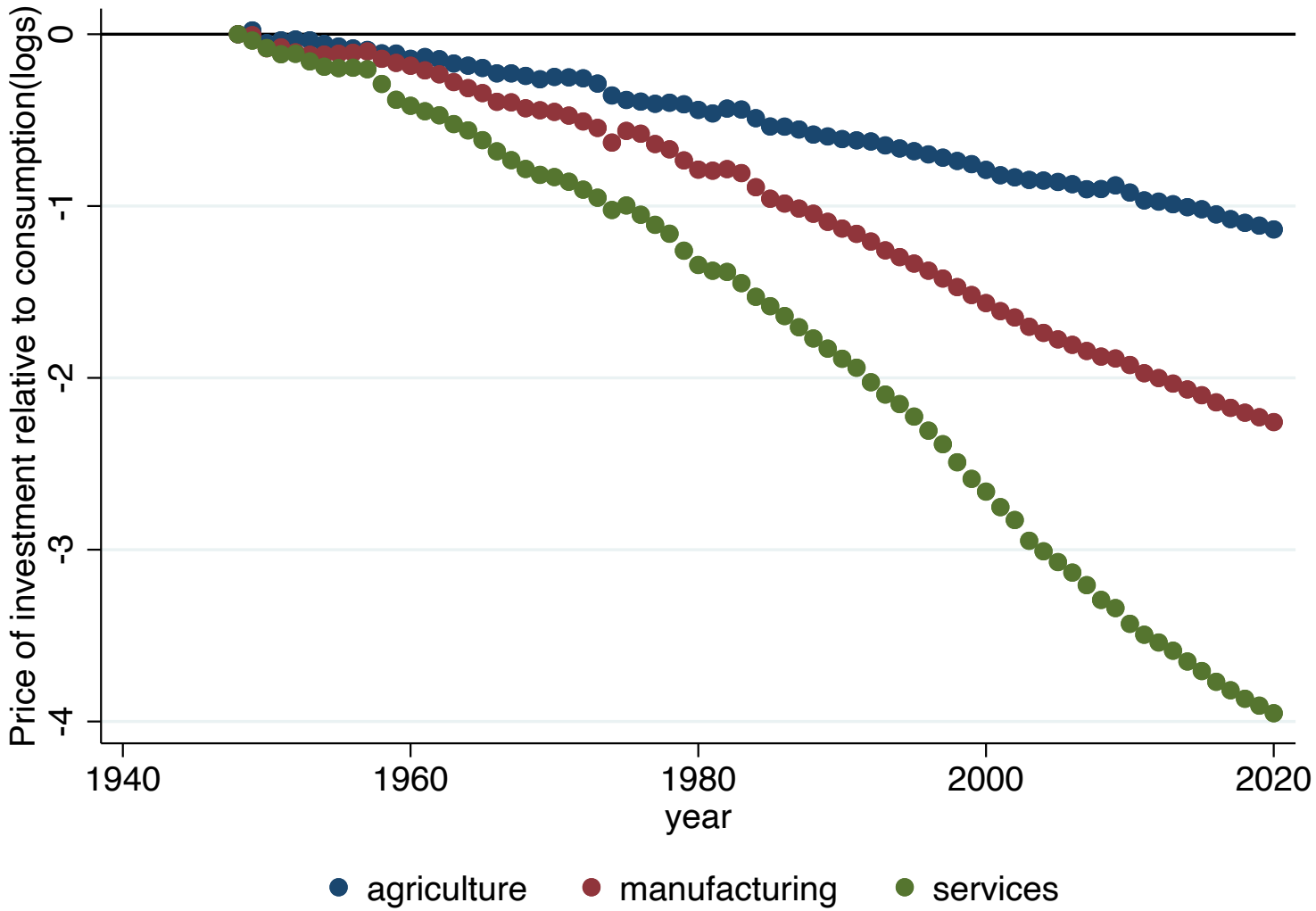

What is the role capital embodied technical change (CETC) for structural change?

- Document larger sectoral disparities in CETC than in TFP growth.

  US time-series for agriculture, industry and services.

- New multisector model with:
  - Sectorial CETC from multiple investment goods,
  - Endogenous disparities in factor shares.

- Quantify *CETC-induced shift in economic activity across sectors.* → capital-embodied structural change.

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- Quantify *CETC-induced shift in economic activity across sectors.* → capital-embodied structural change.

  10-25% of the reallocation of labor into services,
  35-90% of the reallocation of labor out of agriculture.

▸ contribution

Why do we care?

- Sectoral productivity paths need not be set in stone.
  Alvarez-Cuadrado and Poschke (2011).
  - services holds fastest CETC and slowest TFP growth,

  can productivity trends reverse?
  Implications for the incidence of Baumol's cost disease.

- Developing countries import most of their equipment.

  Eaton & Kortum (2001), Mutreja et.al. (2018).

  ...investment policy and development?

  Casal & Caunedo, 2023 *Investment Multipliers for Development*

Overview

1. Measuring sectorial CETC.
   - Framework to look at the data.
   - Empirical findings.

2. A model of capital-embodied structural change.

3. The role CETC for structural change.

Measuring sectorial CETC

Minimal framework

- Sectorial goods:

$$\begin{aligned} Y_s(t) &= A_s(t)\overbrace{F(K_s(t), N_s(t))}^{\text{CRS}}, \\ A_{st+1} &= A_s(t)(1+\gamma_{A_s}). \end{aligned}$$

- Sectorial capital

$$K_{st+1} = \underbrace{I_s(X_{1st}, X_{2st}, ..., X_{Jst})}_{\text{investment bundle, CRS}} + (1-\delta_s)K_{st}$$

- J capital stocks, $X_{jt} = A^x_{jt}\chi_{jt}$.

$$X_{jt} = \sum_s X_{jst}$$

- Final goods, $Y_t = \Upsilon(\{Y_{1t}, ...Y_s(t)\})$

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Factor-augmenting technical change & structural change

$$\frac{P_s(t)}{P_{s'}(t)} = \overbrace{\frac{1-\alpha_{s'}(t)}{1-\alpha_s(t)}}^{\frac{F_n N}{F}} \overbrace{\frac{Y_{s'}(t)/N_{s'}(t)}{Y_s(t)/N_s(t)}}^{\text{labor prod.}}$$

Factor-augmenting technical change & structural change

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- Sectoral factor share: $\alpha_s(t) = \alpha_s$ (Acemoglu and Guerrieri, 2008)

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- Sectoral CETC: $r_s(t)$

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Factor-augmenting technical change & structural change

Measurement & Interpretation

- Measurement:

$$g_{\frac{P_s(t)}{P_{s'}(t)}} = g_{\tilde{A}_{s'}(t)} - g_{\tilde{A}_s(t)} + \frac{\alpha_s(t)}{1-\alpha_s(t)} g_{r_s(t)} - \frac{\alpha_{s'}(t)}{1-\alpha_{s'}(t)} g_{r_{s'}(t)}.$$

where $g_x \equiv \frac{d\ln(x)}{dt}$ and $g_{\tilde{A}_s(t)} = \gamma_{A_s(t)} + (1-\alpha_s(t)) g_{1-\alpha_s(t)} + \alpha_s(t) g_{\alpha_s(t)}$.

Long-run dynamics:

$$g_{r_s} = g_{P_s^x} - g_{P_c} = -\gamma_{A_s^x}$$

- Interpretation:

$$g_{\frac{P_s(t)}{P_{s'}(t)}} = g_{\tilde{A}_{s'}(t)} - g_{\tilde{A}_s(t)} + \overbrace{\frac{\alpha_{s'}(t)}{1-\alpha_{s'}(t)} \gamma_{A_{s'}^x(t)} - \frac{\alpha_s(t)}{1-\alpha_s(t)} \gamma_{A_s^x(t)}}^{\text{incidence of CETC}}.$$

Factor-augmenting technical change & structural change

Measurement & Interpretation

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- Interpretation:

$$\underbrace{g_{\frac{P_s(t)}{P_{s'}(t)}}}_{\text{observed}} = g_{\tilde{A}_{s'}(t)} - g_{\tilde{A}_s(t)} + \underbrace{\sum_j \frac{\alpha_{s'}(t)}{1-\alpha_{s'}(t)} \kappa_{js'}(t) \gamma_{A_{jt}^x} - \frac{\alpha_s(t)}{1-\alpha_s(t)} \kappa_{js}(t) \gamma_{A_{jt}^x}}_{\text{observed}}$$

for $\kappa_{js}(t) = \frac{P_j^x X_{jst}}{\sum_j P_j^x X_{jst}}$ and $\gamma_{A_j^x} \approx g_{\frac{P_j^x}{P_c}}$

Evidence for the US: 1948-2020

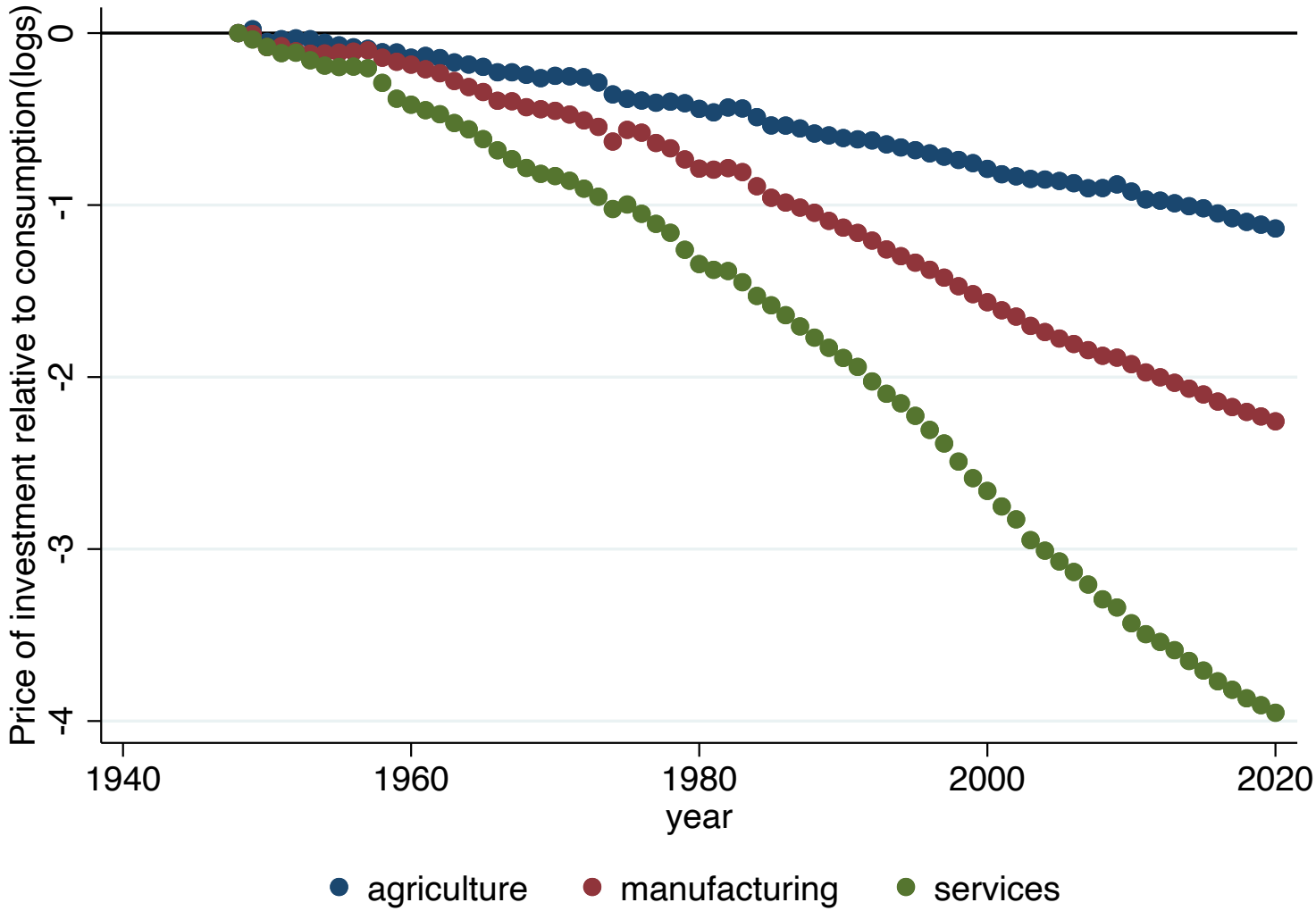
Sector definition

3-sector	NAICS 2-digit
Agriculture	Farms, Forestry and Fishing
Industry	Manufacturing
	Mining
Services	Wholesale Trade
	Retail
	Transportation
	Entertainment
	Acommodation
	Business Administration
	Health Services
	Professional Services
	Education
	Finance and Insurance

No construction (manufacturing) and no real estate (services).

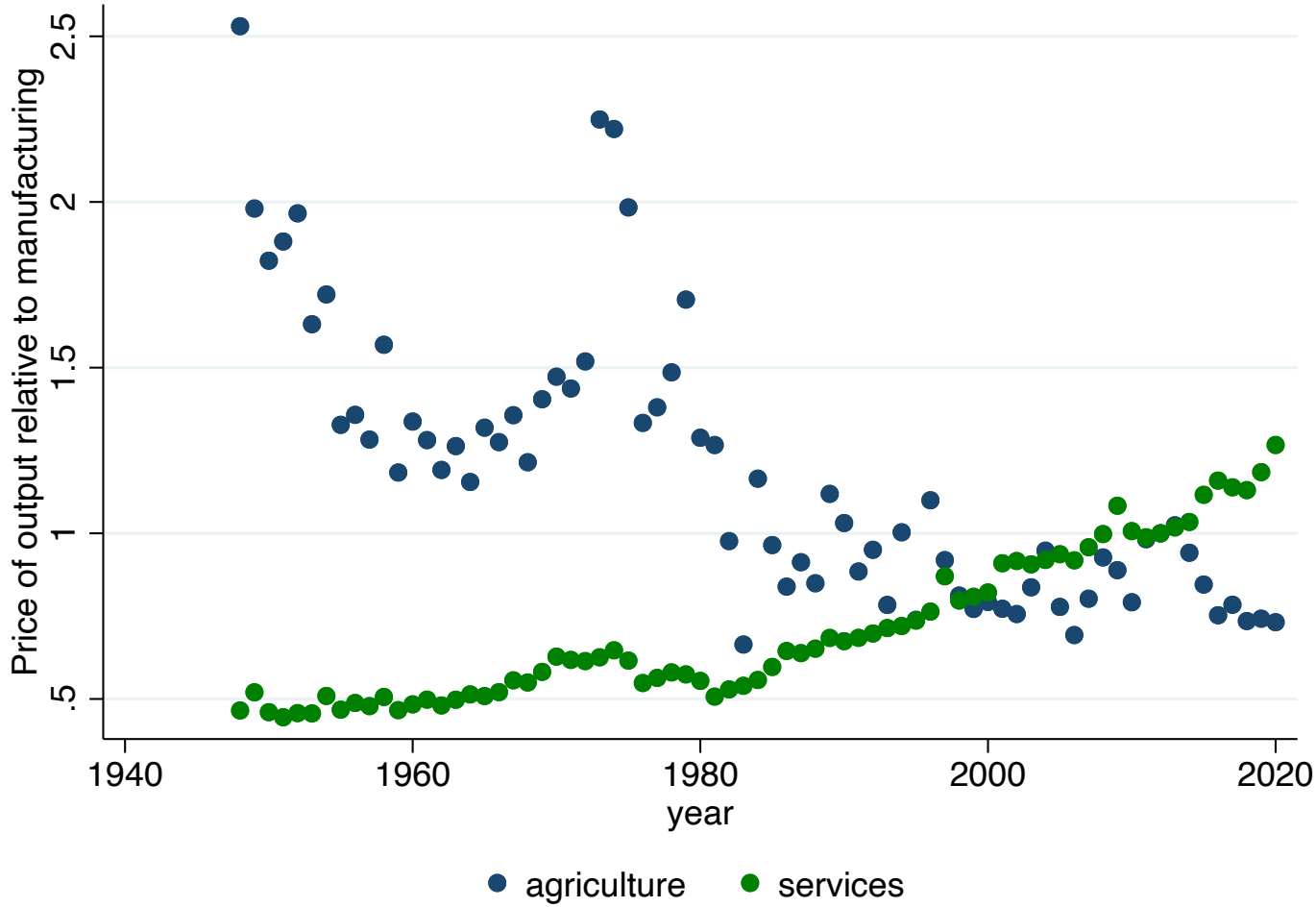
▸ data sources

CETC by sector



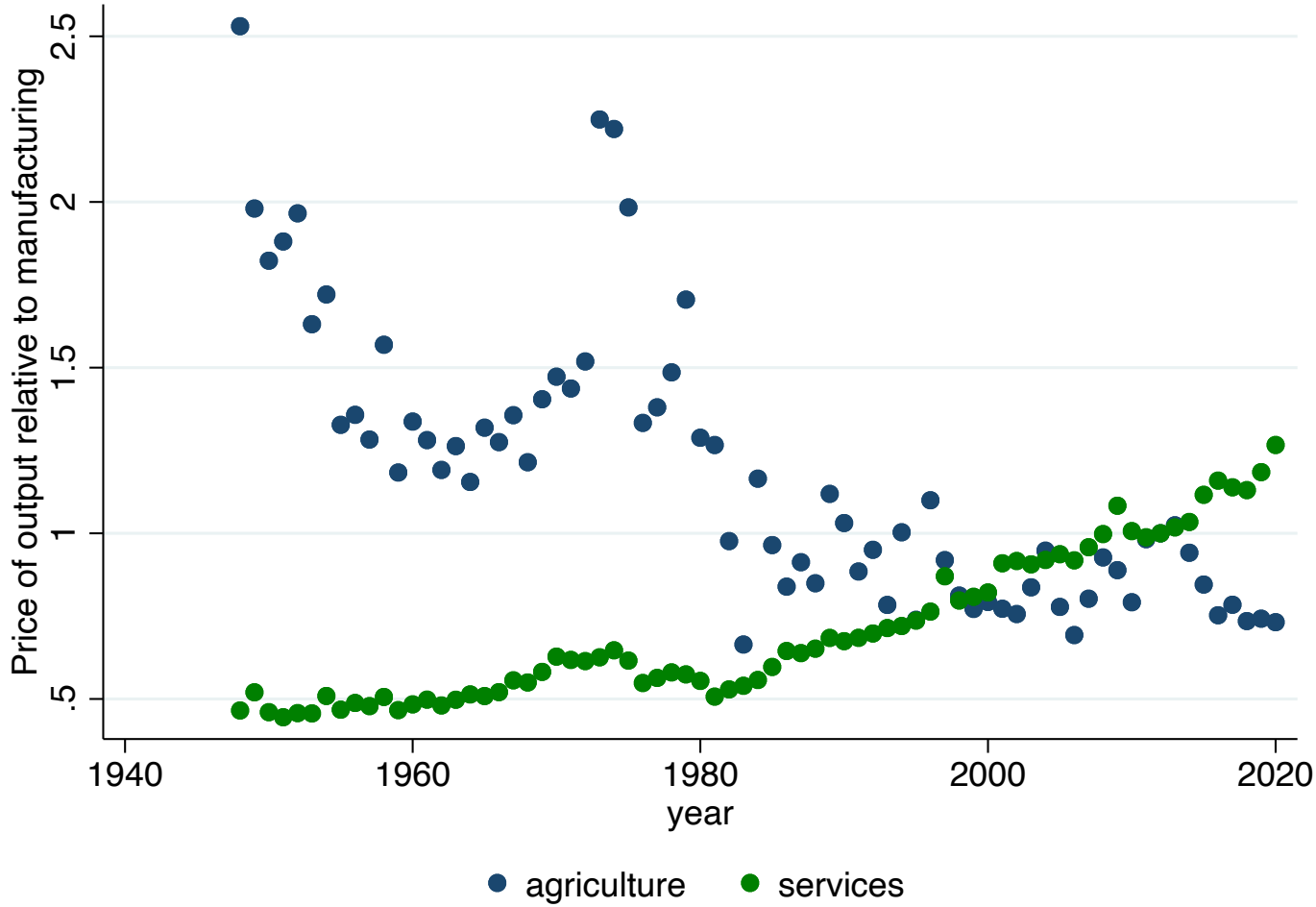
▸ without quality-adj ▸ initial weights ▸ final weights

Relative prices by sector, $P_s/P_{\text{manufacture}}$



$g_{\frac{P_s}{P_m}}$

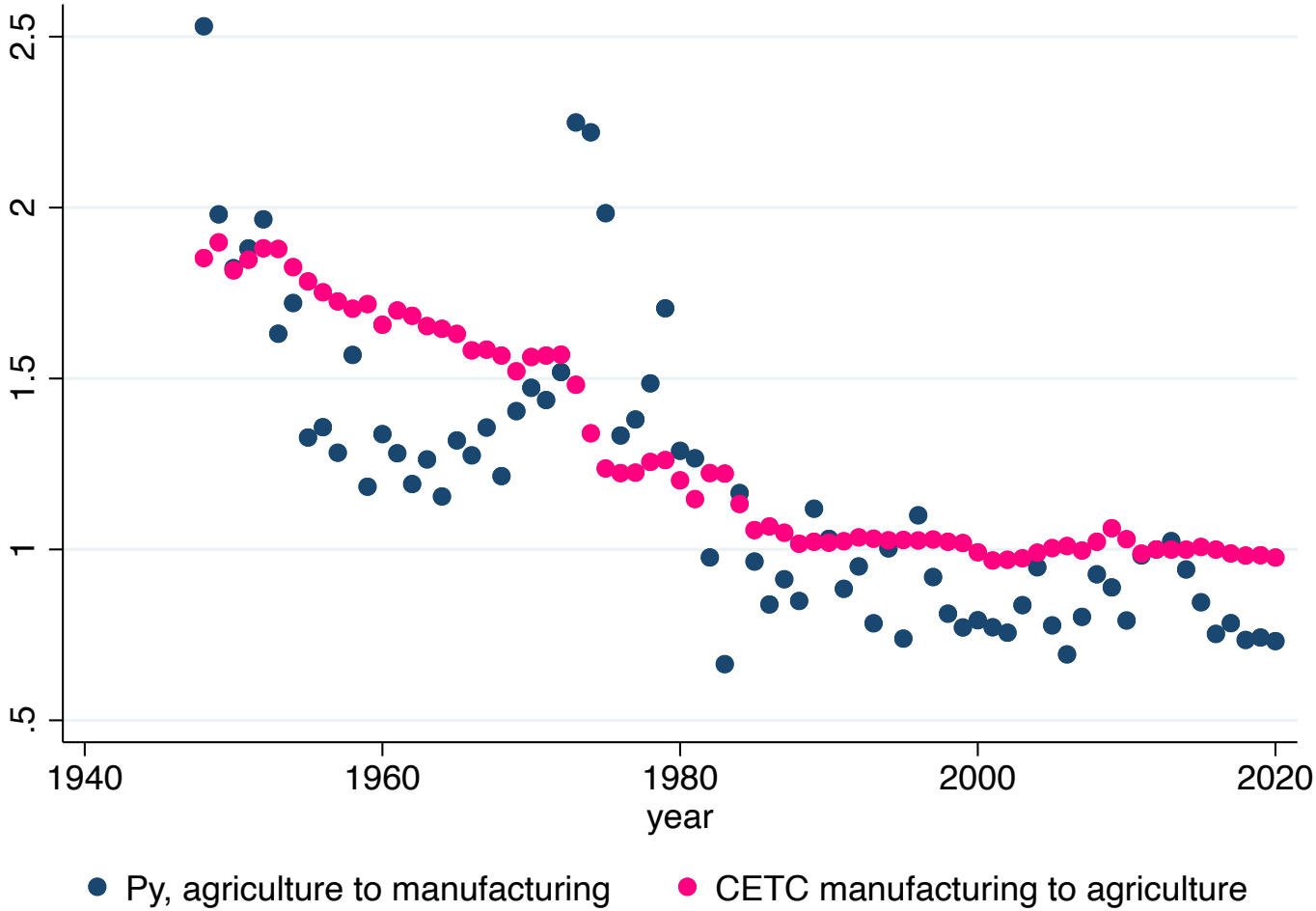
Relative prices by sector, P_s/P_{manuf}



$$g_{\frac{P_s}{P_m}} \approx \left(\gamma_{\tilde{A}_m} - \gamma_{\tilde{A}_s}\right) + \underbrace{\frac{\alpha_{mt}}{1-\alpha_{mt}}\gamma_{A^x_{mt}} - \frac{\alpha_{st}}{1-\alpha_{st}}\gamma_{A^x_{st}}}_{\text{incidence of CETC}}$$

Relative prices and CETC

Agriculture



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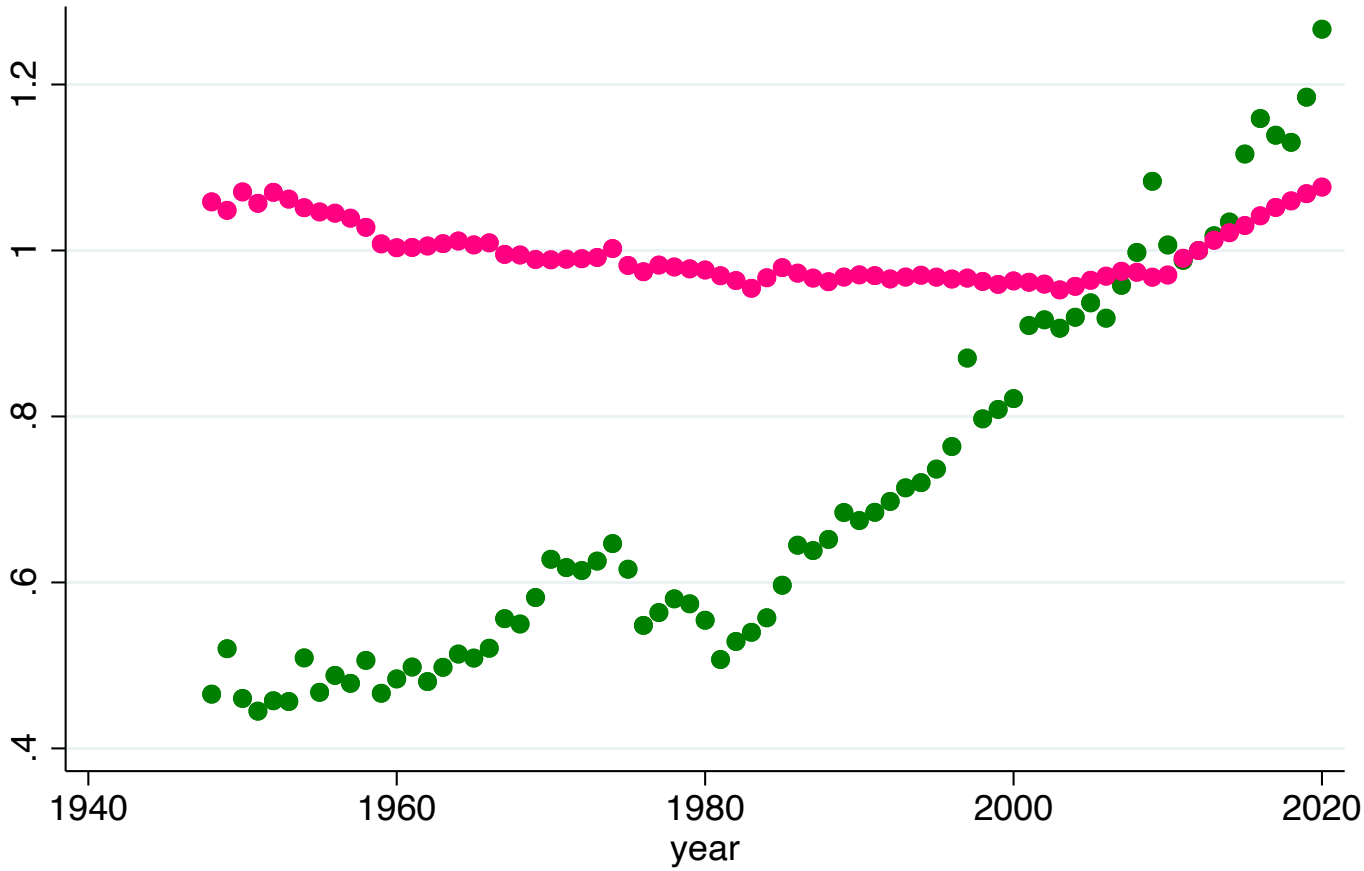
Relative prices and CETC

Services



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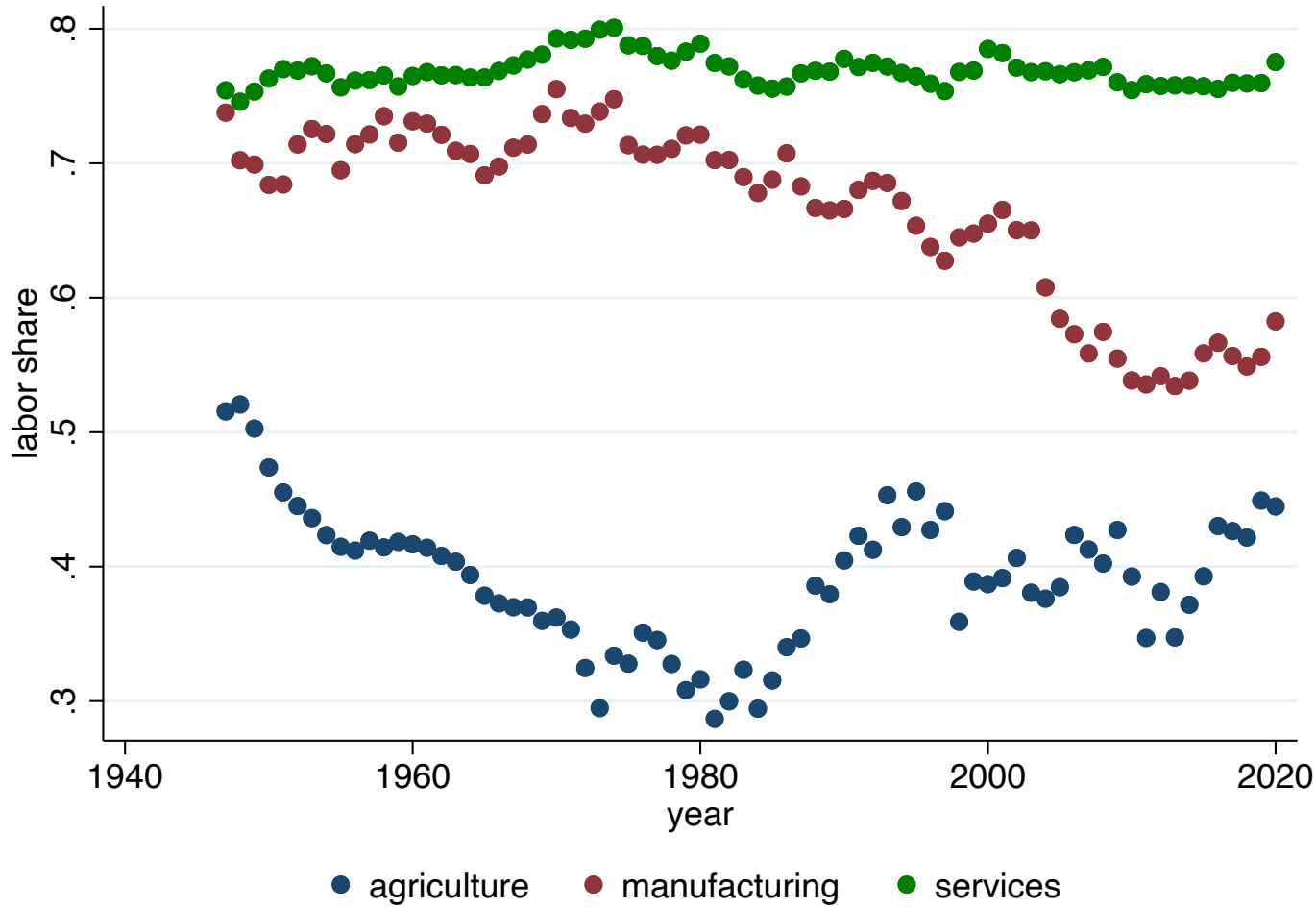
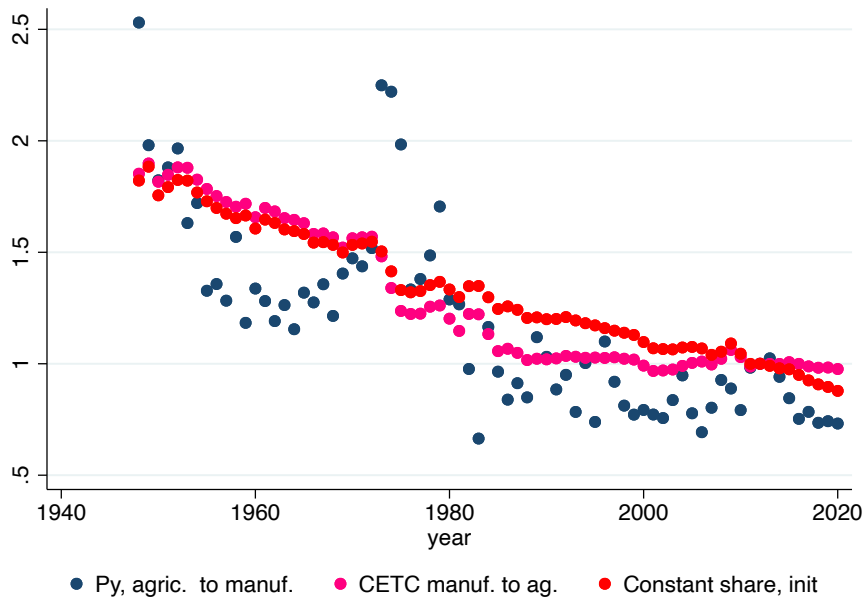
Labor share

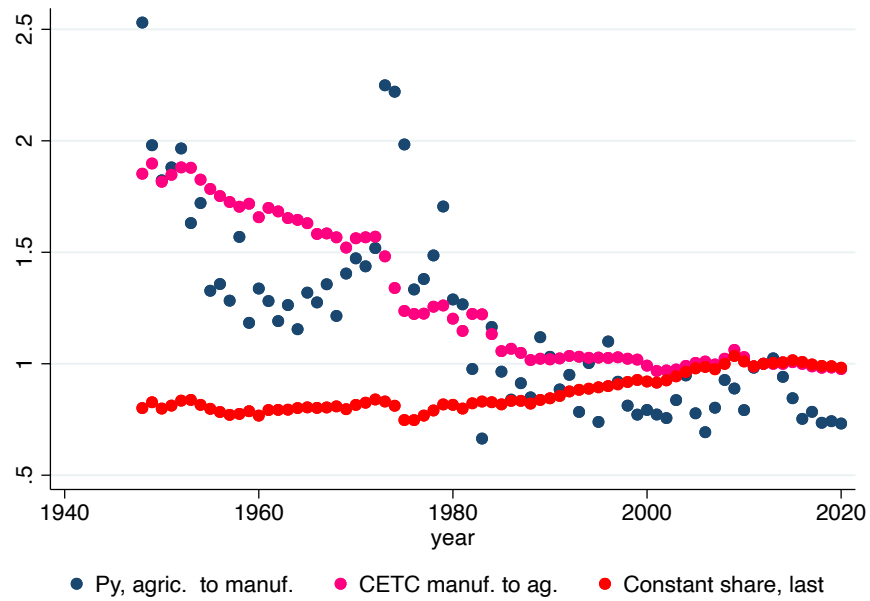

labor share
.3
.4
.5
.6
.7
.8
1940
1960
1980
2000
2020
year
agriculture
manufacturing
services

Constant labor share

Agriculture



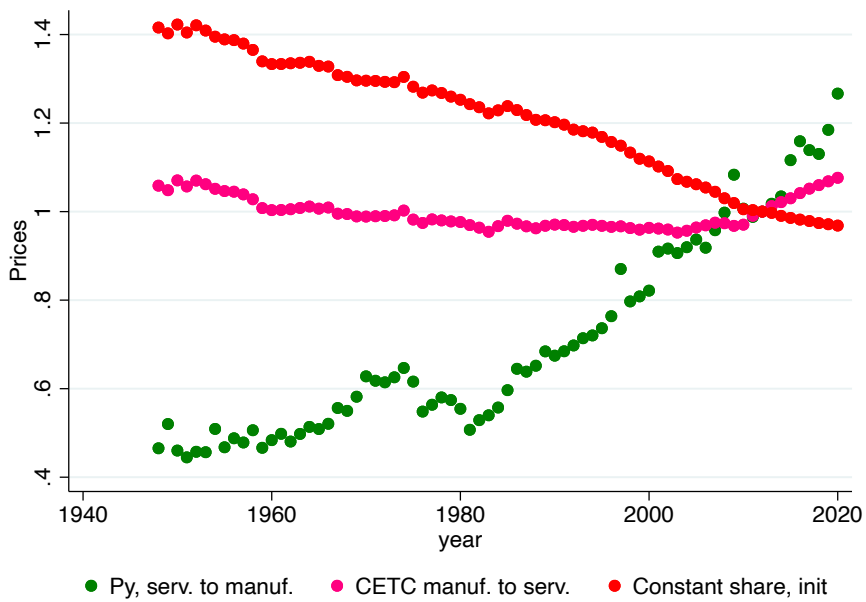
(a) Beginning of sample, α_{s1948}



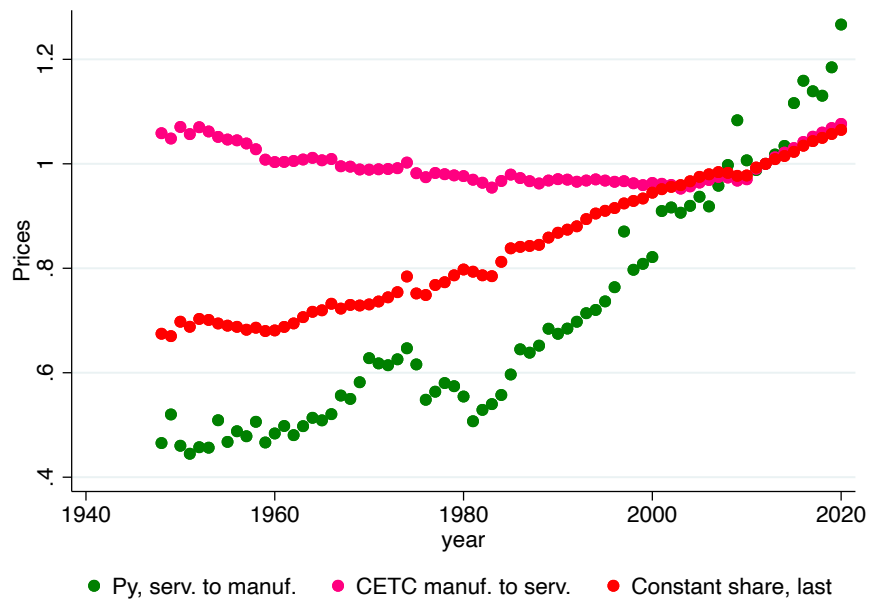
(b) End of sample, α_{s2020}

Constant labor share

Services



(c) Beginning of sample, α_{s1948}



(d) End of sample, α_{s2020}

Evidence for the US

Summary

1. Systematic disparities in CETC across sectors.

2. Non-trivial movements in the labor share within sectors.

3. CETC likely driving the trend in relative price of agriculture and (partially) services to manufacturing.

A model of capital-embodied structural change.

Acemoglu (2003), Jones and Liu (2021) + capital embodied technology.

Technology

- Sectorial output

$$Y_s(t) = \left[(b_s^n(t) N_s(t))^\rho + (b_s^k(t) \tilde{K}_s(t))^\rho \right]^{\frac{1}{\rho}}$$

for $\rho < 0$ and $\tilde{K}$ capital in efficiency units, $\tilde{K}_s \equiv \frac{K_s}{A_s^x}$.

- Implications:
  - Factor shares shift with structural change.
  - CETC and BGP? $\rightarrow$ constant b_s^k (Uzawa, 1961).

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- Activities under the "hood"

$$Y_s(t) = \int_0^{m_s(t)} k_i(t) di + \int_{m_s(t)}^1 \underbrace{(\zeta_i(t) Z_s(t))^{\frac{\rho-1}{\rho}}}_{\text{labor prod} \approx A_s^n(t)} n_i(t) di.$$

$$b_s^n(t) = (1 - m_s(t))^{\frac{1-\rho}{\rho}} A_s^n(t) \qquad b_s^k(t) = m_s(t)^{\frac{1-\rho}{\rho}} A_s^x(t)$$

Optimal allocations

- Activities performed with capital, m_s

$$w(t)\left(\frac{1}{Z_s(t)}\frac{1}{\zeta_i(t)}\right)^{\frac{\rho-1}{\rho}} \geqslant r_s(t), \qquad \rho < 0.$$

  - *race between labor productivity growth* $\uparrow Z_s(t)$ *and*
  - *the decline in the user cost of capital* $\downarrow r_s(t)$.

- Capital share in the sector:

$$\alpha_s(t) = \frac{r_s(t)K_s(t)}{Y_s(t)P_s(t)} = m_s(t)\left(\frac{r_s(t)}{P_s(t)}\right)^{\frac{\rho}{\rho-1}}$$

$\rightarrow \alpha_s(t) \neq b_s^k$ w/ structural change, $\alpha_s(t) = b_s^k\left(\frac{P_s(t)}{P_c(t)}\right)^{\frac{\rho}{\rho-1}}$.

What is the role of CETC for structural change?

Quantification

- Accounting exercise
  - Feed the path of capital in each sector, $K_s(t)$
  - Infer the user cost of capital, $r_s(t)$ from the Euler equation, aggregate consumption and CETC.
  - Augment model with wedges in the optimality condition for capital,

$$\tau_s(t) r_s(t) = P_s(t) MPK_s(t)$$

- Counterfactuals:
  - Shut CETC, $\gamma_{A_s^x}$.
  - Shut $m_s(t)$.

▸ details

What is the role of CETC for structural change?

CETC accounts for:

- 35% of the movement out of agriculture.
- 8% of the movement out of manufacturing.
- 11.4% of the movement into services.

Sector	Data	Model	no $\gamma_{A_s^x}$	no m	both	no $\gamma_{A_m^x}$
Agriculture	-4.24	-3.31	-2.26	-2.2	-0.1	3.1
Manufacturing	-31.05	-14.23	-13.3	-17.4	-16.3	-5.5
Services	35.28	17.55	15.6	19.6	16.5	8.7

Δ Employment shares, 2020-1948.

What is the role of CETC for structural change?

CETC accounts for:

- 35% of the movement out of agriculture.
  ... and reaches $\approx$ 100% when considering both channels.
- 8% of the movement out of manufacturing.
  ... but 62% when only $\gamma_{A_m^x} = 0$.
- 11.4% of the movement into services.

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Services	35.28	17.55	15.6	19.6	16.5	8.7

Δ Employment shares, 2020-1948.

Final remarks

1. Documented **systematic disparities** in the type of capital used by different sectors
   → differential CETC across sectors.

2. Importance of the composition and timing of sectorial investment.
   → industrial policy in developing countries.

3. Productivity differentials across sectors are (endogenously) changing:
   implications for Baumol cost's disease?

Appendix

What is the role of CETC for structural change?

Change between 1948 and 2020, %

Price of sectorial output relative to manufacturing.

Sector	Data	Model	factor neutral	factor intensity
Agriculture	-67.78	-65.92	24.67	-79.21
Services	141.79	166.32	83.88	43.42

back

Calibration

Levels:

Parameter		Value			Target
output elast.	θ		0.76		.
discount factor	β		0.98		Buera et.al. (2020)
		Agr.	Manuf.	Serv.	
depreciation rate	δ	0.14	0.21	0.17	data
labor share	$1-\alpha_s$	0.39	0.67	0.77	data
output shares	ω_s	0.11	0.38	0.51	employment shares, 1948
initial capital	K_{s0}	0.21	0.74	0.91	capital output ratio, 1948
initial TFP	A_{s0}	4.94	3.97	4.70	output per worker, 1948

Trends:

$$\gamma_{\frac{P_s}{P_{s'}}} \overbrace{=}^{\text{long-run}} \frac{1}{1-\alpha_s}\left(\gamma_{A_s} + \alpha_s \gamma_{A_s^x}\right)$$

	agriculture	manufacturing	services
γ_{A_s}	0.94%	1.28%	0.41%
$\gamma_{A_s^x}$	1.51%	2.56%	4.85%

back

Along the transition: identification

- "Mechanized" activities → labor shares:

$$1 - \frac{r_{st} K_t}{P_{st} Y_{st}} = 1 - \alpha_{st} \quad = 1 - m_{st}^{1-\rho} \left(\frac{Y_{st}}{K_{st}} \right)^{-\rho}.$$

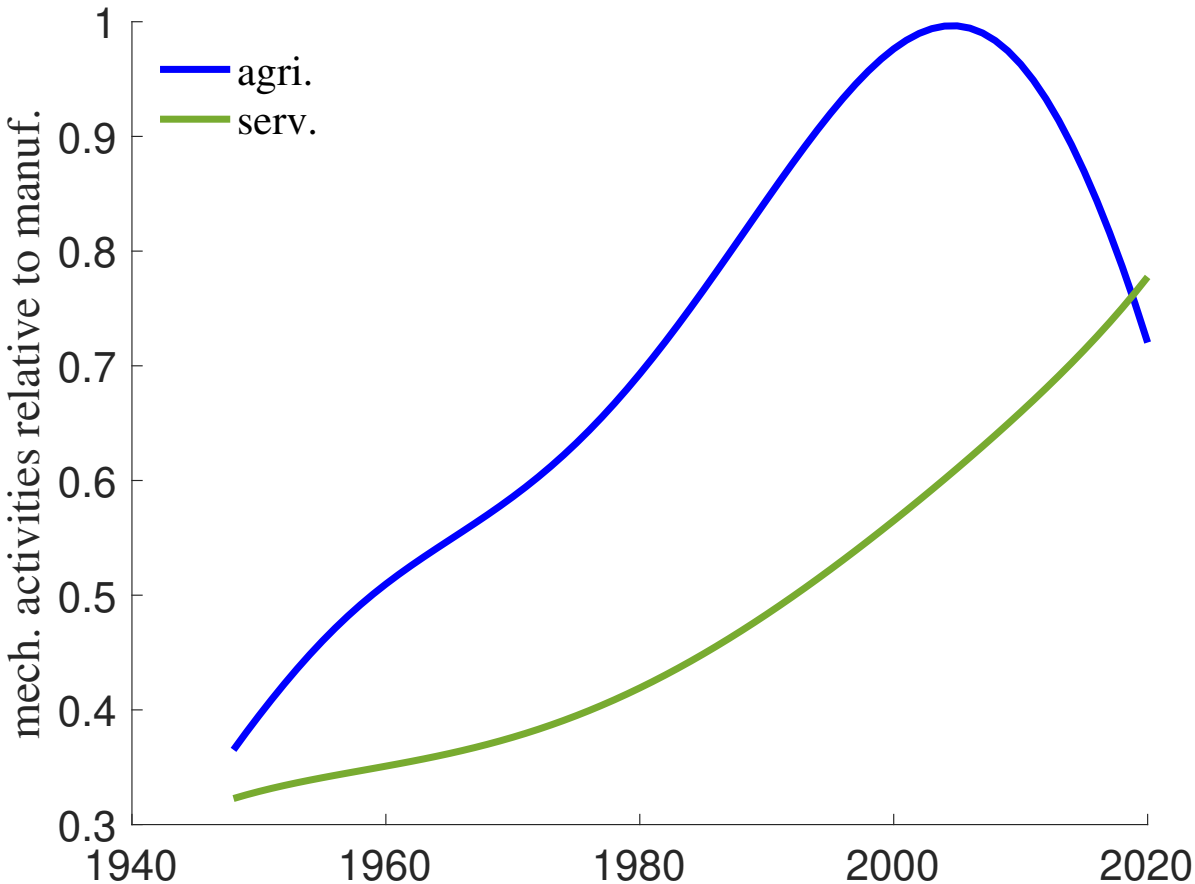
- Labor augmenting technical change $\frac{A^n_{mt}}{A^n_{st}}$ → relative prices P_s / P_{manuf}

- Growth in industry output (levels), A^n_{mt}.

▸ Calibration details ▸ back quant

Empirical paths

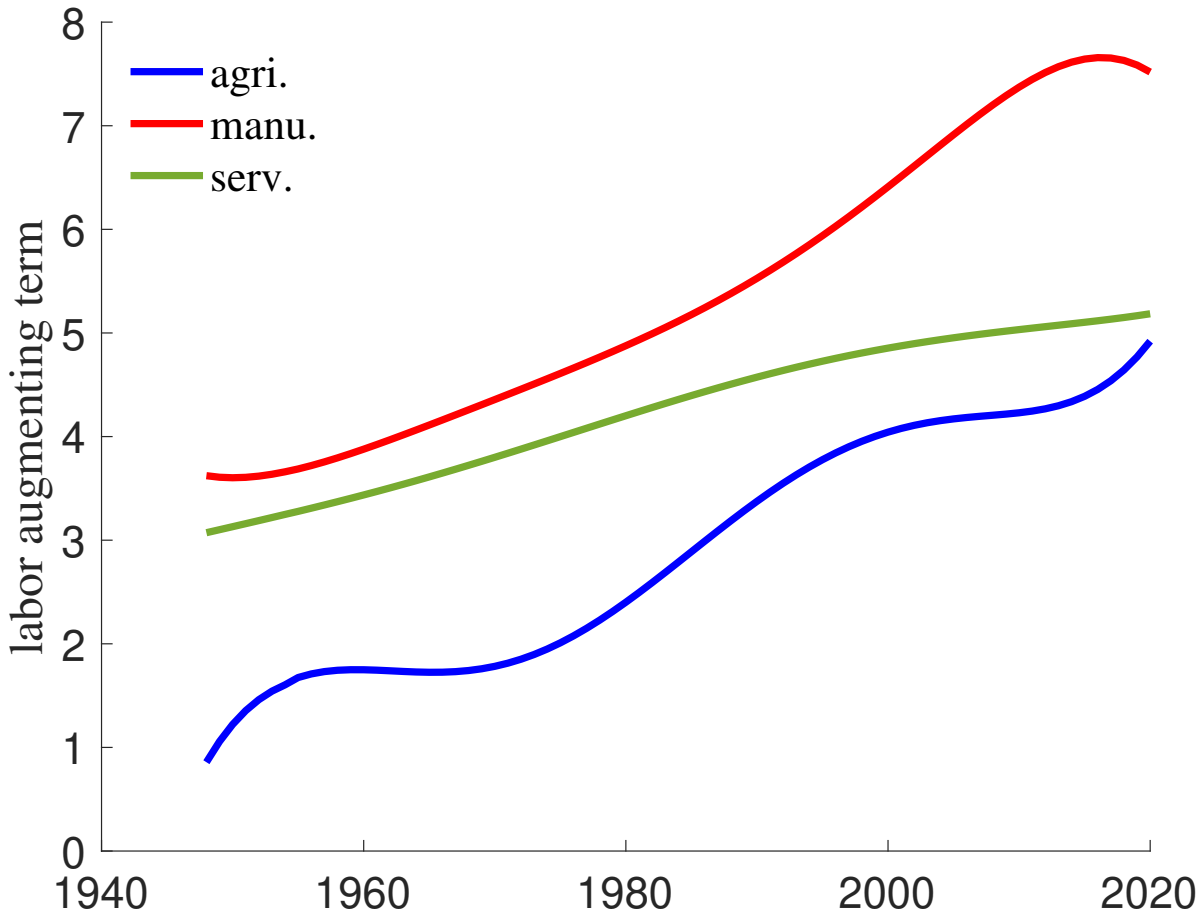
Capital intensive activities m_{st}:



blue: agriculture; green: services. ▸ levels ▸ back quant

Empirical paths

Labor augmenting, $\left(\frac{1}{A_{st}}\int_{m_{st}}^{1}\frac{1}{\zeta_i}d_i\right)^{\frac{1-\rho}{\rho}}$

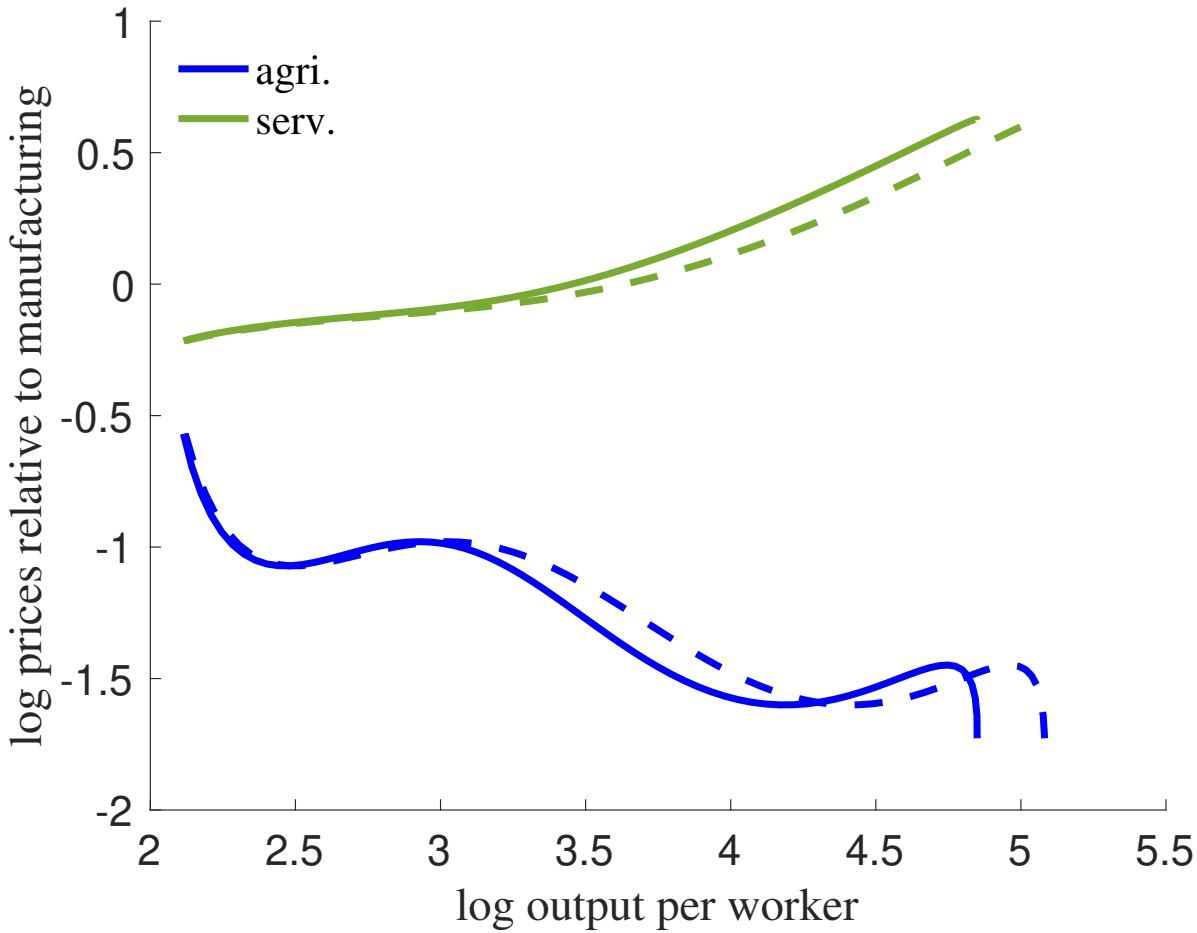


blue: agriculture; red: manufacturing; green: services. ▸ back quant

Calibration

Model fit on targets: relative prices

solid: data; striped: model.



▸ non-targeted ▸ back quant

Contributions

1. *Unpack sectoral TFP growth*: document systematic disparities in sectorial investment composition and CETC.

   Ngai & Pissarides, 2012.

2. Emphasize the role of:
   (i) Heterogeneity in the demand for investment rather than inputs for investment ...

   Acemoglu & Guerrieri, 2009; Garcia Santana, et. al. 2022; Herrendorf, et.al. 2021

   (ii) movements in factor shares...

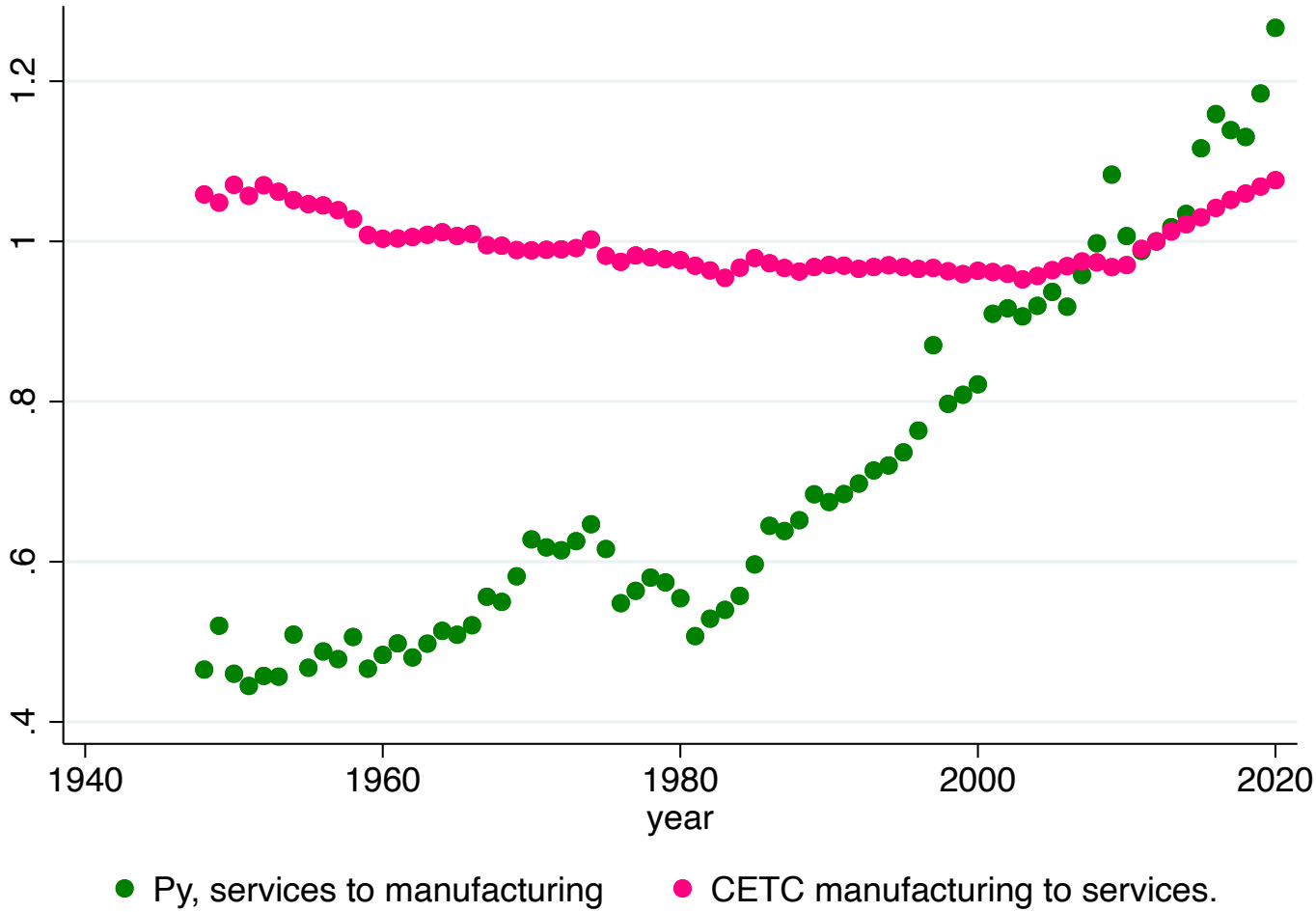
   Herrendorf, et.al. 2016; Boppart, et.al. 2022 with common capital stock

   for structural change.

back

Relative prices and CETC

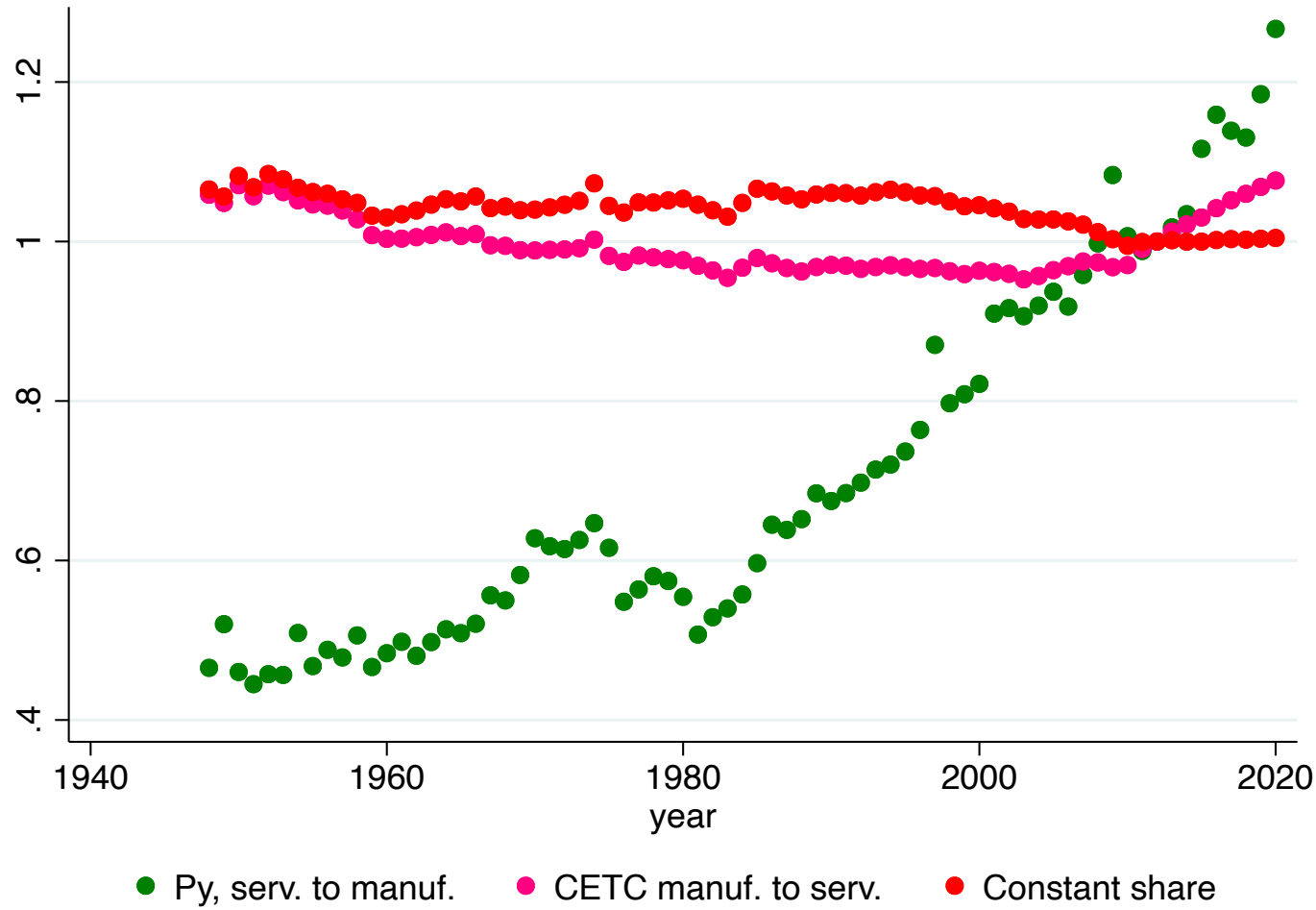
Services back



$$\gamma_{\frac{P_s}{P_{s'}}} \approx \left(\gamma_{\tilde{A}_{s'}} - \gamma_{\tilde{A}_s}\right) + \underbrace{\sum_j \left(\frac{\alpha_{s't}}{1-\alpha_{s't}}\kappa_{js't} - \frac{\alpha_{st}}{1-\alpha_{st}}\kappa_{jst}\right)\gamma_{A^x_{jt}}}_{\text{CETC}}$$

Constant labor share

Services back

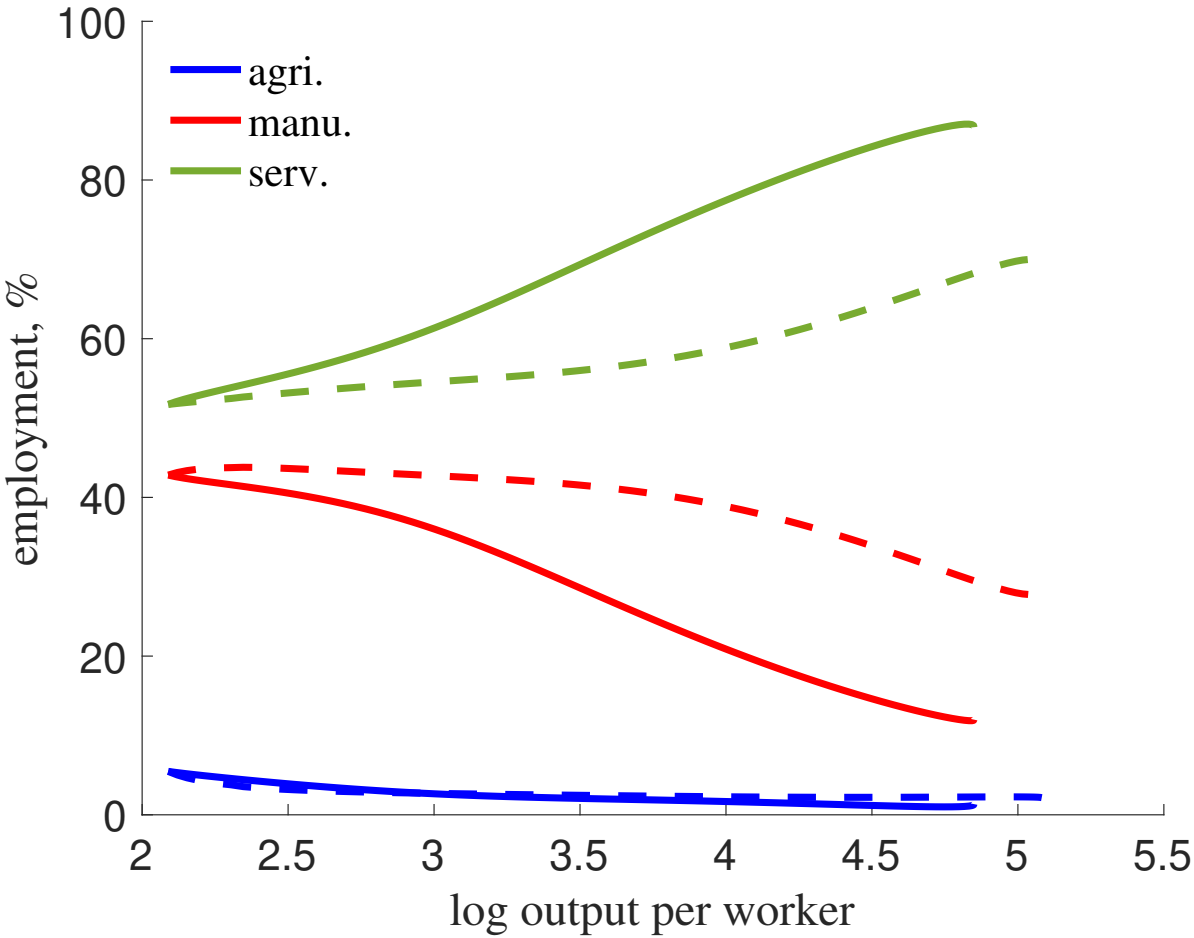


Constant share: $1 - \alpha$ set to Herrendorf, et.al. (2015).

Calibration

Model fit on non-targets: structural change

solid: data; striped: model.



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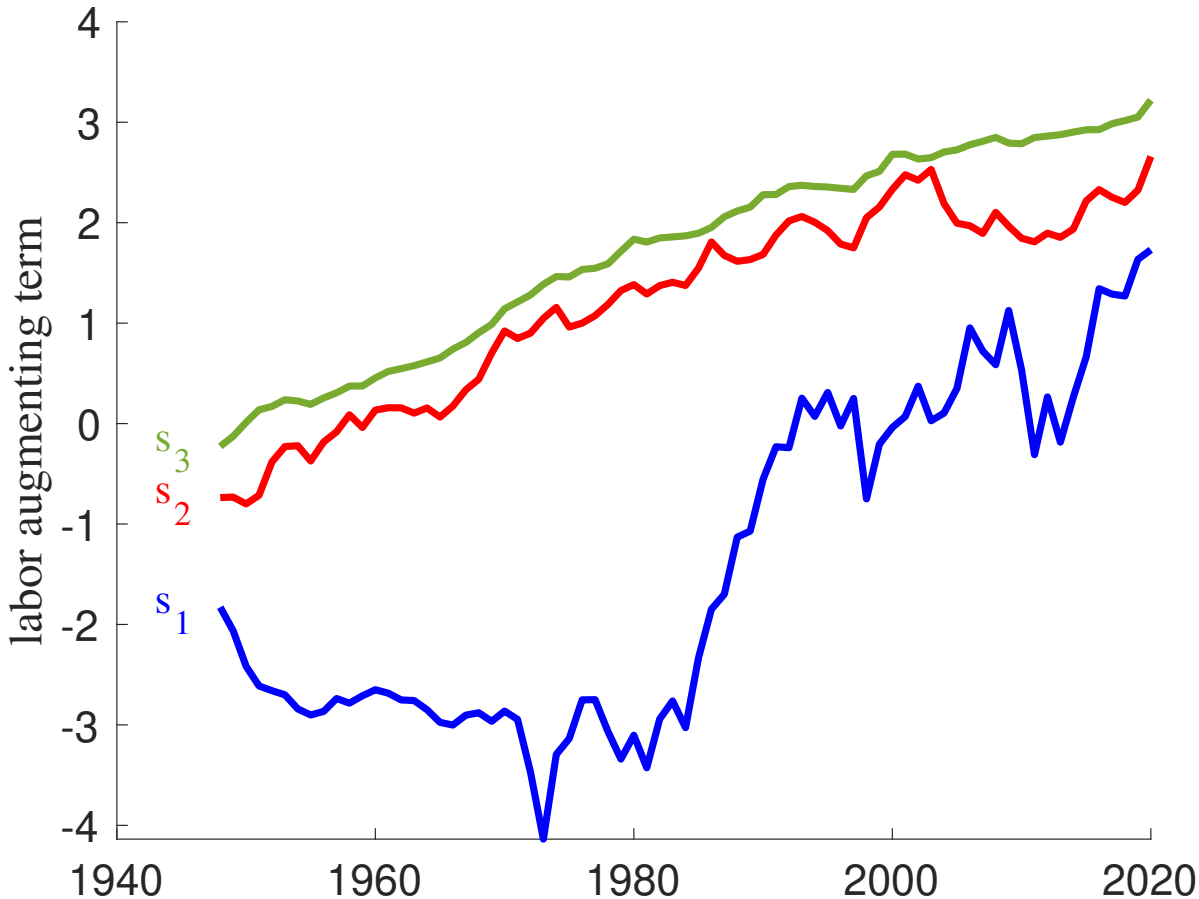
Along the transition: identification

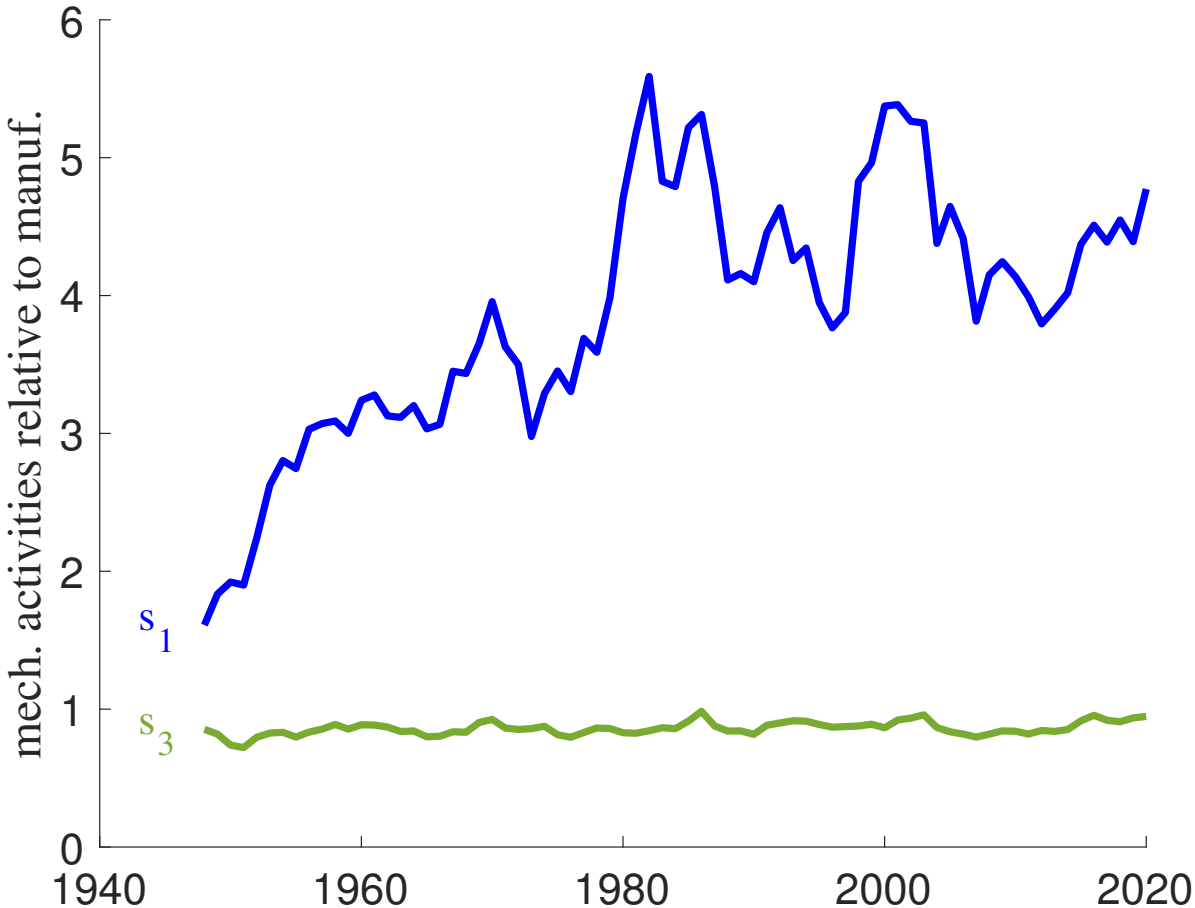
Logs of labor augmenting technology: $\frac{1-\rho}{\rho}\log((1-m_{st})^{-1}Z_{st})$.



blue: agriculture; red: manufacturing; green: services.

Along the transition: identification

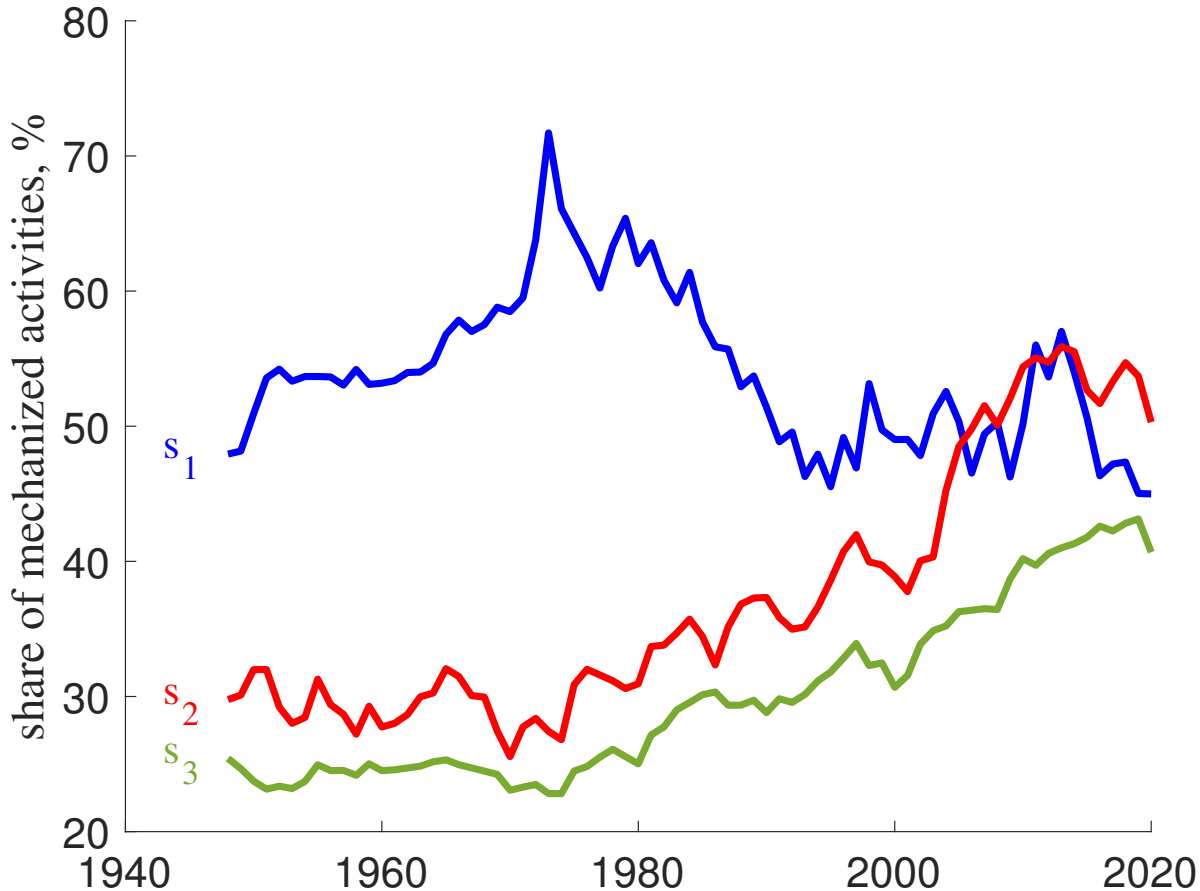
Capital intensive activities m_{st}.



blue: agriculture; green: services. ▸ levels

Along the transition: identification

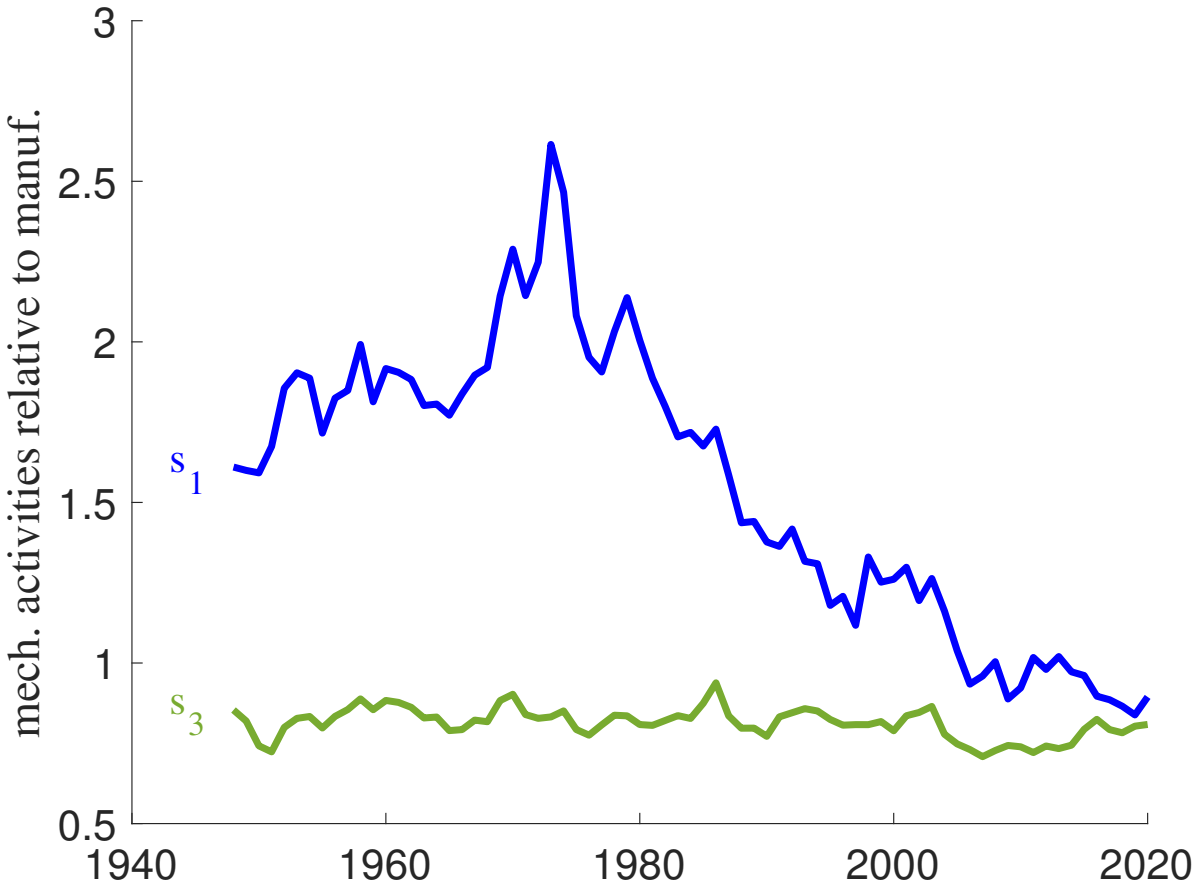
Capital intensive activities m_{st}.



blue: agriculture; red: manufacturing; green: services. ▸ ratios

Along the transition: identification

Share of mechanized activities m_{st}.



blue: agriculture; green: services. ▸ levels

Along the transition: identification

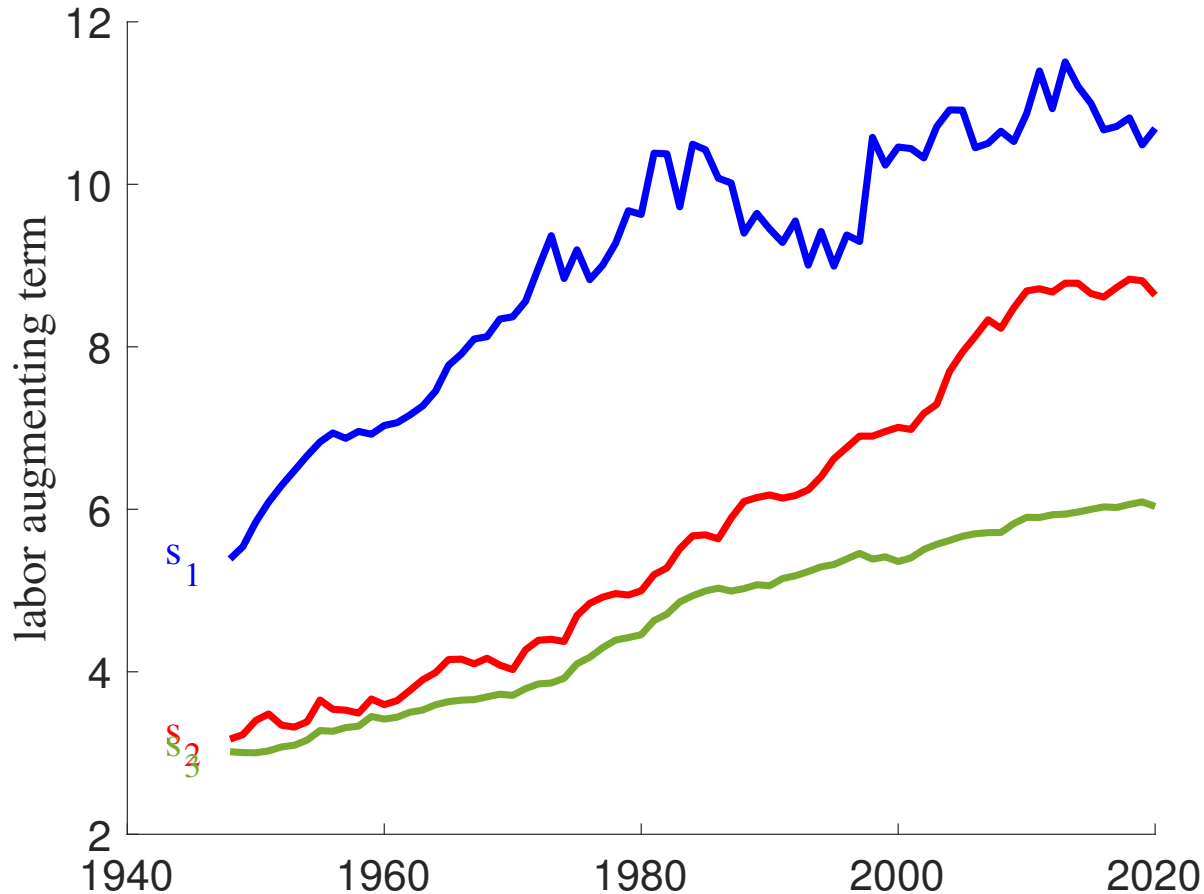
Decomposition of changes in the labor share (LS).

	σ*	CETC	change in m	change in LS	change in LS with no CETC	change in LS with constant m
Agriculture	0.82	1.51	-2.95	-7.58	-16.73	-11.22
Manufacturing	0.82	2.56	20.53	-11.98	-29.19	5.06
Services	0.82	4.85	15.26	2.95	-15.26	11.38

* Source: Herrendorf, Herrington & Valentinyi (2015).

Along the transition: identification

Logs of labor augmenting technology: $\frac{1-\rho}{\rho}\log((1-m_{st})^{-1}Z_{st})$.



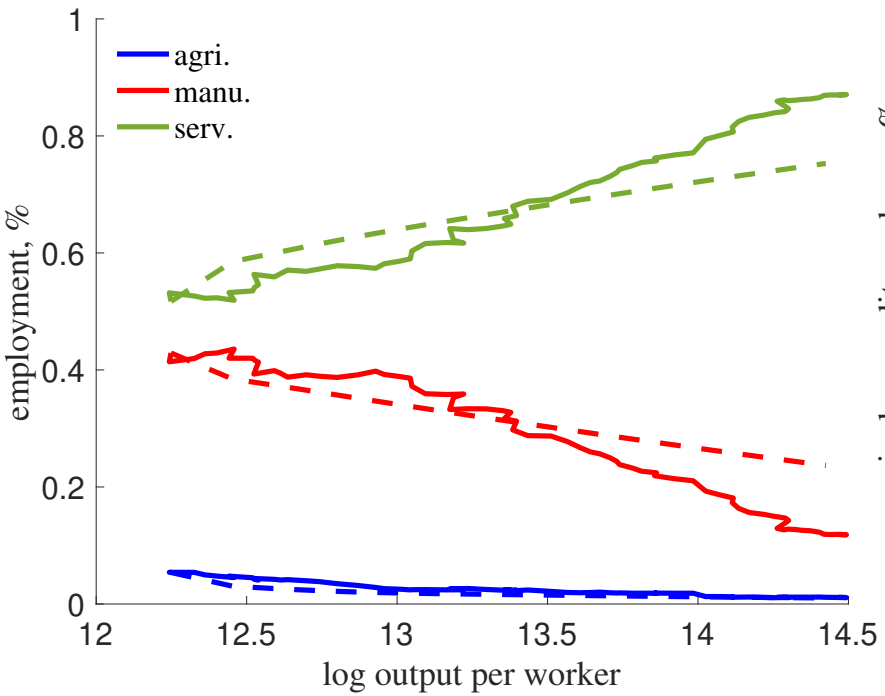
blue: agriculture; red: manufacturing; green: services.

Calibration

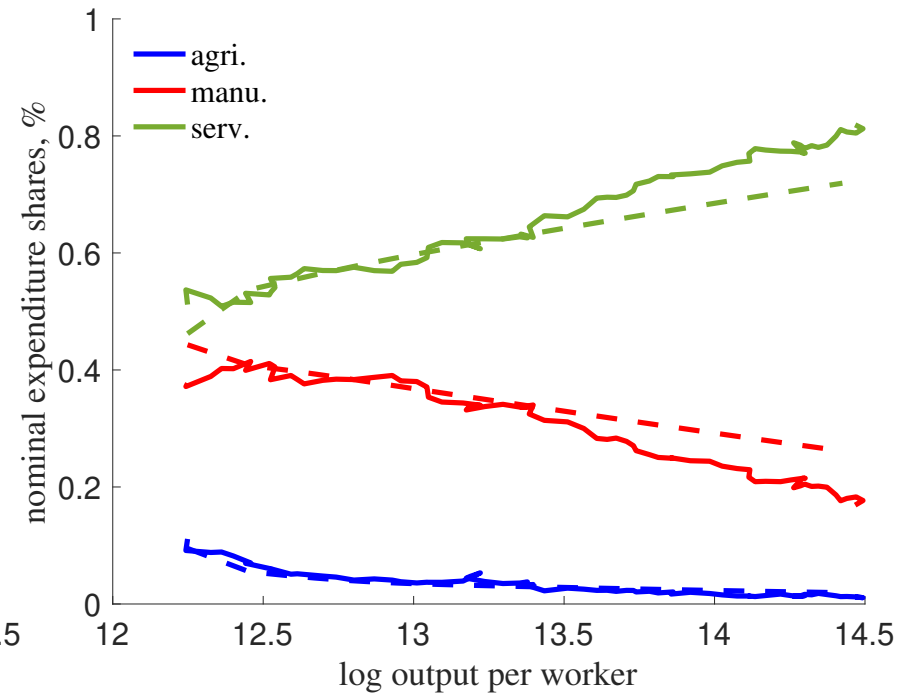
Model fit on non-targets: structural change

back

solid: data; striped: model

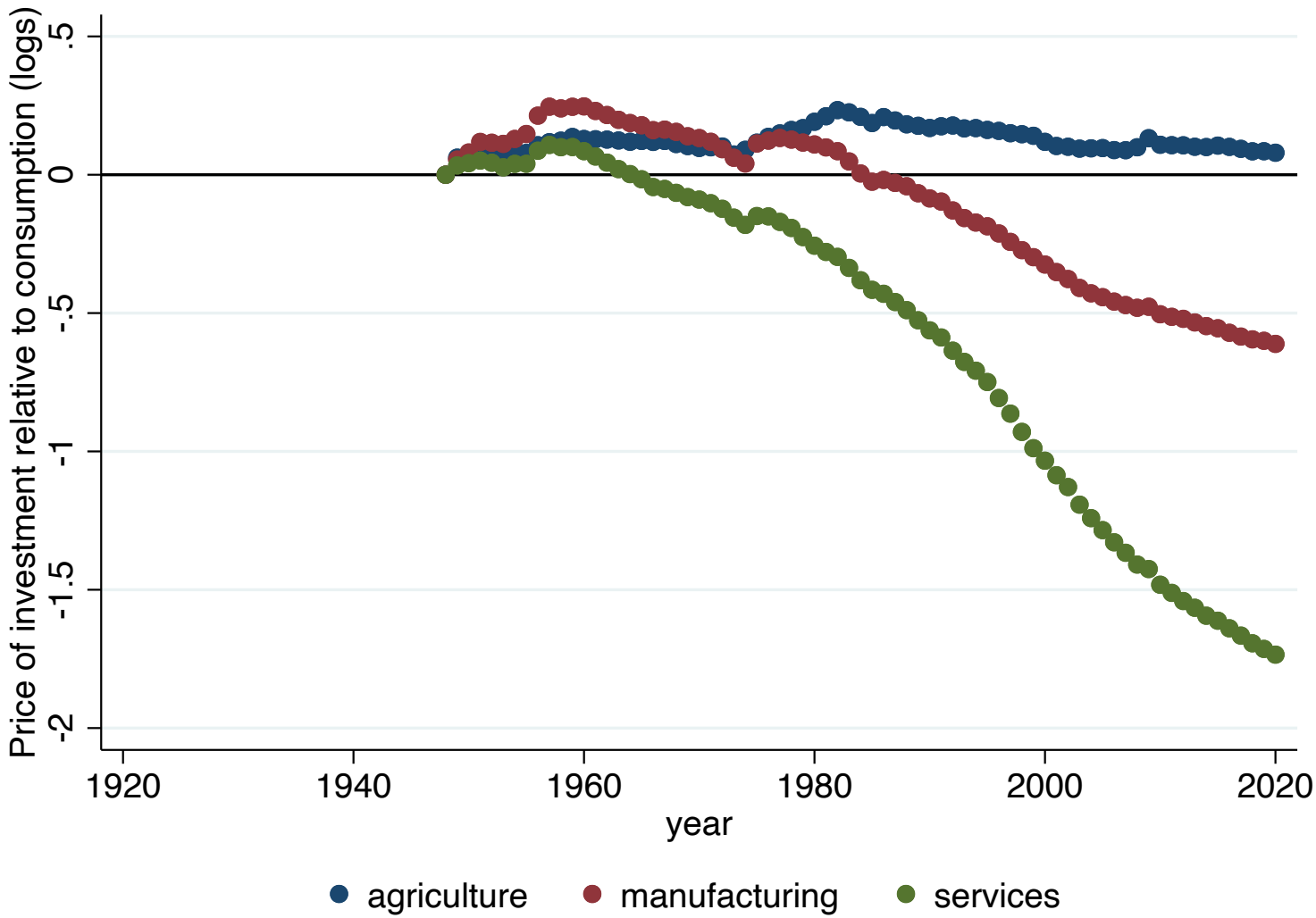


(e) employment



(f) nominal expenditures

CETC by sector



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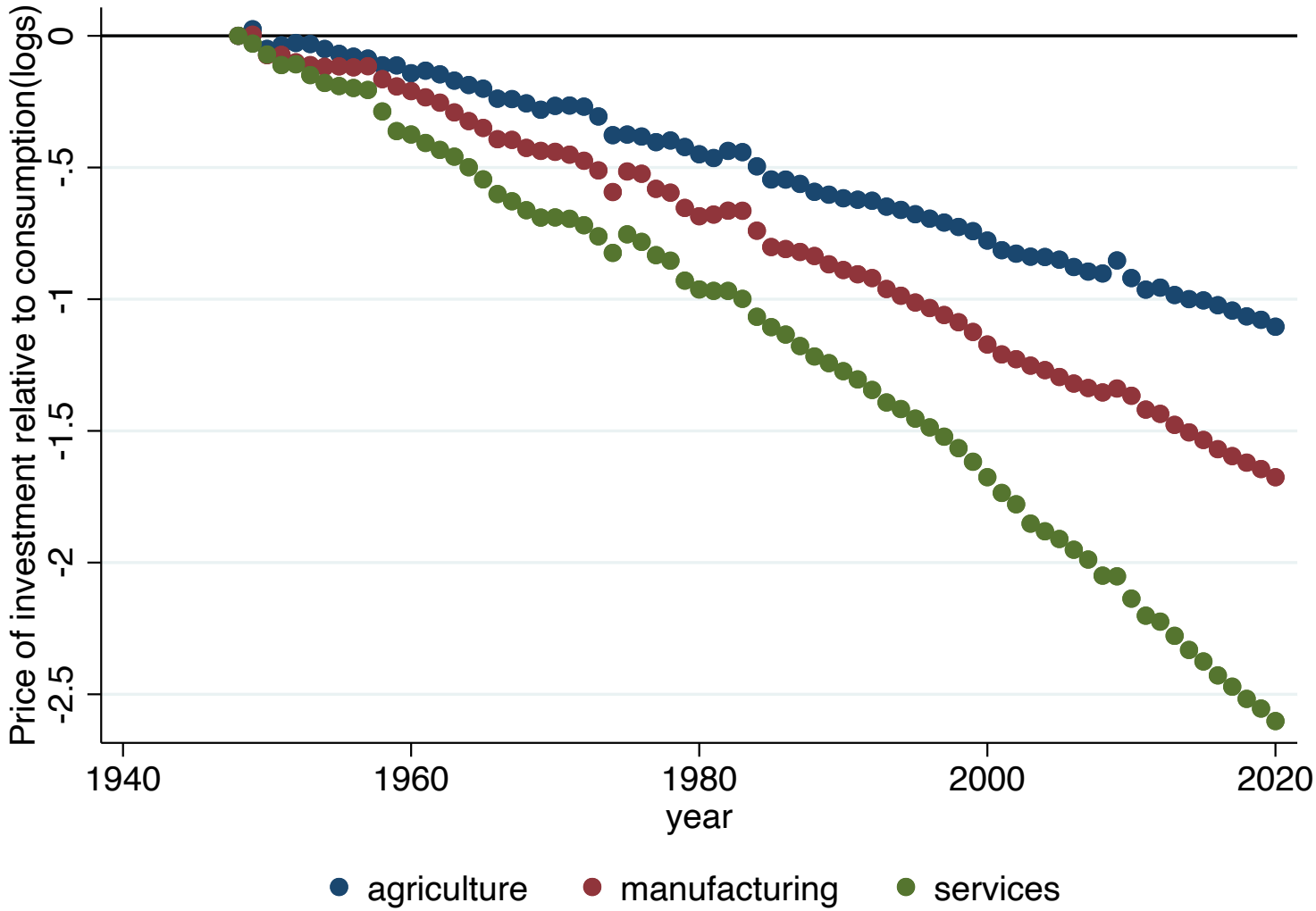
CETC by sector, investment weights 1948



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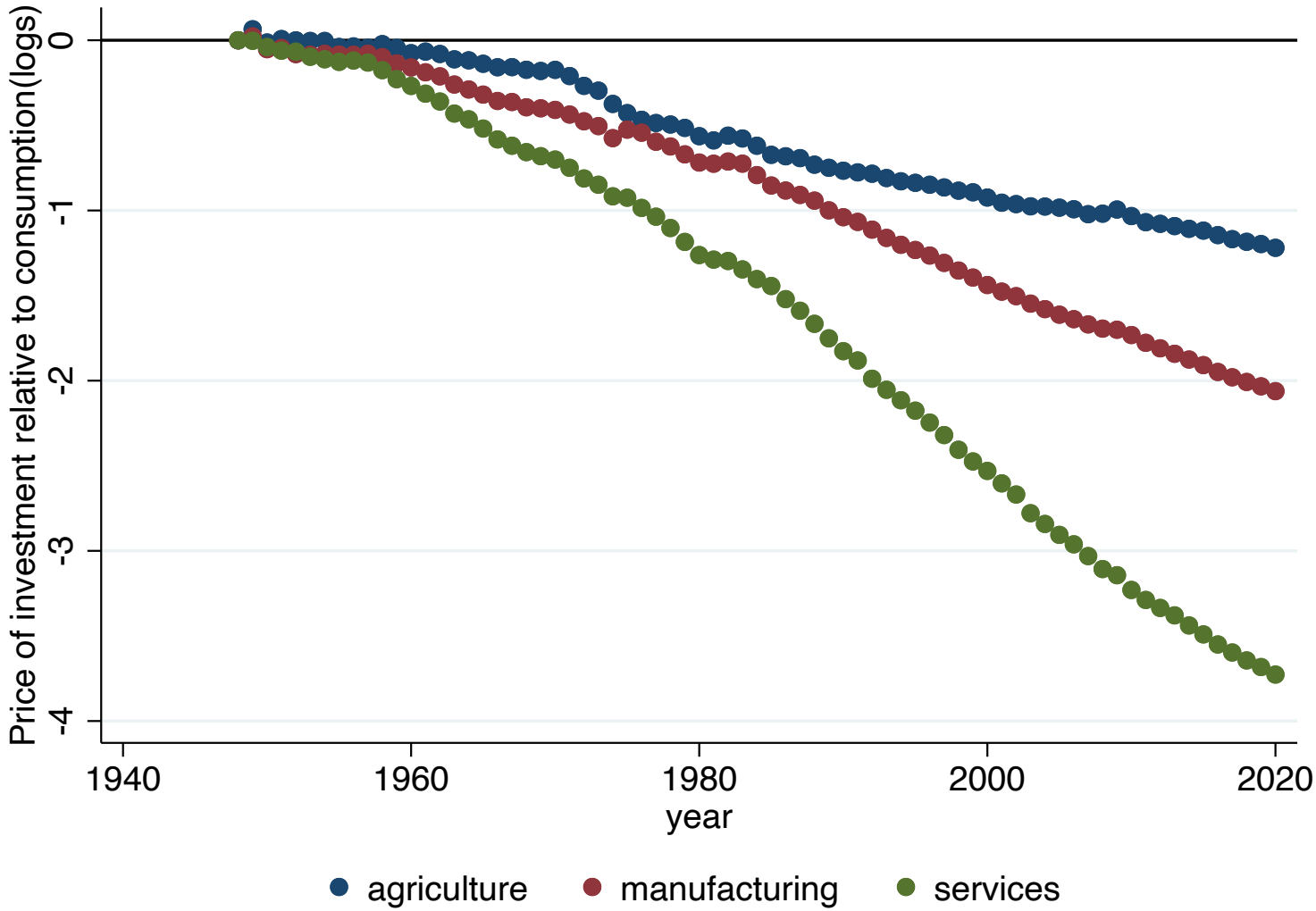
CETC by sector, investment weights 2016



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Evidence for the US: 1948-2020

Data construction

- Price of sectoral output, BEA Herrendorf et.al., 2015.
  3-digit NAICS sectors aggregated to 3 sectors.
- Value added by sector, NIPA.
- Quality-adjusted price of equipment to consumption:
  Cummins & Violante, 2001. DiCecio, 2009.
  22 equipment categories plus 3 categories of software.
  ...aggregated to 3 sectors.
- Investment and stocks by equipment and sector,
  BEA fixed assets tables.

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