Capital-Embodied Structural Change

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Introduction

- Structural change: reallocation of economic activity across agriculture, manufacturing, and services.

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

- But factor-augmenting technical change has been shown to account for more than half of overall output growth. \(\text{(Greenwood, et. al. 1997).}\)

- We study sector-specific factor-augmenting technical change \(\rightarrow\) embodied in capital.
What is the role capital embodied technical change (CETC) for structural change?
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- Document larger sectoral disparities in CETC than in TFP growth.
  - US time-series and multiple cross-sections of countries.

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

- Quantify \textit{CETC-induced shift in economic activity across sectors}. → capital-embodied structural change.
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 and multiple cross-sections of countries.

- **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.**
  
  37% of the reallocation of labor into services,
  88% of the reallocation of labor out of agriculture.
Contributions


2. Highlight *heterogeneity in the type of investment & movements in factor shares* with structural change.
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Why do we care?

- Developing countries import most of their equipment.

- Sectoral productivity paths need not be set in stone.

  services holds fastest CETC and slowest TFP growth, *can productivity trends reverse?* → Baumol’s disease.
Overview

   - Framework to look at the data.
   - Main findings.

2. A model of capital-embodied structural change.

3. The role CETC for structural change.
Empirical Evidence
Overview: minimal framework

- Sectoral goods:

\[
\begin{align*}
Y_{st} &= A_{st} \left( K_{st}, N_{st} \right) \\
A_{st+1} &= A_{st} (1 + \gamma A_s)
\end{align*}
\]

and differ by:

1. factor-neutral technology,
2. capital used → sectoral CETC.
Sectoral capital

- $J$ equipment goods, investment $X_j$, of different CETC:

\[
Y_t = C_t + \sum_j \chi_{jt},
\]
\[
X_{jt} = A_{jt} \chi_{jt}.
\]
\[
A_{xjt+1} = (1 + \gamma A_{xj}) A_{xjt},
\]

\[\Rightarrow \quad \frac{P_{xjt}}{P_{xt}} = \frac{1}{A_{xjt}}.\]

- Sector-specific investment aggregator with constant returns:

\[
K_{st+1} = I_s(\{X_{jst}\}_j) - \delta_s K_{st},
\]

and $X_{jt} = \sum_s X_{jst}$. 
Factor-augmenting technical change & structural change

\[
\frac{P_{st}}{P_{s't}} = \frac{1 - \alpha_{s't}}{1 - \alpha_{st}} \left( \frac{Y_{s't}/N_{s't}}{Y_{st}/N_{st}} \right)
\]

\[\frac{\partial F_n}{F} \text{ labor prod.}\]
Factor-augmenting technical change & structural change

\[
\frac{P_{st}}{P_{s't}} = \frac{\frac{\partial F_{nN}}{F} \text{ labor prod.}}{1 - \alpha_{st}} \frac{Y_{s't}/N_{s't}}{1 - \alpha_{st}} \frac{Y_{st}/N_{st}}{Y_{st}/N_{st}}
\]

- Common factor share: \( \alpha_{st} = \alpha \) (Ngai and Pissarides, 2007)

\[
\frac{P_{st}}{P_{s't}} = \frac{A_{s't}}{A_{st}}.
\]
Factor-augmenting technical change & structural change

\[
\frac{P_{st}}{P_{s't}} = \frac{\frac{\partial F_n N}{F}}{1 - \alpha_{s't}} \frac{Y_{s't}/N_{s't}}{1 - \alpha_{st}} \frac{Y_{st}/N_{st}}}
\]

- **Common factor share:** \( \alpha_{st} = \alpha \) (Ngai and Pissarides, 2007)

\[
\frac{P_{st}}{P_{s't}} = \frac{A_{s't}}{A_{st}}.
\]

- **Sectoral factor share:** \( \alpha_{st} = \alpha_s \) (Acemoglu and Guerrieri, 2008)

\[
\frac{P_{st}}{P_{s't}} = \frac{A_{s't}}{A_{st}} \frac{F_{s'}(\frac{K_{s't}}{N_{s't}})}{F_s(\frac{K_{st}}{N_{st}})} , \quad \frac{K_{st}}{N_{st}} = \frac{W_t}{r_t} \frac{\alpha_s}{1 - \alpha_s}.
\]
Factor-augmenting technical change & structural change

\[
\frac{P_{st}}{P_{s't}} = \frac{\frac{\partial F_n N}{F}}{1 - \alpha_{st}} \frac{Y_{s't}/N_{s't}}{Y_{st}/N_{st}}
\]

- Common factor share: \(\alpha_{st} = \alpha\) (Ngai and Pissarides, 2007)

\[
\frac{P_{st}}{P_{s't}} = \frac{A_{s't}}{A_{st}}.
\]

- Sectoral factor share, time-varying: \(\alpha_{st} = \alpha_{st}\) (Herrendorf et al., 2016)

\[
\frac{P_{st}}{P_{s't}} = \frac{A_{s't}}{A_{st}} \frac{F_s'\left(\frac{K_{s't}}{N_{s't}}\right)}{F_s\left(\frac{K_{st}}{N_{st}}\right)}, \quad \frac{K_{st}}{N_{st}} = \frac{W_t}{r_t} \frac{\alpha_{st}}{1 - \alpha_{st}}.
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Factor-augmenting technical change & structural change

\[ \frac{P_{st}}{P_{s't}} = \frac{\frac{\partial F_n N}{F}}{1 - \alpha_{s't}} \frac{Y_{s't}/N_{s't}}{1 - \alpha_{st}} \frac{Y_{st}/N_{st}}{Y_{st}/N_{st}} \]

- Common factor share: \( \alpha_{st} = \alpha \) (Ngai and Pissarides, 2007)

\[ \frac{P_{st}}{P_{s't}} = \frac{A_{s't}}{A_{st}} \]

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\[ \frac{P_{st}}{P_{s't}} = \frac{A_{s't} F_{s'}(\frac{K_{s't}}{N_{s't}})}{A_{st} F_{s}(\frac{K_{st}}{N_{st}})}, \quad \frac{K_{st}}{N_{st}} = \frac{W_t}{r_t} \frac{\alpha_{st}}{1 - \alpha_{st}} \]

- Sectoral CETC: \( r_{s't} \)

\[ \frac{P_{st}}{P_{s't}} = \frac{A_{s't} F_{s'}(\frac{K_{s't}}{N_{s't}})}{A_{st} F_{s}(\frac{K_{st}}{N_{st}})}, \quad \frac{K_{st}}{N_{st}} = \frac{W_t}{r_{st}} \frac{\alpha_{st}}{1 - \alpha_{st}} \]
Factor-augmenting technical change & structural change
Measurement

\[ \gamma \frac{P_{st}}{P_{s't}} \approx \left( \gamma \bar{A}_{st} - \gamma \bar{A}_{st} \right) + \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \gamma r_{s't} - \frac{\alpha_{st}}{1 - \alpha_{st}} \gamma r_{st} \right) \cdot \]

\[ \gamma \bar{A}_{st} = \gamma A_{st} + (1 - \alpha_{st}) \gamma_{1-\alpha} + \alpha_{st} \gamma_{\alpha st}. \]
Factor-augmenting technical change & structural change

Measurement

\[ \gamma_{\frac{P_{st}}{P_{s't}}} \approx \left( \gamma_{\tilde{A}_{s't}} - \gamma_{\tilde{A}_{st}} \right) + \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \gamma_{r_{s't}} - \frac{\alpha_{st}}{1 - \alpha_{st}} \gamma_{r_{st}} \right). \]

\[ \gamma_{\tilde{A}_{st}} = \gamma_{A_{st}} + (1 - \alpha_{st}) \gamma_{1-\alpha_{st}} + \alpha_{st} \gamma_{\alpha_{st}}. \]

- Long-run dynamics:

\[ \gamma_{r_s} = \sum_j \kappa_{js}(\gamma_{P_{xj}} - \gamma_{P_c}) = - \sum_j \kappa_{js} \gamma_{A_{xj}}. \]

where \( \kappa_{jst} \equiv \frac{P_{xjt}X_{jst}}{\sum_{j'} P_{xj't}X_{j'st}}. \)

- Measurement:

\[ \gamma_{\frac{P_{st}}{P_{s't}}} \approx \left( \gamma_{\tilde{A}_{s't}} - \gamma_{\tilde{A}_{st}} \right) + \sum_j \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \kappa_{js't} - \frac{\alpha_{st}}{1 - \alpha_{st}} \kappa_{jst} \right) \gamma_{A_{xjt}}. \]
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.

¬ (nominal and chained-weighted) Value added by sector, NIPA.

¬ Quality-adjusted price of equipment to consumption:
  22 equipment categories plus 3 categories of software.
  ...aggregated to 3 sectors.

¬ (nominal) Investment and stocks by equipment and sector, BEA fixed assets tables.
## Sector definition

<table>
<thead>
<tr>
<th>3-sector</th>
<th>NAICS 2-digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Farms, Forestry and Fishing</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Manufacturing</td>
</tr>
<tr>
<td></td>
<td>Mining</td>
</tr>
<tr>
<td>Services</td>
<td>Wholesale Trade</td>
</tr>
<tr>
<td></td>
<td>Retail</td>
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<tr>
<td></td>
<td>Transportation</td>
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<tr>
<td></td>
<td>Entertainment</td>
</tr>
<tr>
<td></td>
<td>Accommodation</td>
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<tr>
<td></td>
<td>Business Administration</td>
</tr>
<tr>
<td></td>
<td>Health Services</td>
</tr>
<tr>
<td></td>
<td>Professional Services</td>
</tr>
<tr>
<td></td>
<td>Education</td>
</tr>
<tr>
<td></td>
<td>Finance and Insurance</td>
</tr>
</tbody>
</table>

No construction (manufacturing) and no real estate (services).
Relative price of investment by sector

- CRS investment aggregator in each sector:

\[ I_s(\{X_{jst}\}_j). \]

- Change in the relative price of investment to consumption:

\[
d \ln(P_{xst}) = \sum_j \frac{P_{xjt}X_{jst}}{\sum_j P_{xjt}X_{jst}} d \ln(P_{xjt})
\]

- \( P_{xjt} \) is the relative price of investment good \( j \) to consumption.
- \( P_{xjt}X_{jst} \) nominal investment.
CETC by sector

The graph shows the price of investment relative to consumption (logs) for agriculture, manufacturing, and services from 1940 to 2020. The price is depicted on the y-axis, with a logarithmic scale, while the x-axis represents the year. The trend lines indicate a decreasing price relative to consumption over time, with agriculture showing a trend slightly above manufacturing and services.
Relative prices by sector, $P_s/P_{\text{manuf}}$
Relative prices by sector, $P_s/P_{\text{manuf}}$

$$\gamma \frac{P_s}{P_{s'}} \approx \left( \gamma \tilde{A}_{s'} - \gamma \tilde{A}_s \right) + \sum_j \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \kappa_{j's't} - \frac{\alpha_{st}}{1 - \alpha_{st}} \kappa_{j's'} \right) \gamma A_{xjt}$$

CETC
Relative prices and CETC

Agriculture

\[ \gamma_{\frac{P_s}{P_{s'}}} \approx \left( \gamma \tilde{A}_{s'} - \gamma \tilde{A}_s \right) + \sum_j \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \kappa_{j's't} - \frac{\alpha_{st}}{1 - \alpha_{st}} \kappa_{j's't} \right) \gamma A_{xjt} \]

- Py, agriculture to manufacturing
- CETC manufacturing to agriculture
Relative prices and CETC

Services

\[ \gamma \frac{P_s}{P_{s'}} \approx \left( \gamma \tilde{A}_{s'} - \gamma \tilde{A}_s \right) + \sum_j \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \kappa_{js't} - \frac{\alpha_{st}}{1 - \alpha_{st}} \kappa_{jst} \right) \gamma A_{xjt} \]
Labor share
Constant labor share

Agriculture

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

Services

constant share: $1 - \alpha$ set to Herrendorf et.al. (2015).
Evidence for the US

Summary

1. Systematic disparities in CETC across sectors.

<table>
<thead>
<tr>
<th></th>
<th>Agriculture</th>
<th>Manufacturing</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>CETC, $\gamma_{Ax}$</td>
<td>1.51</td>
<td>2.56</td>
<td>4.85</td>
</tr>
</tbody>
</table>

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.
Sectoral technology

- Production requires completing a measure 1 of activities:

\[ Y_{st} = \left[ \int_{o}^{1} Q_{ist}^\rho \, di \right]^{\frac{1}{\rho}}, \]

for \( \rho < 0 \).

- Activities can be performed with labor:

\[ Q_{ist} = \zeta_{ist}^\rho N_{ist} \quad i \in [0, 1], \]

\[ \zeta_{ist+1} = \zeta_{ist} (1 + \gamma_{As}). \]

- Share \( m_{st} \) can also be performed with capital:

\[ Q_{ist} = K_{ist} \quad i \in [0, m_{st}], \]

\[ m_{st+1} = m_{st} (1 + \gamma_{ms}). \]
Optimal allocations

- $\zeta_{ist}$ strictly increasing in $i \to$ threshold for activities performed with capital, $m_{st}$:

\[ r_{st} \leq w_t (\zeta_{ist}^{-1}) \frac{\rho-1}{\rho}, \quad \rho < 0. \]

race between labor productivity growth $\uparrow \zeta_{ist}$ and the user cost of capital $\downarrow r_{st}$.

- Capital share in the sector:

\[ \frac{r_{st} K_{st}}{Y_{st} P_{st}} = m_{st} \left( \frac{r_{st}}{P_{st}} \right)^{\frac{\rho}{\rho-1}}. \]
Optimal allocations: sectoral output

\[ Y_{st} = \left[ (1 - m_{st})Z_{st}^{-1} \right]^{(1-\rho)} N_{st}^\rho + m_{st}^{(1-\rho)} K_{st}^\rho \right]^{\frac{1}{\rho}}, \]

for \( Z_{st}^{-1} = \frac{1}{1-m_{st}} \int_{m_{st}}^{1} \zeta_{ist}^{-1} d(i) \).

- \( A_{nst} \equiv Z_{st}^{\rho-1} \) to index labor productivity.
- \( A_{xst} \) to index CETC:

\[ K_{st} = A_{xst} \tilde{K}_{st}, \quad A_{xst+1} = A_{xst}(1 + \gamma_{Axst}). \]
Optimal allocations: sectoral output

\[ Y_{st} = \left[ \left( (1 - m_{st}) Z_{st}^{-1} \right)^{(1-\rho)} N_{st}^\rho + m_{st}^{(1-\rho)} K_{st}^\rho \right]^\frac{1}{\rho}, \]

for \( Z_{st}^{-1} = \frac{1}{1-m_{st}} \int_{m_{st}}^{1} \frac{1}{\xi_{ist}} d(i). \)

\( A_{nst} \equiv Z_{st}^\rho \) to index labor productivity.

\( A_{xst} \) to index CETC:

\[ K_{st} = A_{xst} \tilde{K}_{st}, \quad A_{xst} + 1 = A_{xst} (1 + \gamma A_{xst}). \]

\( \Rightarrow \) Output can be rewritten as:

\[ Y_{st} = \left[ \left( b_{st}^n N_{st} \right)^\rho + \left( b_{st}^k \tilde{K}_{st} \right)^\rho \right]^\frac{1}{\rho}, \]

for \( b_{st}^n = \left( (1 - m_{st}) \right)^{\frac{1-\rho}{\rho}} A_{nst} \) and \( b_{st}^k = \left( m_{st} \right)^{\frac{1-\rho}{\rho}} A_{xst}. \)

Observation: when \( \rho \to 0, m_{st} \) arbitrary, technology Cobb-Douglas.
Asymptotic BGP (despite Uzawa)

- Constant capital share for:

\[ \gamma_{m_s} = \frac{\rho}{\rho - 1} (-\gamma_{r_s}) = \frac{\rho}{\rho - 1} \gamma_{A_{xs}}, \]

→ “Mechanization” is slower than CETC:

\[ \gamma_{m_s} < \gamma_{A_{xs}}, \text{ for } \rho < 0. \]

→ Technical change is labor-augmenting (long-run).

constant \( b_{st}^k = m_{st}^p A_{xs} \) for log-preferences in consumption.

- Constant rate of convergence to the BGP for constant \( \gamma_{b_s^n} \):

\[ \gamma_Y \approx (\rho - 1) \gamma_{b_s^n} = \frac{\rho - 1}{\rho} (-\gamma_{1-m_s} + \gamma_{Z_s}), \]

→ \( \gamma_{1-m_s} \) is constant,

→ \( \gamma_{m_s} \) is monotonically decreasing and so is \( \gamma_{A_{xs}} \).
Along the transition: identification

- “Mechanized” activities → labor shares, CETC:

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

- Labor augmenting → employment, output, labor shares:

\[ \frac{w_tL_{st}}{P_{st}Y_{st}} = 1 - \alpha_{st} = (1 - m_{st}) \left( \frac{w_t}{A_{nst}P_{st}} \right)^{\frac{\rho}{\rho - 1}}, \]

\[ w_t = (1 - \alpha_{st}) \frac{P_{st}Y_{st}}{L_{st}}. \]

- Measurement of exogenous path given the elasticity of substitution between capital and labor, \( \frac{1}{1 - \rho} \).
What is the role of CETC for structural change?

- Today: limiting case
What is the role of CETC for structural change?

- Today: limiting case

  Sector specific but constant factor shares.

  Acemoglu and Guerrieri (2008) + sector-specific CETC.
 Quantification

- Sectoral technology:

\[ Y_{st} = A_{st}K_{st}^{m_s}N_{st}^{1-m_s}. \]

- Work directly with \( S \) investment goods, \( X_s \), priced at \( P_{xst} \):
  - inv. aggregator \( I_s(\{X_{jst}\}_j) \rightarrow \) optimal price index \( P_{xst} \).
    
    e.g. for \( I_s(\{X_{js}\}_j) = \left( \sum_j \omega_{xjs}X_{jst}^{\frac{1}{\theta_i}} \right)^{\frac{1}{1-\theta_i}} \), \( P_{xst} = \left( \sum_j \omega_{xjs}P_{xjt}^{1-\theta_i} \right)^{\frac{1}{1-\theta_i}} \).
  
  \( \rightarrow \) sectoral CETC, \( -\gamma_{P_{xst}} \), directly from the data.
Calibration

Levels:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Target</th>
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</thead>
<tbody>
<tr>
<td>output elast.</td>
<td>$\sigma_y$</td>
<td>0.01</td>
</tr>
<tr>
<td>discount factor</td>
<td>$\beta$</td>
<td>0.98</td>
</tr>
<tr>
<td>depreciation rate</td>
<td>$\delta$</td>
<td>0.14</td>
</tr>
<tr>
<td>labor share</td>
<td>$1 - m_s$</td>
<td>0.39</td>
</tr>
<tr>
<td>output shares</td>
<td>$\omega_s$</td>
<td>0.11</td>
</tr>
<tr>
<td>initial capital</td>
<td>$K_{s0}$</td>
<td>0.21</td>
</tr>
<tr>
<td>initial TFP</td>
<td>$A_{s0}$</td>
<td>4.94</td>
</tr>
</tbody>
</table>

Trends:

$$\gamma \frac{P_s}{P_{s'}} = \frac{1}{1 - m_s} \left( \gamma A_s + \alpha_s \gamma A_{xs} \right)$$

<table>
<thead>
<tr>
<th></th>
<th>agriculture</th>
<th>manufacturing</th>
<th>services</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma A_s$</td>
<td>0.94%</td>
<td>1.28%</td>
<td>0.41%</td>
</tr>
<tr>
<td>$\gamma A_{xs}$</td>
<td>1.51%</td>
<td>2.56%</td>
<td>4.85%</td>
</tr>
</tbody>
</table>
Calibration
Model fit on targets: relative prices

solid: data; striped: model.
Calibration
Model fit on non-targets: structural change

solid: data; striped: model.

![Graph showing employment and log output per worker](image-url)
What is the role of CETC for structural change?

Exogenous driving forces of structural change:

1. factor neutral productivity growth: sectoral $\gamma A_s$.
2. CETC: sectoral $\gamma A_{xs}$.
3. Acemoglu & Guerrieri: sectoral $m_s$.

- Counterfactual 1: **Only factor neutral.**
  - $\gamma A_{xs} = 0$ & identical $m_s$ (=0.33).
- Counterfactual 2: **Only CETC & sectoral $m_s$.**
  - identical $\gamma A_s$ (=1.25%).
What is the role of CETC for structural change?
Change between 1948 and 2020, %

Prices of sectoral output relative to manufacturing.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Data</th>
<th>Model</th>
<th>Factor neutral</th>
<th>CETC &amp; sectoral $m_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-67.78</td>
<td>-65.92</td>
<td>24.67</td>
<td>-79.21</td>
</tr>
<tr>
<td>Services</td>
<td>141.79</td>
<td>166.32</td>
<td>83.88</td>
<td>43.42</td>
</tr>
</tbody>
</table>
What is the role of CETC for structural change?

Change between 1948 and 2020, %

Employment shares.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Data</th>
<th>Model</th>
<th>Factor neutral</th>
<th>CETC &amp; sectoral $m_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-4.24</td>
<td>-4.36</td>
<td>-1.15</td>
<td>-4.42</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>-31.05</td>
<td>-19.22</td>
<td>-12.66</td>
<td>-6.53</td>
</tr>
<tr>
<td>Services</td>
<td>35.28</td>
<td>23.58</td>
<td>13.80</td>
<td>10.94</td>
</tr>
</tbody>
</table>

Capital-embodied structural change accounts for:

- 88% of the movement out of agriculture.
- 27% of the movement out of manufacturing.
- 37% of the movement into services.
Conclusion and next steps

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

2. Productivity differentials across sectors may be (endogenously) changing:
   → Importance of the composition and timing of sectorial investment.
   → Implications for Baumol cost’s disease?

3. Next steps.
   - Results for the model with time-movement in labor shares.
   - Build time-series evidence for other countries (noticeably South Korea).
Appendix
Relative prices and CETC

Services

\[
\gamma \frac{P_{s}}{P_{s}'} \approx \left( \gamma \tilde{A}_{s} - \gamma \tilde{A}_{s} \right) + \sum_{j} \left( \frac{\alpha_{s't}}{1 - \alpha_{s't}} \kappa_{js't} - \frac{\alpha_{st}}{1 - \alpha_{st}} \kappa_{jst} \right) \gamma A_{xjt}
\]

CETC

Py, services to manufacturing  CETC manufacturing to services.
Constant share: \( 1 - \alpha \) set to Herrendorf, et.al. (2015).
\[ \gamma Y_s = \frac{1}{1 - \alpha_s} (\gamma_{A_s} + \alpha_s \gamma_{A_{xs}}). \]

<table>
<thead>
<tr>
<th>Sector</th>
<th>( \gamma_{A_s} )</th>
<th>( \gamma_{A_{xs}} )</th>
<th>( \alpha_s, BEA )</th>
<th>( \alpha_s \gamma_{A_{xs}} )</th>
<th>( \gamma_{A_s} + \alpha_s \gamma_{A_{xs}} )</th>
<th>CETC/Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3.37</td>
<td>3.49</td>
<td>0.74</td>
<td>2.58</td>
<td>5.95</td>
<td>43</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>2.23</td>
<td>5.26</td>
<td>0.40</td>
<td>2.10</td>
<td>4.33</td>
<td>49</td>
</tr>
<tr>
<td>Services</td>
<td>0.34</td>
<td>7.27</td>
<td>0.50</td>
<td>3.64</td>
<td>3.98</td>
<td>91</td>
</tr>
</tbody>
</table>
Evidence for the US
Accounting exercise: 1986-2004

\[ \gamma Y_s = \frac{1}{1 - \alpha_s} (\gamma A_s + \alpha_s \gamma A_{xs}). \]

<table>
<thead>
<tr>
<th>Sector</th>
<th>(\gamma A_s)</th>
<th>(\gamma A_{xs})</th>
<th>(\alpha_s, B E A)</th>
<th>(\alpha_s \gamma A_{xs})</th>
<th>(\gamma A_s + \alpha_s \gamma A_{xs})</th>
<th>CETC/Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3.37</td>
<td>3.49</td>
<td>0.74</td>
<td>2.58</td>
<td>5.95</td>
<td>43</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>2.23</td>
<td>5.26</td>
<td>0.40</td>
<td>2.10</td>
<td>4.33</td>
<td>49</td>
</tr>
<tr>
<td>Services</td>
<td>0.34</td>
<td>7.27</td>
<td>0.50</td>
<td>3.64</td>
<td>3.98</td>
<td>91</td>
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</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>(\gamma A_s)</th>
<th>(\gamma A_{xs})</th>
<th>(\alpha_s, K L E M S)</th>
<th>(\alpha_s \gamma A_{xs})</th>
<th>(\gamma A_s + \alpha_s \gamma A_{xs})</th>
<th>CETC/Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3.37</td>
<td>3.49</td>
<td>0.53</td>
<td>1.87</td>
<td>5.23</td>
<td>36</td>
</tr>
<tr>
<td>Manufacturing</td>
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<td>0.65</td>
<td>3.41</td>
<td>5.64</td>
<td>60</td>
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<tr>
<td>Services</td>
<td>0.34</td>
<td>7.27</td>
<td>0.34</td>
<td>2.48</td>
<td>2.83</td>
<td>88</td>
</tr>
</tbody>
</table>
Optimal allocations: Structural change

- $C_t$: CES sectoral goods aggregator with elasticity $\sigma_y < 1$.
- Log-preferences in consumption, $\ln(C_t)$.
- Labor allocation:

\[
\frac{N_{st}}{N_{s't}} = \frac{\omega_s}{\omega_{s'}} \left( \frac{1 - \alpha_{st}}{1 - \alpha_{s't}} \right)^{\sigma_y} \left( \frac{Y_{st}/N_{st}}{Y_{s't}/N_{s't}} \right)^{\sigma_y-1},
\]

\[
= \frac{\omega_s}{\omega_{s'}} \left( \frac{b_{st}^n (\rho-1)}{b_{s't}^n (\rho-1)^{\frac{1}{\rho}}} \right)^{(\sigma_y-1)} \left( \frac{\tilde{y}_{st}}{\tilde{y}_{s't}} \right)^{\sigma_y (1-\rho)-1},
\]

for $b_{st}^n = ((1 - m_{st}) Z_{st}^{-1})^{\frac{1-\rho}{\rho}}$ and $\tilde{y}_{st} = \frac{Y_{st}}{N_{st} b_{st}^n (\rho-1)}$ or de-trended output per worker.
Along the transition: identification
Share of mechanized activities $m_{st}$.

**blue:** agriculture; **red:** manufacturing; **green:** services.
Along the transition: identification
Decomposition of changes in the labor share (LS).

<table>
<thead>
<tr>
<th></th>
<th>$\sigma^*$</th>
<th>CETC</th>
<th>change in $m$</th>
<th>change in LS</th>
<th>change in LS with no CETC</th>
<th>constant $m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>1.58</td>
<td>1.51</td>
<td>61.40</td>
<td>-7.58</td>
<td>13.96</td>
<td>23.60</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.8</td>
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<td>21.58</td>
<td>-11.98</td>
<td>-31.50</td>
<td>5.57</td>
</tr>
<tr>
<td>Services</td>
<td>0.75</td>
<td>4.85</td>
<td>25.82</td>
<td>2.95</td>
<td>-25.82</td>
<td>14.27</td>
</tr>
</tbody>
</table>

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 $m_{st}$.

The graph shows the share of mechanized activities from 1940 to 2020,
with the following trends:

- Blue line: agriculture
- Red line: manufacturing
- Green line: services

The ratios $s_1$, $s_2$, and $s_3$ are indicated on the graph.

** keto: agriculture; red: manufacturing; green: services.**
Along the transition: identification
Share of mechanized activities $m_{st}$.

blue: agriculture; green: services.
Along the transition: identification

Decomposition of changes in the labor share (LS).

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<th>change in LS</th>
<th>change in LS with no CETC</th>
<th>constant $m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.82</td>
<td>1.51</td>
<td>-2.95</td>
<td>-7.58</td>
<td>-16.73</td>
<td>-11.22</td>
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<td>Manufacturing</td>
<td>0.82</td>
<td>2.56</td>
<td>20.53</td>
<td>-11.98</td>
<td>-29.19</td>
<td>5.06</td>
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<tr>
<td>Services</td>
<td>0.82</td>
<td>4.85</td>
<td>15.26</td>
<td>2.95</td>
<td>-15.26</td>
<td>11.38</td>
</tr>
</tbody>
</table>

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

solid: data; striped: model

(a) employment

(b) nominal expenditures
What is the role of CETC for structural change?
Change between 1948 and 2020, %

Relative prices to manufacturing.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Data</th>
<th>Model</th>
<th>Factor neutral</th>
<th>CETC &amp; sectoral $m_s$</th>
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</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-67.78</td>
<td>-65.92</td>
<td>24.67</td>
<td>-79.21</td>
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<td>Services</td>
<td>141.79</td>
<td>166.32</td>
<td>83.88</td>
<td>43.42</td>
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</table>

Employment shares.

<table>
<thead>
<tr>
<th>Sector</th>
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<th>CETC &amp; sectoral $m_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-4.24</td>
<td>-4.36</td>
<td>-1.15</td>
<td>-4.42</td>
</tr>
<tr>
<td>Manufacturing</td>
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<td>-19.22</td>
<td>-12.66</td>
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<tr>
<td>Services</td>
<td>35.28</td>
<td>23.58</td>
<td>13.80</td>
<td>10.94</td>
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</table>

Nominal expenditure shares.

<table>
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<th>Sector</th>
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<th>Model</th>
<th>Factor neutral</th>
<th>CETC &amp; sectoral $m_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
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<td>-7.71</td>
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<td>Services</td>
<td>30.73</td>
<td>25.72</td>
<td>13.80</td>
<td>12.57</td>
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