Technology and Structural Transformation

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Motivation

Structural Transformation

• Reallocation of production factors across broad sectors

• As economies develop,
  ◦ agriculture shrinks
  ◦ manufacturing first grows and then shrinks
  ◦ services grow
Sectoral Employment Shares – Ten Developed Countries 1800–2000

Agriculture

Manufacturing

Services

Log of GDP per capita (1990 international $)

Share in total employment

Herrendorf, Herrington, Valentinyi
Our Research Question:

What are the Economic Forces behind Structural Transformation?

- **Herrendorf, Rogerson, Valentinyi (AER, 2013): Forces coming from preferences**
  - Income effects
  - Substitution effects

- **This paper: Forces coming from technology**
  - Factor shares
  - Factor substitutability
  - Technological progress
These features of sectoral technology influence

- Sectoral labor allocation
- Relative price of sectoral output
- For example, ceteris paribus, sector with higher labor share gets more labor
Our Contribution

- We estimate CES and Cobb–Douglas (CD) technologies on postwar US data
  - CES: Factor shares, factor substitutability and technical progress shape ST
  - CD with unequal factor shares: factor shares and technical progress shape ST
  - CD with equal factor shares: technical progress shapes ST

- We compare the implied labor allocations and relative prices with those in US data

- We find that
  - CD production functions with equal factor shares capture essence of secular trends
  - Differences in sectoral technical change are main technology force behind US ST
Digression on Production Functions

- In multi-sector models, sectors produce value added from capital, labor
- In the data, sectors produce gross output from capital, labor, intermediate inputs
- How do we connect the two approaches to each other?
Aggregate Production Function

- Closed economy
  - Gross output \( G \) is produced with capital, labour and intermediate inputs
  - Intermediate inputs are produced exclusively with domestic capital and labor

\[
G = H(K, L, Z)
\]

- Typical focus is on GDP which equals value added
- “Value–added” production function

\[
Y = G - Z = F(K, L)
\]
Open economy

- Gross output is produced with domestic capital, labor, domestic and imported intermediate inputs:
  \[ Y = H(K, L, Z) \]
- Imported intermediate inputs often abstracted from
Sectoral Production Functions

- Sectoral gross output is produced with capital, labor, and intermediate inputs:

$$ G_i = H_i(K_i, L_i, Z_i) $$

- $Z_i$ is a vector of intermediate inputs from all sectors

- But multi-sector models typically use value-added production functions:

$$ Y_i \equiv \frac{P_{gi}G_i - \sum_j P_{ij}Z_{ij}}{P_{yi}} = F_i(K_i, L_i) $$

- When do value-added production functions exist?
Existence of Value–added Production Functions

- Sato (REStud, 1976):
  1. Separability between capital/labor and intermediate inputs:
     \[ G_i = H_i(F_i(K_i, L_i), Z_i) \]
  2. Perfect competition
Equivalence result

• The same \((K_i^*, L_i^*)\) solves the following problems:

  **Gross–output problem**

  \[
  \min_{K_i, L_i, Z_i} R_i K_i + W_i L_i + \sum_j P_{ij} Z_{ij} \quad \text{s.t.} \quad H_i(F_i(K_i, L_i), Z_i) \geq G_i
  \]

  **Value–added problem**

  \[
  \min_{K_i, L_i} R_i K_i + W_i L_i \quad \text{s.t.} \quad F_i(K_i, L_i) \geq Y_i
  \]

• \((K_i^*, L_i^*)\) is independent of \(Z_i\)


Sufficient condition for separability

\[ G_i = \left[ F_i(K_i, L_i) \right]^{\eta_i} \left[ X_i(Z_i) \right]^{1-\eta_i} \]

Intermediate Input Shares in Sectoral Gross Outputs – Evidence

Source: Input-Output Tables for the United States, Bureau of Economic Analysis

Herrendorf, Herrington, Valentinyi
Summary

- The intermediate input shares in gross output do not show (strong) trends

- In what follows, we assume that sectoral value–added production functions exist

- We ask two questions
  - What are the properties of sectoral value–added production functions?
  - What roles do the features of sectoral production functions play for ST?
Estimating Production Functions

CES Functional Form

\[
F_i(K_{it}, L_{it}) = \left[ \alpha_i \left[ \exp(\gamma_{ik}t)K_{it} \right]^{\sigma_i^{-1}} + (1 - \alpha_i) \left[ \exp(\gamma_{il}t)L_{it} \right]^{\sigma_i^{-1}} \right]^{\sigma_i} \quad i \in \{a, m, s\}
\]

- **Features**
  - \(\sigma_i\) is elasticity of substitution between capital and labor
  - \(\gamma_{ik}, \gamma_{il}\) are growth rate of capital- and labor-augmenting technical progress
  - \(\alpha_i\) is a relative weight.
  - As \(\sigma_i \to 1\), we get the Cobb–Douglas production function:

\[
F_i(K_{it}, L_{it}) = \left[ \exp(\gamma_{ik}t)K_{it} \right]^{\alpha_i} \left[ \exp(\gamma_{il}t)L_{it} \right]^{1-\alpha_i}
\]
Léon–Ledesma et al (AER, 2010)

- Re-parameterization improves estimation
- Divide variables by their sample averages

\[ F_i(K_{it}, L_{it}) = \bar{Y}_i \left[ \bar{\theta}_i \left( \frac{\exp(\gamma_{ik}t)K_{it}}{\exp(\gamma\bar{t})\bar{K}_i} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \theta_i) \left( \frac{\exp(\gamma t)L_{it}}{\exp(\gamma_{il}\bar{t})\bar{L}_i} \right)^{\frac{\sigma_i-1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i-1}} \]

- \( \bar{\theta}_i \) and \( 1 - \theta_i \) are the geometric averages of the income shares of capital and labor, respectively

\[ \bar{\theta}_i = \alpha_i \left[ \exp(\gamma_{ik} \cdot \bar{t}) \frac{\bar{K}_i}{\bar{Y}_i} \right]^{\frac{\sigma_i-1}{\sigma_i}} \quad , \quad 1 - \theta_i = (1 - \alpha_i) \left[ \exp(\gamma_{il} \cdot \bar{t}) \frac{\bar{L}_i}{\bar{Y}_i} \right]^{\frac{\sigma_i-1}{\sigma_i}} \]

- \( \bar{Y}, \bar{K} \) and \( \bar{L} \) are the geometric averages of value added, capital and labor
- \( \bar{t} \) is arithmetic average of time index
System of Equations

- Perfect competition and profit maximization imply

\[
\log\left(\frac{Y_{it}}{\bar{Y}_i}\right) = \frac{\sigma_i}{\sigma_i - 1} \log \left[ \bar{\theta}_i \left( \exp(\gamma_{ik}(t - \tilde{t})) \frac{K_{it}}{K_i} \right)^{\frac{\sigma_i - 1}{\sigma_i}} + \left(1 - \theta_i\right) \left( \exp(\gamma_{il}(t - \tilde{t})) \frac{L_{it}}{L_i} \right)^{\frac{\sigma_i - 1}{\sigma_i}} \right] + \epsilon_{yit}
\]

\[
\log(r_{it}) = \log \left( \frac{\bar{\theta}_i Y_i}{\bar{K}_i} \right) + \frac{\sigma_i - 1}{\sigma_i} [\gamma_{ik}(t - \tilde{t})] + \frac{1}{\sigma_i} \log \left( \frac{Y_{it}}{K_{it}} \right) + \epsilon_{rit}
\]

\[
\log(w_{it}) = \log \left( \frac{(1 - \theta_i)\bar{Y}_i}{\bar{L}_i} \right) + \frac{\sigma_i - 1}{\sigma_i} [\gamma_{il}(t - \tilde{t})] + \frac{1}{\sigma_i} \log \left( \frac{Y_{it}}{L_{it}} \right) + \epsilon_{wit}
\]

- Three equations for aggregate economy

- Nine equations for three–sector economy
Estimation procedure

- Observe $Y_{it}/\bar{Y}_i$, $K_{it}/\bar{K}_i$, $L_{it}/\bar{L}_i$, $r_{it}$, $w_{it}$, $\theta_i (1 - \theta_i)$
  - Calculate factor payments as factors shares times value added
  - Calculate rental prices as factor payments divided by factor quantity

- Estimate $\sigma_i$, $\gamma_i$, and $\xi_i$ with Cochrane–Orcutt procedure
  - Three–stage least squares
  - AR(1) error structure
    \[ \epsilon_{jit} = \rho_{ji} \epsilon_{jit-1} + \nu_{jit} \]
  - One–period lagged variables as instruments
Data

- **Value Added**
  - BEA’s “Industry Tables”
    - Value added at current prices by industries
    - Quantity index of value added by industries
  - Sectors
    - Agriculture: farms, fishing, forestry
    - Manufacturing: construction, manufacturing, mining
    - Services: rest (i.e. education, real estate, trade, transportation, government etc.)

- **Labor input**
  - Hours worked per persons engaged
• Capital share in value added
  ○ BEA’s “Industry Tables”
    ◦ “Compensation of employees” is labor income
    ◦ “Rent paid to nonoperator landlords” is capital income
    ◦ “Gross operating surplus minus proprietors’ income” is capital income
    ◦ Proprietors’ income split into capital and labor income according to above shares

• Capital input
  ○ BEA’s “Fixed Asset Tables”
    ◦ Year–end current cost and quantity index of net stock of fixed assets
    ◦ Real capital stock geometric average of current and previous real fixed assets
  ○ Farm Land
    ◦ Adding value of farm land from the USDA to fixed assets in agriculture using rates of returns as weights
Estimation Results

CES

Table 1: Estimation Results

<table>
<thead>
<tr>
<th></th>
<th>Aggregate</th>
<th>Agriculture</th>
<th>Manufacturing</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma )</td>
<td>0.84**</td>
<td>1.58**</td>
<td>0.80**</td>
<td>0.75**</td>
</tr>
<tr>
<td></td>
<td>(0.041)</td>
<td>(0.068)</td>
<td>(0.015)</td>
<td>(0.020)</td>
</tr>
<tr>
<td>( \gamma_k )</td>
<td>–0.010</td>
<td>0.023**</td>
<td>–0.045**</td>
<td>–0.002</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.003)</td>
<td>(0.009)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>( \gamma_l )</td>
<td>0.022**</td>
<td>0.050**</td>
<td>0.044**</td>
<td>0.016**</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.004)</td>
<td>(0.007)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>( \bar{\theta} )</td>
<td>0.33</td>
<td>0.61</td>
<td>0.29</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Standard errors in parentheses; ** \( p < 0.01 \)
Summary of CES estimation results

- Technological progress
  - Labor–augmenting technical progress fastest in agriculture, slowest in services
  - Capital–augmenting technical progress is positive in agriculture, negative in manufacturing, and not significantly different from zero in services

- Elasticity of substitution
  - most substitutable in agriculture, least substitutable in services
  - more substitutable than Cobb–Douglas in agriculture
    (consistent with view that mechanization led to substitution of capital for labor)
  - less substitutable than Cobb–Douglas in manufacturing and services
CES versus Cobb–Douglas production functions

\[ F_i(K_{it}, L_{it}) = \left[ \bar{\theta}_i (A_{ikt} K_{it})^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - \theta_i) (A_{ilt} L_{it})^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}} \]  

(1)

\[ F_i(K_{it}, L_{it}) = (A_{ikt} K_{it})^{\alpha_i} (A_{ilt} L_{it})^{1 - \bar{\theta}_i} \]  

(2)

\[ F_i(K_{it}, L_{it}) = (A_{ikt} K_{it})^{\alpha} (A_{ilt} L_{it})^{1 - \alpha} \]  

(3)
Estimation

- (1)
  - set $\bar{\theta}_i$ and $1 - \theta_i$ equal to the geometric averages of sectoral capital and labour shares
  - estimate $\gamma_{ki}$, $\gamma_{li}$, $\sigma_i$ from nine-equation system

- (2)
  - set $\alpha_i$ equal to the arithmetic average of the sectoral capital shares
  - estimate $\gamma_i$ from three-output-equations system

- (3)
  - set $\alpha_i$ equal to the arithmetic average of the aggregate capital shares
  - estimate $\gamma_i$ from three-output-equations system
### Estimation Results for Cobb Douglas

#### Average Annual Growth Rates of TFP (in %)

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>CD with $\alpha_i$</td>
<td>1.1</td>
<td>3.3</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>CD with $\alpha$</td>
<td>1.1</td>
<td>3.9</td>
<td>1.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Sectoral Technology and Structural Transformation
Exercise 1: Implied Sectoral Labor Allocations

- Take output and factor price ratio $r/w$ as given
- Assume that firms behave competitively when choosing capital and labor
- Plot the implied labor allocation across sectors

\[
L_{it} = \left( \frac{\bar{\theta}_i}{1 - \theta_i} \frac{A_{ikt} w_{it}}{A_{ilt} r_{it}} \right)^{1-\sigma_i} \frac{Y_{it}}{A_{ilt}}
\]

\[
L_{it} = \left( \frac{\alpha_i}{1 - \alpha_i} \frac{A_{ikt} w_{it}}{A_{ilt} r_{it}} \right)^{-\alpha_i} \frac{Y_{it}}{A_{ilt}}
\]

\[
L_{it} = \left( \frac{\alpha}{1 - \alpha} \frac{A_{ikt} w_{it}}{A_{ilt} r_{it}} \right)^{-\alpha} \frac{Y_{it}}{A_{ilt}}
\]
• **Cobb Douglas**
  - \([\alpha_i/(1 - \alpha_i)]^{-\alpha_i}\)
    - sector with larger capital share receives less labor
  - \([((A_{ikt}w_{it})/(A_{ilt}r_{it}))^{-\alpha_i}]\):
    - increase in \(r/w\) implies decrease in capital–labor ratio and increase in labor
    - these changes are larger when the capital share is larger

• **CES**
  - **Additional substitution effect**
    - \(\sigma_i > 1\)
      - increase in \(r/w\) implies larger reduction of capital–labor ratio and larger increase in labor
    - \(\sigma_i < 1\)
      - increase in \(r/w\) implies smaller reduction in capital–labor ratio and a smaller increase in labour
Technology and Structural Transformation

Hours worked
CES
Data=1 in 1948

Data
Model

Agriculture
Manufacturing
Services

Herrendorf, Herrington, Valentinyi
Hours worked
Cobb Douglas with unequal factor shares
Data=1 in 1948

Herrendorf, Herrington, Valentinyi
Hours worked
Cobb Douglas with equal factor shares
Data=1 in 1948
• All three functional forms capture main secular changes in sectoral hours worked
  ○ Differences in relative weights and substitution elasticities largely cancel each other
    ♦ Agriculture: high $\bar{\theta}_a$ and high $\sigma_a$
    ♦ Manufacturing: small $\bar{\theta}_m$ and small $\sigma_m$
  ○ Uneven technical progress dominating force behind structural transformation
Exercise 2: Implied relative prices

- Cost minimization implies for the price of sector $i$ relative to services

$$P_{it} = P_{it} = \frac{W_{it}}{W_{st}} \frac{MPL_{st}}{MPL_{it}}$$

- Nominal wages are observed
- Marginal products are implied by observed variables and model
Relative prices
CES
Sector price relative to manufacturing = 1 in 1948

Data
Model

Agriculture
Services
Relative prices
Cobb-Douglas with unequal factor shares
Sector price relative to manufacturing = 1 in 1948

Data
Model
Services
Agriculture
Relative prices
Cobb-Douglas with equal factor shares
Sector price relative to manufacturing=1 in 1948
Digression

Implications for Building Multi–sector Models

Aim: Want to use our estimated production functions in multi–sector models

Problem: Marginal value products not equalized in the data
What to do?

- Need to model reason for difference in marginal value products
- Capital: differences in unmeasured capital
- Labor: differences in human capital
Conclusion

- How important for structural transformation are sectoral differences in
  - technical progress
  - substitution elasticity
  - capital intensity?

- Differences in technical progress, particularly, labor–augmenting technical progress, are predominant force behind US structural transformation

- Sectoral Cobb–Douglas production functions with equal capital shares capture main trends of US structural transformation
Defensive Slides

Labor input

- Needed are hours worked per persons engaged according to NAICS
    - Hours worked by full and part–time employees by industry
    - Full and part–time employees by industry
    - Full–time equivalent employees by industry
    - Self–employed persons by industry
    - Persons engaged in production by industry (this is the sum of full–time equivalent employees and self–employed)
  - BEA’s “GDP–by–Industry” tables 1947–2010
    - Full and part–time employees by industry
    - Classification: NAICS
Construction of sectoral hours worked by persons engaged according to NAICS

\[
\text{Self–emp}_{NAICS} = \frac{\text{Self–emp}_{SIC}}{\text{Part– and full–time emp}_{SIC}} \times \frac{\text{Part & full–time emp}_{NAICS}}{\text{Part & full–time emp}_{SIC}}
\]

\[
\text{Full–time eq emp}_{NAICS} = \frac{\text{Full–time eq emp}_{SIC}}{\text{Part & full–time emp}_{SIC}} \times \frac{\text{Part & full–time emp}_{NAICS}}{\text{Part & full–time emp}_{SIC}}
\]

\[
\text{Hours full–time eq emp}_{NAICS} = \frac{\text{Hours full–time eq emp}_{SIC}}{\text{Full–time eq emp}_{SIC}} \times \frac{\text{Full–time eq emp}_{NAICS}}{\text{Full–time eq emp}_{SIC}}
\]

\[
\text{Hours persons engaged}_{NAICS} = \text{Hours full–time eq emp}_{NAICS} + \frac{\text{Hours full–time eq emp}_{NAICS} \times \text{Self–emp}_{NAICS}}{\text{Full–time eq emp}_{NAICS}}
\]