Lecture 3: Key Theories of Structural Transformation

STEG Lecture Series on
Key Concepts in Macro Development

Berthold Herrendorf
Arizona State University and CEPR
February 2021
Teaching Assistant: Santiago Garcia-Couto

- PhD student at ASU; will join Georgetown-Qatar in the summer.
- santiago.garcia-couto@asu.edu

Tutorial Session

- Monday, February 22, 4:00 pm UK time.
- Send questions by Sunday 8:00 pm UK time.
- Problem set, which is at the end of the slides.
Key Background Paper

- Herrendorf, Rogerson & Valentinyi:

  “Growth and Structural Transformation” (Handbook of Economic Growth 2014)

Outline

1. Introduction

2. The Stylized Facts of Structural Transformation

3. Background: A Two–Sector Version of the Growth Model

4. A Benchmark Model of Structural Transformation

5. Conclusion
1 Introduction

Structural Transformation (ST)

• ST is the reallocation of economic activity across broad sectors.

• Kuznets listed ST as a key feature of modern economic growth.

• Typical sector split
  ○ agriculture: tangible edible output;
  ○ manufacturing: tangible non-edible output (exception processed food);
  ○ services: intangible output.

• ST has important aggregate implications when sectoral composition matters: labor market outcomes, productivity, skill premium, urbanization etc.
Models with Balanced Growth and Structural Transformation

• I first present the stylized facts of structural transformation.

• I then develop a multi-sector extension of the one-sector growth model that
  ◦ is consistent with the stylized facts;
  ◦ serves as a natural benchmark model to study structural transformation.

• Lastly, I ask whether it is possible to simultaneously deliver balanced growth and ST.
2 The Stylized Facts of ST

2.1 How to Measure ST

- The three most common measures of sectoral economic activity are: employment, value added, and final expenditures.

- Employment shares are calculated either by using workers or hours worked by sector, depending on data availability.

- Value added shares and final consumption expenditure shares are typically expressed in current prices (“nominal shares”).

- There are at least two reasons for differences among these measures:
  - investment and trade imply that production and consumption measures differ;
  - value added is a distinct concept from final expenditure.
Background: Some Basic Concepts

- **Industries**: collections of establishments that produce similar goods or services.
  - Establishments produce (gross) output from capital, labor and intermediate goods.
  - Establishments sell output to final uses, other establishments, or themselves.

- **Sectors**: aggregates of industries with similar characteristics.

- **Value added**: value of gross output minus value of intermediate inputs.

- **Final expenditures**: gross output delivered to final uses.
  - Final expenditure are a composite of value added from different sectors.
  - Total requirement matrix gives the composition
    (like in Herrendorf, Rogerson & Valentinyi, AER, 2013).
2.2 Production Measures of ST
**Sectoral Employment Shares – Currently Rich Countries 1800–2000**

**Sectoral Value-Added Shares – Currently Rich Countries 1800–2000**
Sectoral Employment Shares – Cross Sections of WDI 1980–2000

Sectoral Value-Added Shares – Cross Sections of UN National Accounts 1975–2005
Summary: Stylized Facts

- When GDP per capita increases, the shares of employment and nominal value added
  - decrease in agriculture;
  - increase in services;
  - follow a hump shape in manufacturing.

- For low levels of development the value added share in agriculture is considerably lower than the employment share (i.e., agriculture is relatively unproductive).

- The employment share and the nominal value added share for the service sector are bounded away from zero even at very low levels of development.

- For a log of GDP per capita around 9
  - the increase in the nominal value added share in services accelerates;
  - the nominal value added share for manufacturing peaks.
3 Background: A Two–Sector Version of the Growth Model

- We start by developing the standard two–sector model with consumption and investment.

- This model goes back to Uzawa (REStud, 1963).

- We present a version building on Greenwood, Hercowitz & Krusell (AER, 1997).
3.1 Environment

Preferences and Endowments

- Infinitely lived representative household.

- Preferences over consumption sequences are described by the utility function

\[
\sum_{t=0}^{\infty} \beta^t \log C_t
\]  

(1)

where \(0 < \beta < 1\) is the discount factor.

- Endowments: one unit of time in each period; positive initial stock of capital, \(K_0 > 0\).
Technology

- Consumption ($C$) and investment ($X$) are produced from capital ($k$) and labor ($n$).

- We use upper–case (lower–case) letters to refer to aggregate (sectoral) variables.

- Production takes place in two separate sectors.

- The production functions are Cobb–Douglas with the same exponents:

  \[ C_t = k_{ct}^{\theta}(A_{ct}n_{ct})^{1-\theta} \]
  \[ X_t = k_{xt}^{\theta}(A_{xt}n_{xt})^{1-\theta} \]

- Changes in $A_{it}$ represent exogenous labor–augmenting technological progress in sector $i$.  

Capital Accumulation and Feasibility

- Capital accumulates as usual:

\[ K_{t+1} = (1 - \delta)K_t + X_t \]

where \(0 < \delta < 1\) is the depreciation rate.

- We assume capital and labor can be used in both sectors, implying that feasibility requires:

\[ K_t \geq k_{ct} + k_{xt} \]
\[ 1 \geq n_{ct} + n_{xt} \]
3.2 Competitive Equilibrium

- We want to emphasize the role of relative prices. Therefore we consider a sequence-of-markets competitive equilibrium.
- The investment good is the numeraire (i.e., it’s price equals one in each period).
- The price of the consumption good relative to the investment good is denoted by $P_t$.
- The rental rates for capital and labor are denoted by $R_t$ and $W_t$.
- We assume that the household accumulates capital and rents it to firms.
Characterization of Equilibrium

- Capital–to–labor ratios are equalized across sectors at each point in time:

\[
\frac{k_{ct}}{n_{ct}} = \frac{k_{xt}}{n_{xt}} = \frac{K_t}{N_t} = K_t
\]

- The equilibrium value of the relative price is pinned down by technology:

\[
P_t = \left( \frac{A_{xt}}{A_{ct}} \right)^{1-\theta}
\]

- The model aggregates on the production side:

\[
Y_t = X_t + P_tC_t = K_t^\theta A_{xt}^{1-\theta}
\]
• The sectoral expenditure shares equal the sectoral employment shares:

\[
\frac{p_t c_t}{Y_t} = \frac{n_{ct}}{N_t}
\]

• The Euler equation results from the household problem:

\[
\frac{p_t c_t}{p_{t-1} c_{t-1}} = \beta (1 - \delta + R_{t+1})
\]
• Aggregate Balanced Growth Path (ABGP):
The Kaldor facts hold for aggregate variables, that is,
  ◦ constant growth of GDP pc and capital pc
  ◦ constant capital-GDP ratio, real interest rate, capital share

• Assume constant sectoral TFP growth

\[
\frac{A_{it+1}}{A_{it}} = 1 + \gamma_i, \quad i = c, x
\]

**Proposition 1.** A unique ABGP exists.
4 A Benchmark Model of Structural Transformation

4.1 Preferences

- I will present three classes of preferences that generate ST.

- I will then assess whether they are consistent with ABGP.
Generalized Stone-Geary from Herrendorf, Rogerson & Valentinyi (AER, 2013)

\[ C_t = \left[ \omega_a \frac{c_{at}}{\bar{c}_a} \left( \frac{c_{at}}{\bar{c}_a} \right)^{-1} + \omega_m \frac{c_{mt}}{\bar{c}_m} \left( \frac{c_{mt}}{\bar{c}_m} \right)^{-1} + \omega_s \frac{c_{st}}{\bar{c}_s} \left( \frac{c_{st}}{\bar{c}_s} \right)^{-1} \right]^\frac{1}{\varepsilon} \]

- Implied demand system:

\[
\frac{p_{at} c_{at}}{p_{mt} c_{mt}} = \frac{\omega_a}{\omega_m} \left( \frac{p_{at}}{p_{mt}} \right)^{1-\varepsilon} + \frac{p_{at} \bar{c}_a}{p_{mt} c_{mt}}
\]

\[
\frac{p_{st} c_{st}}{p_{mt} c_{mt}} = \frac{\omega_s}{\omega_m} \left( \frac{p_{st}}{p_{mt}} \right)^{1-\varepsilon} - \frac{p_{st} \bar{c}_s}{p_{mt} c_{mt}}
\]
Non-homothetic CES from Comin, Lashkari & Mestieri (R&R^4 ECTRA, 2020)

\[
C_t = \left[ \frac{1}{\omega_a} C_t^{\sigma_a+(\varepsilon-1)} (c_{at})^\frac{\varepsilon-1}{\varepsilon} + \frac{1}{\sigma_m} (c_{mt})^\frac{\varepsilon-1}{\varepsilon} + \frac{1}{\omega_s} C_t^{\sigma_s+(\varepsilon-1)} (c_{st})^\frac{\varepsilon-1}{\varepsilon} \right]^\frac{\varepsilon}{\varepsilon-1}
\]

- Implied demand system:

\[
\frac{p_{it}c_{it}}{p_{jt}c_{jt}} = \frac{\omega_i}{\omega_j} \left( \frac{p_{it}}{p_{jt}} \right)^{1-\varepsilon} C_t^{\sigma_i-\sigma_j}
\]
PIGL preferences from Boppart (ECTRA, 2014)

- PIGL stands for Price-independent-generalized-linearity:

\[ V(E_t, P_{gt}, P_{st}) = \frac{1}{\chi} \left( \frac{E_t}{P_{st}} \right)^{\chi} - \frac{\nu}{\gamma} \left( \frac{P_{gt}}{P_{st}} \right)^{\gamma} - \frac{1}{\chi} + \frac{\nu}{\gamma} \]

where \( E_t \) is expenditures.

- Implied demand system:

\[ \frac{P_{gt}C_{gt}}{E_t} = \nu \left( \frac{P_{gt}}{P_{st}} \right)^{\gamma} \left( \frac{E_t}{P_{st}} \right)^{-\chi} \]

- Alder, Mueller & Boppart (AEJ: Macro, 2021) generalize PIGL to many goods.
4.2 Technology

- Cobb–Douglas production functions with equal exponents:

\[
c_{it} = k_{it}^\theta (A_{it} n_{it})^{1-\theta}, \quad i \in \{a, m, s\}
\]

\[
X_t = k_{xt}^\theta (A_{xt} n_{xt})^{1-\theta}
\]

- Generalizations
  - Acemoglu & Guerrieri (JPE, 2008):
    generate ST with Cobb-Douglas production functions with different exponents.
  - Herrendorf, Herrington & Valentinyi (AEJ: Macro, 2015):
    estimate CES production functions when substitution elasticity is not one.
  - Alvarez-Cuadrado & Poschke (TE, 2017):
    generate ST with CES production functions.
Remarks

• The literature often works with only three production functions, assuming all investment is produced by the manufacturing sector.

• This specification is not supported by the data; e.g., U.S. investment exceeds value added of U.S. manufacturing.

• I have therefore left investment separate so that ST happens only within consumption.

• Recent work on ST within investment:
  ○ Herrendorf, Rogerson & Valentinyi (REStud, 2021): along ABGP.
4.3 Feasibility Conditions

\[ K_t \geq k_{at} + k_{mt} + k_{st} + k_{xt} \]

\[ 1 \geq n_{at} + n_{mt} + n_{st} + n_{xt} \]
4.4 Equilibrium Properties of the Benchmark Model

Key properties from before also hold in the four-sector model

- The capital-to-labor ratios equal the aggregate capital-to-labor ratio.
- Relative prices are determined by technology.
- The four-sector model aggregates on the production side.
- The sectoral employment shares equal the sectoral expenditure shares.
Breaking the household’s problem into two subproblems

\[
\max_{\{c_{at}, c_{mt}, c_{st}, K_{t+1}\}} \sum_{t=0}^{\infty} \beta^t \log C(c_{at}, c_{mt}, c_{st}) \\
\text{s.t. } p_{at}c_{at} + p_{mt}c_{mt} + p_{st}c_{st} + K_{t+1} = (1 - \delta + R_t)K_t + W_t
\]

(i) Intertemporal Problem
Allocate total income among the composite consumption good and savings

(ii) Static Problem
Allocate the period t consumption expenditure \(P_tC_t\) among the consumption goods
4.5 Key Results

**Proposition 2.** (Kongsamut, Rebelo & Xie, REStud 2001 – “Income Effects”) 

- Suppose that $\gamma_i = \gamma > 0$ and that utility is Stone-Geary ($\varepsilon = 1$):

  $$C_t = \omega_a \log (c_{at} - \bar{c}_a) + \omega_m \log (c_{mt}) + \omega_s \log (c_{st} + \bar{c}_s)$$

- There is an ABGP along which the employment and expenditure shares
  - are constant for investment;
  - decrease for agriculture; increase for services; are constant for manufacturing.

• Suppose that \( \gamma_a > \gamma_m > \gamma_s \), \( \bar{c}_a = \bar{c}_s = 0 \), and \( \varepsilon \in [0, 1) \):

\[
C_t = \left[ \omega_a \varepsilon^{\frac{\varepsilon-1}{\varepsilon}} c_{at} + \omega_m \varepsilon^{\frac{\varepsilon-1}{\varepsilon}} c_{mt} + \omega_s \varepsilon^{\frac{\varepsilon-1}{\varepsilon}} c_{st} \right]^{\frac{\varepsilon}{\varepsilon-1}}
\]

• There is an ABGP along which the employment and expenditure shares
  ◦ are constant for investment;
  ◦ decrease for agriculture; increase for services
    lie between the other two shares for manufacturing.
4.6 Additional Results

Non-homothetic CES from Comin, Lashkari & Mestieri (R&R$^4$ ECTRA, 2021)

- Persistent income effects and usual relative-price effects.
- Replicates agricultural and services shares over long horizons.
- Asymptotic ABGP.
Generalized PIGL from Alder, Mueller & Boppart (AEJ: Macro 2021)

- Persistent income effects and usual relative-price effects.
- Replicates all shares (including hump shape of manufacturing) over long horizons.
- ABGP.
5. Conclusion

• There are clear stylized facts of structural transformation:
  ◦ agriculture shrinks;
  ◦ manufacturing follows a hump shape;
  ◦ services expand.

• There are two main forces behind structural transformation:
  ◦ relative prices change with low elasticity of substitution:
    sector with low (high) productivity growth expands (contracts);
  ◦ income changes with different income elasticities:
    luxuries expand and necessities contract.

• CES and PIGL utility generate these forces and are consistent with ABGP.
Problem Set

Kongsamut-Rebelo-Xie Economy

- Intertemporal utility over total consumption:

\[
\sum_{t=0}^{\infty} \beta^t \log C_t
\]

where \( \beta \in (0, 1) \) is the discount factor.

- Intratemporal utility over agriculture, manufacturing, and services consumption:

\[
C_t = \omega_a \log (c_{at} - \bar{c}_a) + \omega_m \log (c_{mt}) + \omega_s \log (c_{st} + \bar{c}_s)
\]

where \( \omega_i > 0, \omega_a + \omega_m + \omega_s = 1, \) and \( \bar{c}_a, \bar{c}_s > 0. \)
• Endowments in each period:
  ○ one unit of time;
  ○ a positive initial stock of capital, $K_0 > 0$.

• Capital accumulation:

$$K_{t+1} = (1 - \delta)K_t + X_t$$

(4)

where $\delta \in [0, 1]$ is the depreciation rate and $X_t \geq 0$ is investment.
• Cobb–Douglas production functions for each good:

\[ c_{it} = k_{it}^\theta (A_{it} n_{it})^{1-\theta}, \quad i \in \{a, m, s\} \tag{5} \]

\[ X_t = k_{xt}^\theta (A_{xt} n_{xt})^{1-\theta} \tag{6} \]

• Capital and labor can be used in both sectors.

• Feasibility:

\[ K_t \geq k_{at} + k_{mt} + k_{st} + k_{xt} \tag{7} \]

\[ 1 \geq n_{at} + n_{mt} + n_{st} + n_{xt} \tag{8} \]
Solve the Following Problems

• Define a sequence-of-markets equilibrium in this economy.

• Define an aggregate balanced growth path (ABGP) in this economy.

• Show that there is an ABGP.

• Show that along the ABGP the employment and expenditure shares
  - are constant for investment
  - decrease for agriculture
  - are constant for manufacturing
  - increase for services