Endogenous Structural Transformation in Economic Development

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Outline

Structural transformation in economic growth

- A sustained income growth per capita is a modern phenomenon, which arises only after the 18th century and resulted in the great divergence in the world (Pomeranz, 2001)
- To achieve dynamic income growth is a dream for every country, especially for developing countries, but only a few developing countries were able to realize this dream
- Kuznet (1966) identified that the economic growth in a country is accompanied, in addition to the increases of population and per capita income, by switching structural transformation in
  - Technology
  - Sector composition of industries
  - Ratio of rural urban population
  - Hard infrastructure
  - Social, economic, legal and political institution
  - Preference, value and identity

Literature and motivation

- Historical, empirical studies on structural transformation abound
  - The catching up process among European countries after the Industrial Revolution (Gerschenkron, 1962)
  - The Flying Geese pattern in Japan's and East Asian economic development (Akamatsu, 1962)
  - Rapid structural changes in dynamic growing economies (Commission on Growth and Development, 2008)
  - African Transformation Report (ACET, 2014)
  - Asian Transformation (Deepak Nayyar, 2019)
- Theoretical literature focuses mostly on technological innovation or changing sector composition with **a given structure**.
- The paper proposes a novel method to model **the structural transformation** in a market economy by combining optimal control and optimal switching to study the static and the dynamic equilibria of resource alloaction under a given structure and the structural equilibrium when the condition for structural transformation arises.

Attributes of economic structures

The overall structure and its constituent structure has the following three attributes.

- Structurality refers to the organic relationships of all the economic and noneconomic structures, each with specific characteristics, in the overall structure of an economy or society.
- Durationality means that the overall structure and each of its substructures in an economy will not change instantaneously and will have different levels of stability.
- Transformality means that a substructure or even the overall structure is not constant forever; it can transform into another structure under certain conditions during the process of economic development and growth.

Questions on *endogenous structural transformation* (EST)

- How to decouple structural and economic variables and represent economic activities in a neoclassical growth economy?
- What kinds of decisions to make for the social planner?
- How to characterize the relationship between structural transformation and competitive equilibrium?
- How to design stagewise development/growth models with different economic structures?
- How to incorporate structural changes of economic institutions, political regimes and institutions into the EST framework?

A neoclassical economy: Decoupling of structural and economic variables

Table: Representation of economic activities in a neoclassical growth economy

	Measurement	Characteristics
Households	$\mathcal{H} = \{$A number of households$\}$	$\mathscr{H} = \{$All are representative$\}$
Firms	$\mathcal{F} = \{$A number of firms$\}$	$\mathscr{F} = \{$All are representative$\}$
Production	$\mathcal{Y} = \{$Output level $Y(t)\}$	$\mathscr{Y} = \{Y(\cdot) \| Y(t) = F(K(t), L(t), A(t))\}$
Labor market	$\mathcal{L} = \{$Labor amount $L(t)\}$	$\mathscr{L} = \{L(\cdot) \| L(t) = L_0 e^{nt}\}$
Capital market	$\mathcal{K} = \{$Capital amount $K(t)\}$	$\mathscr{K} = \{K(\cdot) \| \dot{K}(t) = Y(t) - \delta K(t) - C(t)\}$
Technology	$\mathcal{A} = \{$Technology level $A(t)\}$	$\mathscr{A} = \{A(\cdot)$ is given exogenously.$\}$
Consumption	$\mathcal{C} = \{$Consumption level $C(t)\}$	$\mathscr{C} = \{C(\cdot) \| C$ maximizes the total utility.$\}$
Price	$\mathcal{P} = \{$Price level $P(t)$, rental rate $R(t)$, wage $w(t)\}$	$\mathscr{P} = \{P(t) \equiv 1$, factor prices are determined by firms to maximize their profit.$\}$
Utility	$\mathcal{U} = \{$Utility level $U(t)\}$	$\mathscr{U} = \{U(\cdot) \|$Utility functions over time.$\}$
Market institution	$\mathcal{M} = \{$the demand and supply level for labor, capital, and the goods.$\}$	$\mathscr{M} = \{U(\cdot) \|$households and firms are price-takers and pursue their own goals and prices clear markets and all markets are complete.$\}$
Economic activities	$\mathcal{E} := (\mathcal{H}, \mathcal{F}, \mathcal{Y}, \mathcal{L}, \mathcal{K}, \mathcal{A}, \mathcal{C}, \mathcal{P}, \mathcal{U}, \mathcal{M})$ Economic/numerical variables	$\mathscr{E} := (\mathscr{H}, \mathscr{F}, \mathscr{Y}, \mathscr{L}, \mathscr{K}, \mathscr{A}, \mathscr{C}, \mathscr{P}, \mathscr{U}, \mathscr{M})$ Structural/functional variables

Industrial structure

- The final good in the economy can be produced by I aggregate production functions or industrial structures in the world:

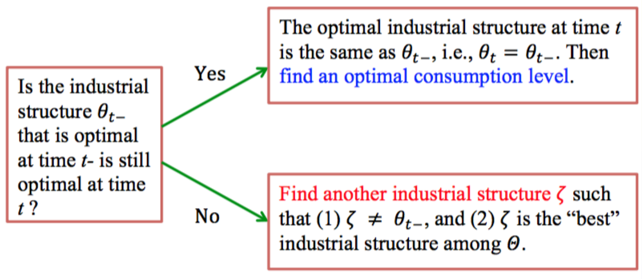
$$Y(t) = F_i[K(t), L(t), A(t)], \qquad i \in \mathbb{I} := \{1, \ldots, I\}. \tag{1}$$

- Knowledge on the world's industrial structures for the social planner $\mathcal{I}_{\mathscr{Y}} = \{\mathscr{Y}_i | \mathscr{Y}_i = \{F_i\}, i \in \mathbb{I}\}$, this can be freely obtained by economies in the world.
- When the final good is produced by production function F_i, the industrial and economic structures of the economy are given by $(\mathcal{Y}, \mathscr{Y}_i) = (\{Y(t)\}, \{F_i\})$ and $(\mathcal{E}, \mathscr{E}_i)$, respectively.
- With industrial structure $\mathscr{Y}_i$, the accumulated capital per capita is

$$\dot{k}(t) = f_i(t, k(t)) - (\delta + \pi)k(t) - c(t), \qquad i \in \mathbb{I}, \tag{2}$$

where $k(t) = K(t)/L(t)$, $c(t) = C(t)/L(t)$.

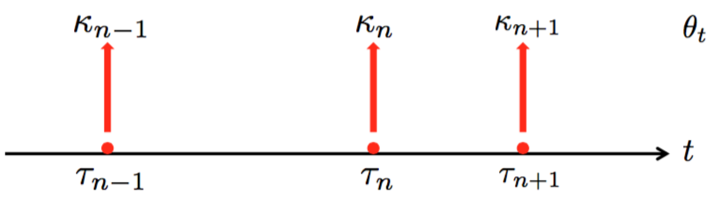
The social planner's two types of decisions



- Assume that there is neither market failure nor market friction.
- Let τ_n = the nth transformation time, κ_n = the nth transformed structure. The industrial structure of the economy at time t is

$$\theta(t) = \sum_{n\geq 0} \kappa_n 1_{[\tau_n,\tau_{n+1})}(t), \quad \text{for } t \geq \tau_0 = t_0,$$

The social planner's objective



- The capital accumulation process per capita

$$\begin{cases} \dot{k}(t) = f_{\kappa_n}(t, k(t); \theta_t) - (\delta + \pi)k(t) - c(t), & t \in [\tau_n, \tau_{n+1}), \\ k(\tau_{n+1}) = k(\tau_{n+1}^-), & t = \tau_{n+1}, \end{cases} \tag{3}$$

- Given $\kappa_0 = \theta$ and $k_0 = k$, the social planner maximizes

$$V(t, k; \theta) = \max_{\{c(s), \{\tau_n, \kappa_n\}\}} \int_t^\infty e^{-(\rho-\pi)s} u(c(s)) ds \quad \text{subject to (3).} \tag{4}$$

- **Combined infinite-horizon optimal control and optimal switching problems**

The *Hamilton-Jacobi-Bellman and quasi-variational inequalities* (HJB-QVI) system

Proposition 2.1

For each $i \in \mathbb{I}$, *the value function* $V_i(t,k)$ *defined by* (4) *is a viscosity solution to*

$$\max\left\{\sup_{c\in\mathfrak{U}}\left[\frac{\partial V_i}{\partial t}(t,k)+\left[f_i(t,k)-(\delta+\pi)k-c\right]\frac{\partial V_i}{\partial k}(t,k)\right.\right.$$
$$\left.\left.+e^{-(\rho-\pi)t}u(c)\right],\ \max_{j\neq i}V_j(t,k)-V_i(t,k)\right\}=0, \tag{5}$$

and such solution is unique on $[0,\infty)\times\mathbb{R}^+$.

- $\mathbb{I}=\{1\}$ — Existing growth models (no structural transformation)
- $\mathbb{I}=\{1,2\}$ — An economy with the current and the target structures (Optimal entry and exit times)
- $\mathbb{I}=\{1,2,\ldots,I\}$ $(I\geq 3)$ — STEG problems in reality (Optimal structures, optimal entry and exit times, optimal resouce allocation)

Static and dynamic equilibria in the EST

$$\begin{cases} \sup_{c \in \mathfrak{U}} \left[\frac{\partial V_i}{\partial t}(t,k) + \left[f_i(t,k) - (\delta + \pi)k - c \right] \frac{\partial V_i}{\partial k}(t,k) + e^{-(\rho-\pi)t} u(c) \right] = 0, \\ \max_{j \neq i} V_j(t,k) - V_i(t,k) < 0. \end{cases}$$

- Static equlibrium under $\mathscr{E}_i$: Optimal consumption $c_i^*(t,k)$ at time t.
- Dynamic equilibrium under $\mathscr{E}_i$: Optimal paths of capital per capita $k_i^*(t)$, consumption $c_i^*(t,k^*)$, and factor prices.
- The unique final good can be extended to multi-sector goods.
- Difference between the EST model and the neoclassical model
  - In the neoclassical growth model, the industrial structure is fixed, static and dynamic equilibria are always defined.
  - In our model, the static and dynamic equilibria are defined for the given optimal structure. (which will be defined later). If an economic structure $\mathscr{E}_i$ is not optimal at time t, its associated static and dynamic equilibria at time t do not exist.

Structural equilibrium in the EST

$$\begin{cases} \sup_{c\in\mathfrak{U}}\left[\frac{\partial V_i}{\partial t}(t,k)+\left[f_i(t,k)-(\delta+\pi)k-c\right]\frac{\partial V_i}{\partial k}(t,k)+e^{-(\rho-\pi)t}u(c)\right]<0, \\ \max_{j\neq i} V_j(t,k)-V_i(t,k)=0. \end{cases}$$

- The optimal industrial structure at time t is a function of t and $k(t)$. Hence optimal industrial (or generally, economic) structures are endogenous to the capital intensity (or generally, the factor endowments of the economy).
- Optimal entry and exit times of an industrial structure can also be determined.
- Different structures can be compared at any time t and at any level of capital intensity $k(t)$.

An example of I industrial structures

- Assumption
  - $L(t) \equiv 1$, so that $\pi \equiv 0$.
  - $f_i(k) = A_i(k - x_i)_+$ for $i \in \mathbb{I}$, where A_i is the technology level, $(k - x_i)_+ = \max(k - x_i, 0)$, and x_i is a threshold for the ith production function.
  - $0 < A_1 < A_2 < \cdots < A_I$ and $0 = x_1 < x_2 < \cdots < x_I$.
  - Utility $U(c) = c^{1-\gamma}/(1-\gamma)$.
- Capital accumulation

$$\begin{cases} \dot{k}(t) = (A_i - \delta)(k(t) - x_i)_+ - c(t), & \tau_n \le t < \tau_{n+1}, \\ k(\tau_n) = k(\tau_n -), & n = 1, 2, \ldots \end{cases}$$

- The HJB-QVI system of the value function

$$\max\left\{ \sup_c \left\{ [(A_i - \delta)(k - x_i)_+ - c] v_i'(k) - \rho v_i(k) + \frac{c^{1-\gamma}}{1-\gamma} \right\}, \sup_{j \ne i} v_j(k) - v_i(k) \right\} = 0.$$

Economy with $I = 4$ industrial structures

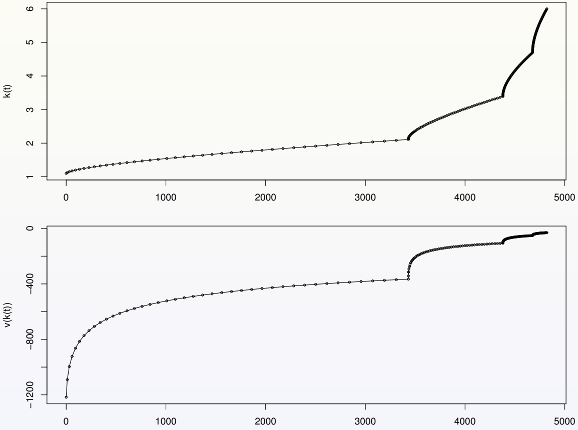


Figure: An economy of $I = 4$ industries with $\rho = 0.02, \delta = 0.05$, $\gamma = 1.5$, $A = [0.1, 0.2, 0.3, 0.4], x = [1, 2, 3, 4]$ (Top: k_t; Bottom: $v(k_t)$).

Stagewise development/growth models with EST

- The generic EST model and its competitive equilibrium theory can be generalized to include complex economic structures.
- To design a stage-wise development/growth model characterize how a country develops from the early, catching-up stage to the advanced, sustained stage in a market economy, one may use existing development/growth models as building blocks and link them together via EST.
- The EST model provides a unified framework that links economic models at different stages of the development process.

Industrial, consumption, and technology structures

- Design of multi-sector stagewise development/growth models
  - Stagewise non-balanced growth model with hierarchical industrial structures $Y(t) = \left(\sum_{j=1}^{m} w_j Y_j(t;\omega)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon-1}{\epsilon}}$.
  - Stagewise balanced growth model with composite of consumption good $c(t) = \left(\sum_{j=1}^{m} w_j (c_i(t) + \bar{c}_i)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon-1}{\epsilon}}$
- Features and implications of stagewise development/growth models
  - Economic structural transformation & sectoral structural transformation
  - Multiple equilibria under different economic structues
  - Poverty trap, middle-income trap, reindustralization
- Transformation of technology structures
  - Countries on the global production possibility frontier
  - Countries inside the global production possibility frontier
  - Countries inside but near the global production possibility frontier.

Infrastructure, economic and political institutions

- Hard/physical infrastructure (public transformation, electricity grids, etc.) can be modeled as public goods that are common external input to firms' production function.
- When economic policies (eg, tax policy) are explained as parts of economic institutions, the EST framework can be used to study optimal policies and their optimal entry and exit times.
- Changes of political institutions can be discussed similarly.
- The EST framework and its competitive equilibrium implies
  - optimal institutional structures are endogenous to the capital intensity or the factor endowment of the economy;
  - there are optimal entry and exit times for a particular institutional structure.

Concluding remarks

Contribution

- Summarize three attributes of structures from the literature, struaturality, durationality, and transformality.
- Develop a theoretical framework to model EST and efficient resource allocation in a market economy.
- Establish the competitive equilibrium (static, dynamic & structural)

Future work

- EST for other structures (heterogeneous agents, overlapping generations, trade structures, ...)
- Role of government in market failure

Thank You!

The paper link: http://arxiv.org/abs/2011.03695

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