Industrial Transformation

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A. Introduction

Industrial transformation is a long process, from agriculture, to manufacture, and then to service. The modern literature is rooted on Goodfriend-McDermontt (1995), Laitner (2000), Hansen-Prescott (2002); Gollin-Parente-Rogerson (2003, 2007):

- **Transition to modern economy and industrial transformation:**
  - **Ashraf-Galor (2011): Malthusian epoch**
  - **Young (2012): African miracle**
- **Activation of the industrial transformation process:**
  - ***Wang-Xie* (2003); *Chang-Wang-Xie* (2015)**
- **Industrial transformation and economic growth:**
  - ***Kongsamut-Rebelo-Xie* (2002): transformation from agriculture to manufactur and to service**
  - ***Matsuyama* (2002): transformation to a mass-consumption economy**
  - **Buera-Kaboski (2009): shift from home to market and service society**
  - ***Herrendorf-Rogerson-Valentinyi* (2013): multi-sector structural transformation to meet various stylized facts**
  - **Buera-Kaboski-Rogerson (2015): the rise of skill-intensive sectors**
  - **Hansen-Vizcaino-Wang (2017): disaggregation and nonhomotheticity**
  - ***Hu-Kunieda-Nishimura-Wang* (2022): flying geese or middle income trap**
  - ***Hu-Kunieda-Nishimura-Wang* (2024): foreign technology & flying geese**

B. Activation of the Industrial Transformation Process: Wang-Xie (2003)

- **East Asian NICs: rapid growth + drastic industrial transformation**
- **Some African, South American and South Asian countries: low-growth trap in traditional industries**
- **Examples:**
    - **Korea and Taiwan took off successfully in mid-1960 (Balassa 1972, Kuo 1983, Amsden 1989 and Thorbecke and Wan 1999)**
    - **The emperor's new clothes were not made in Colombia (Morawetz 1981)**
    - **Morogoro Shoe Factory in Tanzania was shut down not too long after opening**
    - **Both Akosombo Dam in Ghana and $2 billion US Aid in Zambia were failed (Easterly 2001)**
- **Questions:**
    - **What could be the barrier to activation of a modern industry?**
    - **Are there any public policies that could overcome this barrier to entry?**
- **Shortcomings of the literature:**
    - **Conventional studies lack a formal model to explain the activation process**
    - **Big push theory largely ignores the underlying process of creating a modern industry**

- **Key Features of the paper:**
  - **Production in the modern industry requires high-skilled labor in addition to new technologies**
  - **modern sector needs industrial coordination (industry-wide networking) => the scale barrier**
  - **modern goods are not necessary for survival**

1. A Simple Illustration

- **Two sectors (i=1,2): traditional industry (sector 1) versus modern (sector 2)**
- **Homogeneous labor + perfectly mobile capital**
- **Production technologies:** $Y_i = A_i K_i^{\alpha} L_i^{1-\alpha} \qquad A_2 > A_1 > 0$
- **Preferences: $U = \ln(C_1) + \ln(C_2 + \theta)$, where $\theta > 0$ (C_2 is luxury good, though on-going increase in the standard of living implies θ decreases over time)**
- **Factor allocation (FA) constraints: $L_1 + L_2 \leq L$ and $K_1 + K_2 \leq F$, where L is fixed and F depends on foreign aid/FDI**
- **Material balance conditions: $C_1 = Y_1$ and $C_2 = Y_2$**
- **Real GNP: $GNP=Y_1+pY_2$ (good 1 is numeraire)**

- **Optimization: max U s.t. (FA)**
  - **factor allocation:** $\frac{K_1}{L_1} = \frac{K_2}{L_2} = \frac{F}{L}$
  - **equalization of VMPK across sectors:** $\frac{\alpha}{K_1} = \frac{\alpha A_2 K_2^{\alpha-1} L_2^{1-\alpha}}{A_2 K_2^{\alpha} L_2^{1-\alpha} + \theta}$
  - **results:** $K_2 = \frac{1}{2}\frac{A_2 F^{\alpha} L^{1-\alpha} - \theta}{A_2 F^{\alpha-1} L^{1-\alpha}}$
    - **industry 2 will emerge iff** $A_2 F^{\alpha} L^{1-\alpha} - \theta > 0$
    - **activation of a modern industry requires sufficient funding and labor in addition to the technological factor**
    - **modern industry always emerge if θ=0**

2. A Complete Framework with External Effect and Heterogenous Labor

- **Modern industry exhibits social IRS in the Romer (1986) convention and requires skilled labor**
- **Production technologies:** $Y_1 = A_1 K_1^{\alpha_1} L_1^{1-\alpha_1}$ **and** $Y_2 = A_2 K_2^{\alpha_2} L_2^{1-\alpha_2} \bar{K}_2^{1-\alpha_2}$**, where** $\alpha_2 > \alpha_1$ **and** $A_2 > A_1$
- **Heterogeneous labor (low-skilled with mass** N_1 **and high-skilled with mass** N_2**):**
  - $L_2 \leq N_2$ (modern production requires skills)
  - $L_1 + L_2 \leq N_1 + N_2$ (the skilled can downgrade to work as unskilled)

- **Funds allocation:** $K_1 + qK_2 \leq F$**, where q > 1 as it is more costly to invest in modern industry) – q captures the effects of investment subsidies/tax rebates and tariff reductions**

3. **Competitive equilibrium:**

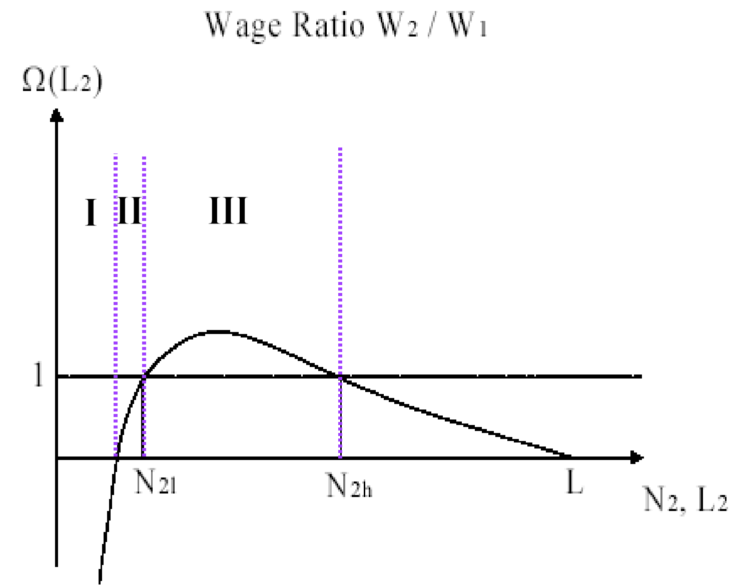
- **Equalization of relative price and MRS:** $p = \dfrac{A_1 K_1^{\alpha_1} L_1^{1-\alpha_1}}{A_2 K_2 L_2^{1-\alpha_2} + \theta}$
- **Equalization of MVKs (**$MPK_1 = \frac{p}{q} MPK_2$**):** $\dfrac{\alpha_1}{K_1} = \dfrac{\alpha_2 A_2 L_2^{1-\alpha_2}}{A_2 (F - K_1) L_2^{1-\alpha_2} + q\theta}$
- **Solution for K1:** $K_1 = \dfrac{\alpha_1}{(\alpha_1 + \alpha_2)} \left[F + \dfrac{q\theta}{A_2 L_2^{1-\alpha_2}} \right]$**, implying the K_1/F ratio is**
  - **decreasing in F and L_2**
  - **increasing in q and θ**
- **Results: Industry 2 remains non-operative if $F\text{-}K_1 \leq 0$, or,** $\dfrac{\alpha_1}{F} \geq \dfrac{\alpha_2 A_2 N_2^{1-\alpha_2}}{q\theta}$**, i.e., if**
  - **less funding or skilled labor (low F or N_2)**
  - **imperfect copy of advanced technology (low A_2)**
  - **too expensive modern capital investment (high q)**
  - **too much preference bias (high θ)**

- In order for the modern industry to be activated, to have sufficient funding ($F-K_1>0$) is necessary but not sufficient, as it does not account for skilled labor reallocation, driven by the relative wage ($\Omega=W_2/W_1$):

$$\Omega(L_2) = \frac{\alpha_1(1-\alpha_2)}{(1-\alpha_1)\alpha_2}\left[\frac{L-L_2}{L_2}\right]\left[\frac{(\alpha_1+\alpha_2)\,A_2L_2^{1-\alpha_2}F}{\alpha_1(A_2L_2^{1-\alpha_2}F+q\theta)}-1\right]$$

  - increasing in F and A_2
  - decreasing in q, θ, L_2

- **Staged development:**
  - I: $\Omega(N_2)<0$: industry 2 is unprofitable
  - II: $0\leq\Omega(N_2)<1$: the relative wage is too low for skilled workers to participate in industry 2
  - III: when $\Omega(N_2)\geq1$: activation of the modern industry 2, which requires:
    - sufficient capital funding
    - sufficient skilled labor
    - good access to new technologies
    - appropriate matches between capital and labor



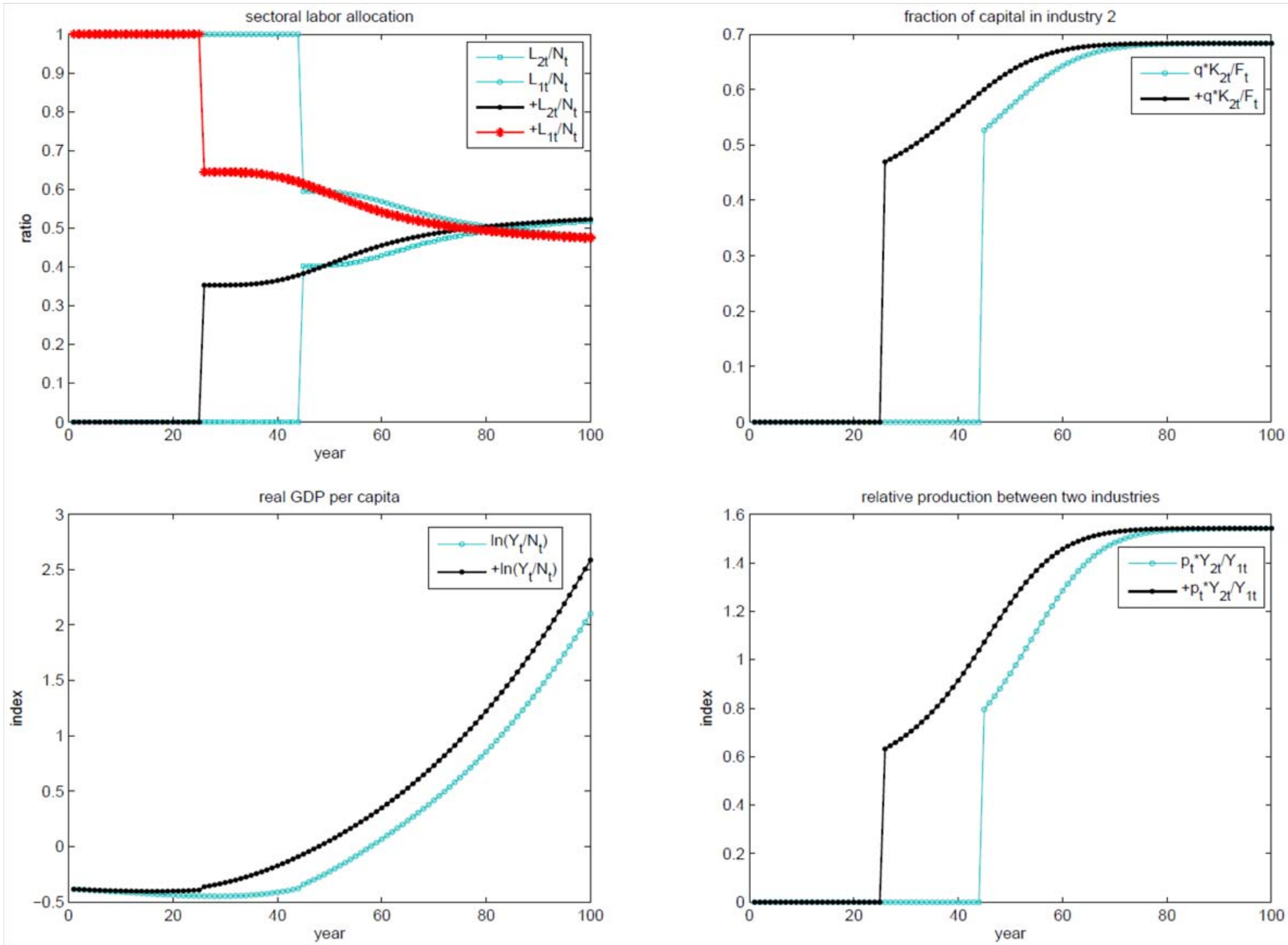
4. Development Policy Recommendation

- **Short-term policy prescriptions:**
  - **external assistance to raise F (EIB loans/U.S. Aid)**
  - **technological transfer from developed countries to advance A_2**
  - **immigration of high skill to increase N_2**
- **Long-term policy prescriptions:**
  - **better education/training**
  - **greater saving incentives**
  - **more R&D investments**

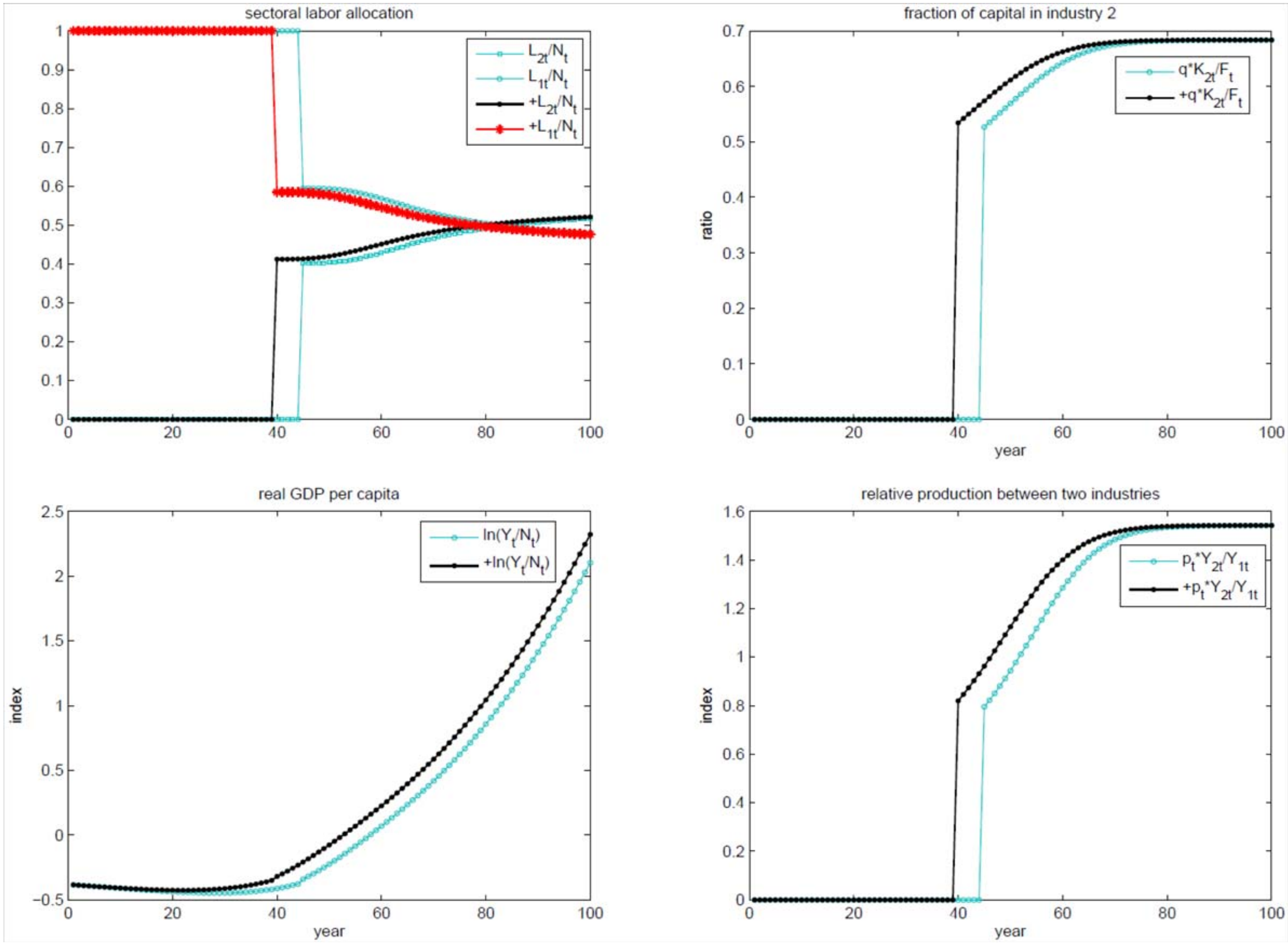
5. On dynamic take-off and development: Chang-Wang-Xie (2015)

- **Endogenous skill accumulation**
- **Endogenous saving & funds/capital accumulation**
- **Endogenous modern technology advancement (accompanied by exogenous traditional technology evolution)**
- **Model: one-period non-overlapping generations with intergenerational transfers and transmissions**

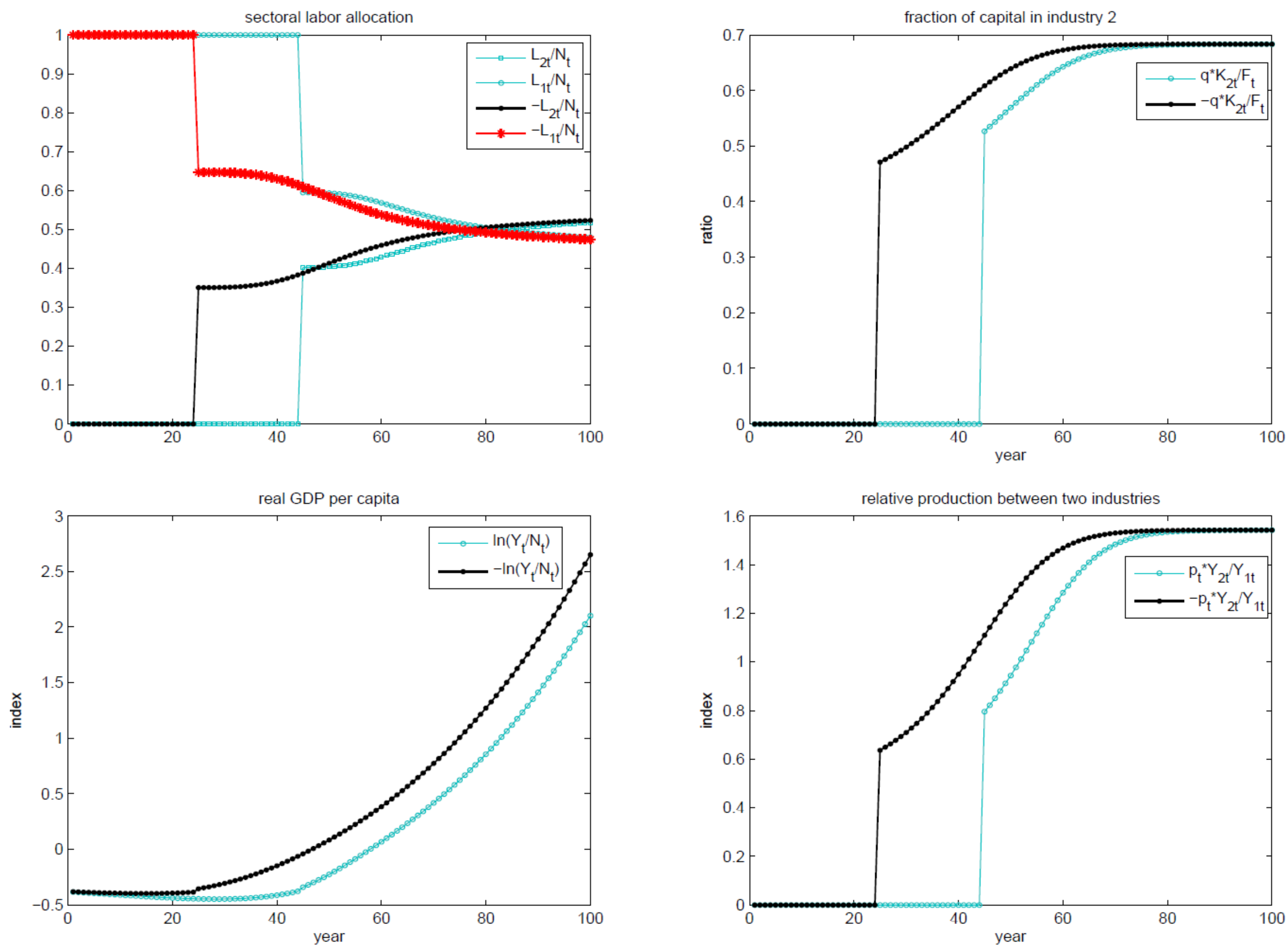
- **Effects of better initial modern technology**



- **Effects of higher initial skills**

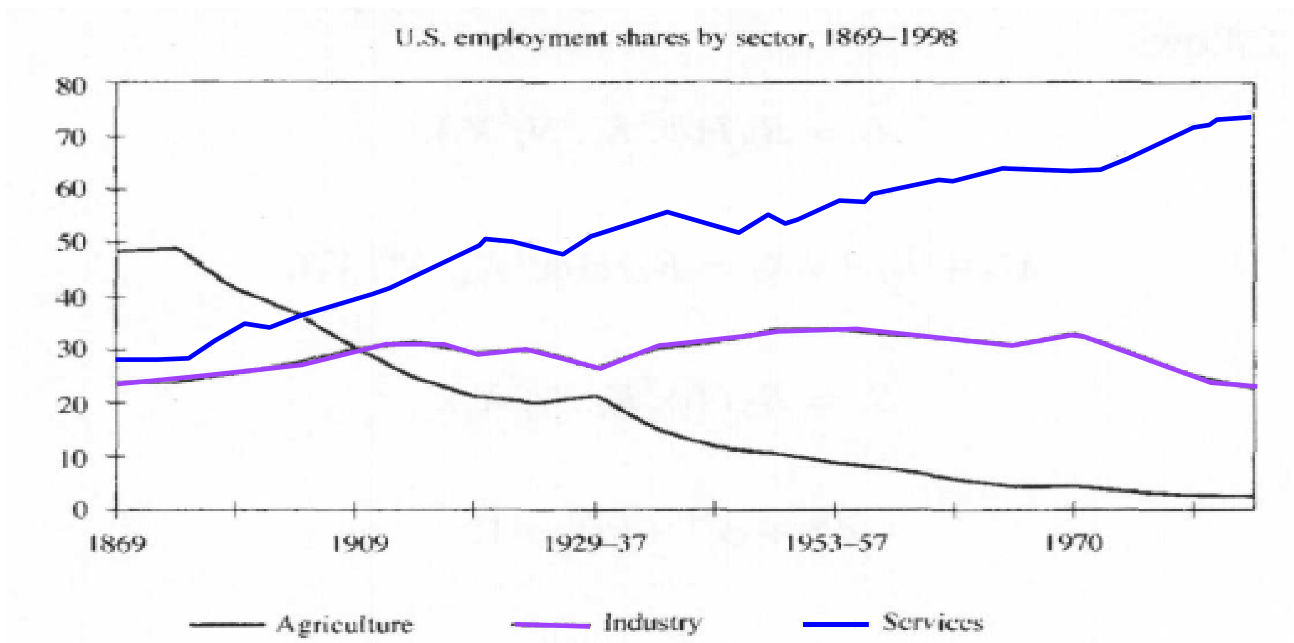


- **Effects of reduction in capital allocation barriers**



C. Industrial Transformation and Unbalanced Growth: Kongsamut-Rebelo-Xie (2002)

- **Stylized fact:**
  - **declining agriculture employment share**
  - **inverted-U manufacture employment share**
  - **rising service employment share**



1. The Model

- **Three sectors: A = agriculture, M = manufacture (numeraire), S = service**
- **Production technologies and factor allocation constraints:**

$$A_t = B_A F(\phi_t^A K_t, N_t^A X_t),$$

$$M_t + \dot{K}_t + \delta K_t = B_M F(\phi_t^M K_t, N_t^M X_t),$$

$$S_t = B_S F(\phi_t^S K_t, N_t^S X_t),$$

$$\phi_t^A + \phi_t^M + \phi_t^S = 1,$$

$$N_t^A + N_t^M + N_t^S = 1,$$

- **Preference:** $U = \int_0^\infty e^{-\rho t} \frac{[(A_t - \bar{A})^\beta M_t^\gamma (S_t + \bar{S})^\theta]^{1-\sigma} - 1}{1-\sigma} dt$ **, implying:**
  - **A is necessity with a minimum subsistence level of consumption**
  - **S is luxury**

- **Resource constraint:** $M_t + \dot{K}_t + \delta K_t + P_A A_t + P_S S_t = B_M F(K_t, X_t)$
- **Production/consumption efficiency and competitive profit conditions:**
  - **labor allocation:** $\frac{\phi_t^A}{N_t^A} = \frac{\phi_t^M}{N_t^M} = \frac{\phi_t^S}{N_t^S} = 1$
  - **capital efficiency:** $r = B_M F_1(k, 1) - \delta$
  - **optimal consumption allocation:** $\frac{P_A(A_t - \bar{A})}{\beta} = \frac{M_t}{\gamma}$ **and** $\frac{P_S(S_t + \bar{S})}{\theta} = \frac{M_t}{\gamma}$
  - **competitive profit:** $P_A = B_M/B_A$ **and** $P_S = B_M/B_S$
- **Results:**
  - **constant manufacture output growth:** $\frac{\dot{M}}{M} = \frac{r - \rho}{\sigma}$ **= g (Keynes-Ramsey)**
  - **declining agriculture and rising service output growth:**

    $$\frac{\dot{A}_t}{A_t} = g\frac{A_t - \bar{A}}{A_t}, \qquad \frac{\dot{S}_t}{S_t} = g\frac{S_t + \bar{S}}{S_t}$$
  - **negative agriculture, zero manufature and positive service employment growth:**

    $$\dot{N}_t^A = -g\frac{\bar{A}}{B_A X_t F(k, 1)}, \quad \dot{N}_t^M = 0, \quad \dot{N}_t^S = g\frac{\bar{S}}{B_S X_t F(k, 1)}$$
- **Problem: fail to explain the inverted-U manufacture employment share**

D. Transformation to a Mass-Consumption Economy: Matsuyama (2002)

- **Main idea: activation of industries driven by demands**
- **Key Features:**
  - **content of luxuries changes over time**
  - **increased productivity reduces prices of goods and enlarges customer-base (scale economies)**
  - **trickle-down: scale effect from the high-income demand makes luxuries more affordable to the low-income**
  - **trickle-up: scale effect from the low-income demand reduces the high-income cost and enables the latter to move up to consume better goods**
  - **such processes require suitable level of inequality**

1. The Basic Setup

- **Sectors:**
  - **0 = food (homogeneous, divisible)**
  - **1-J = manufacturing (heterogenous, indivisible)**

- **Preferences:** $U = \begin{cases} c & \text{if } c \leq 1 \\ 1 + \sum_{k=1}^{J} \left(\prod_{j=1}^{k} x_j \right) + \eta l & \text{if } c > 1 \end{cases}$
  - **good 0 (captured by c) is necessary up to a subsistence level (= 1)**
  - **good i < j is needed for consuming j**
  - **leisure is the numeraire that takes care of the jumps due to indivisibility of manufacturing goods ($\eta p_i < 1$)**
- **Budget Constraint (BC):** $p_0 c + \sum_{j=1}^{J} p_j x_j + l \leq I.$

2. Consumer Optimization and Aggregate Demand:

- **Optimization problem:**

$$\max_{k \in \{1, \ldots, J\}} \quad U = \begin{cases} c & \text{if } c \leq 1 \\ 1 + k + \eta l & \text{if } c > 1 \end{cases}$$

$$\text{s.t.} \quad p_0 c + \textstyle\sum_{j=1}^{k} p_j + l \leq I.$$

- **Consumption Pattern**
  - **low-income:** $I < P_0 \Rightarrow c = \frac{I}{P_0},\ l = 0,\ x_j = 0\ (j = 1, \ldots, J)$
  - **middle-income:** $P_k \leq I < P_{k+1} \Rightarrow c = 1, l = I - P_k,$
    $x_j = 1\ (j = 1, \ldots, k),\ x_j = 0\ (j = k+1, \ldots, J)$
  - **high-income:** $I \geq P_J \Rightarrow c = 1,\ l = I - P_J,\ x_j = 1\ (j = 1, \ldots, J)$

    where $P_k = \sum_{j=0}^{k} p_j$ = minimum income required for consuming good k

- **Income Distribution F(I):**
  - **only those with I > $P_k = \sum_{j=0}^{k} p_j$ can purchase j**
  - **such mass gives a measure of the aggregate demand (AD) for good j:**

    $$C_j = 1 - F(P_j) = 1 - F\left(\sum_{i=0}^{j} p_i\right)$$

    - **aggregate demand depends on distribution**
    - **only mass (not income) matters**
    - **Hicks-Allen demand complementarity from i≤j to j**
    - **mass C_j is decreasing in j (as the degree of necessity becomes lower)**

3. Production:

- **Food is CRS; manufacture is IRS**
  - **unit labor requirements a_0(t) = a_0 and $a_j(t) = A_j(Q_j(t))$, where $A_j' < 0$ and the value of production is:**

$$Q_j(t) \equiv \delta_j \int_{-\infty}^{t} C_j(s) \exp[\delta_j(s-t)]ds \leq 1$$

    with δ_j captures both the speed of learning and the rate of depreciation of learning experience
  - **this implies the following learning dynamics (LD): $\dot{Q}_j(t) = \delta_j[C_j(t) - Q_j(t)]$**

4. Equilibrium

- **Competitive Profit (CP) Conditions: $p_0 = a_0, \quad p_j(t) = A_j(Q_j(t))$**
- **(CP) + (AD) => $C_j(t) = 1 - F\left(a_0 + \sum_{i=1}^{j} A_i(Q_i(t))\right) \equiv D_j(\mathbf{Q}(t))$, which together with (LD) yields, (DY): $\dot{Q}_j(t) = \delta_j[D_j(\mathbf{Q}(t)) - Q_j(t)] \equiv \Psi_j(\mathbf{Q}(t))$, with $\Psi_{ij} \geq 0$ (complementarity)**

- **Main findings:**
  - **trickle-down:**
    demand $C_j \uparrow$
    => $p_j \downarrow$
    => those initially with $I < I_j$ can now afford to consume j
  - **trickle-up:**
    demand $C_i \uparrow$
    => $p_i \downarrow$
    => those initially with $I_j > I_i$ can now save expenses on i and move up to purchase $h > j$

E. Structural Transformation in Multi-Sector Dynamic General Equilibrium: Herrendorf-Rogerson-Valentinyi (2013)

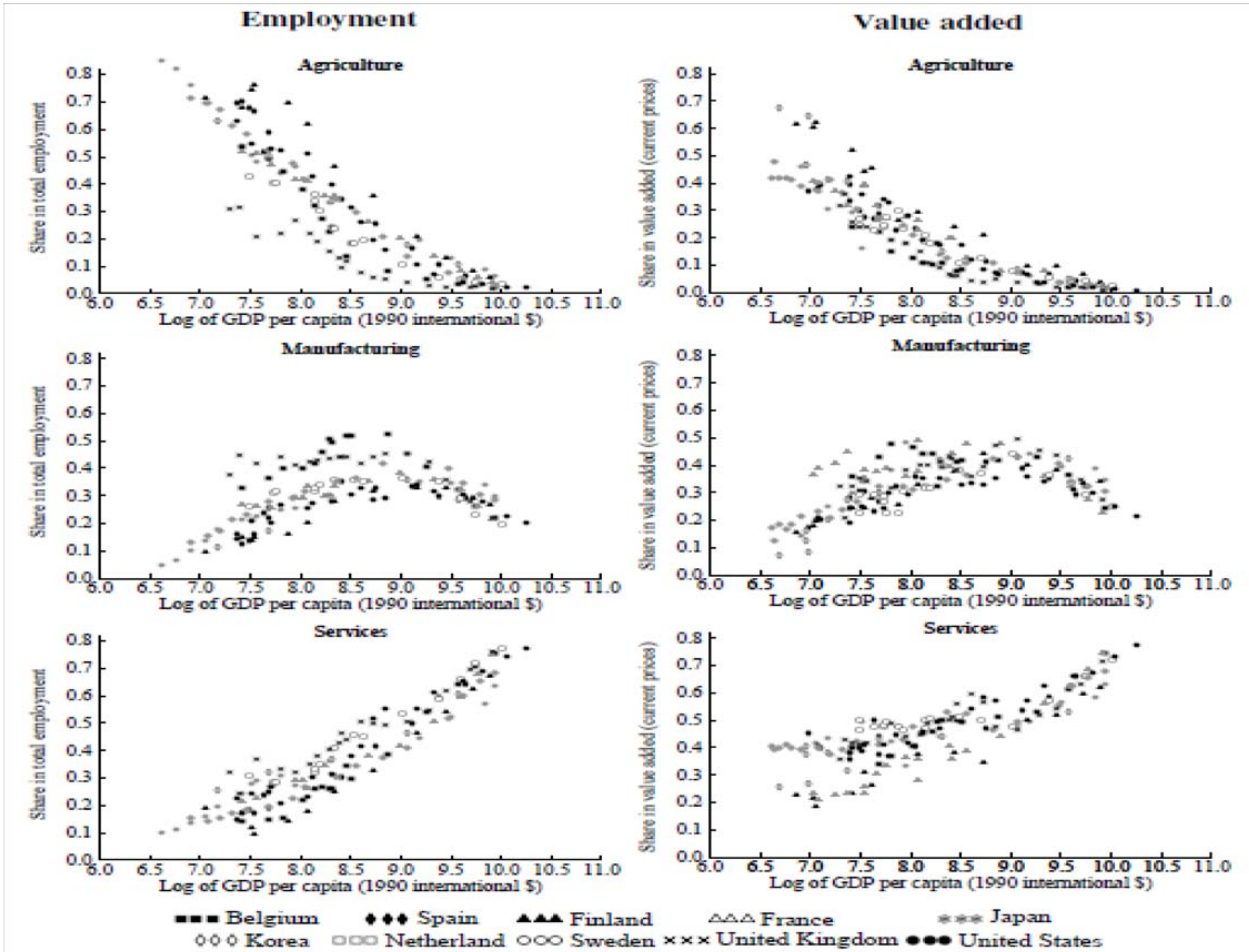
- **Multi-sector DGE model of structural transformation to meet various stylized facts concerning, most importantly,**
  - **economic development**
  - **regional income convergence**
  - **aggregate productivity trends**
  - **hours worked**
  - **wage inequality**

- **Key indicators:**
  - **performance measure: real GDP per capita (not per worker)**
  - **structural transformation measure:**
    - **employment shares**
    - **value-added or consumption shares**
      - **benchmark: nominal shares – local currency for production or consumption**
      - **alternative: real shares – international goods/services flows**

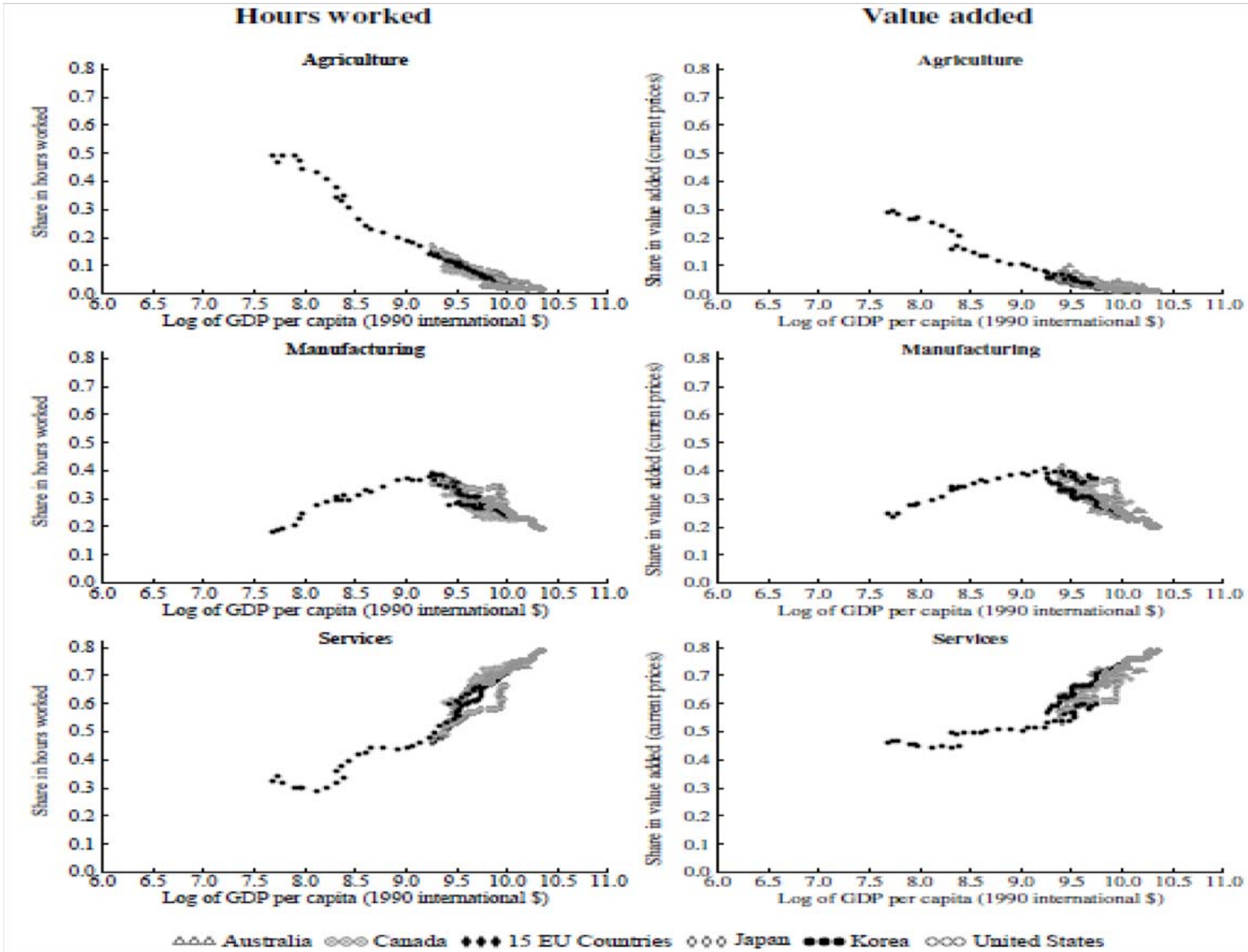
1. Stylized Facts

- **Sectoral shifts:**
  - **agriculture down**
  - **manufacture hump-shaped**
  - **service up**

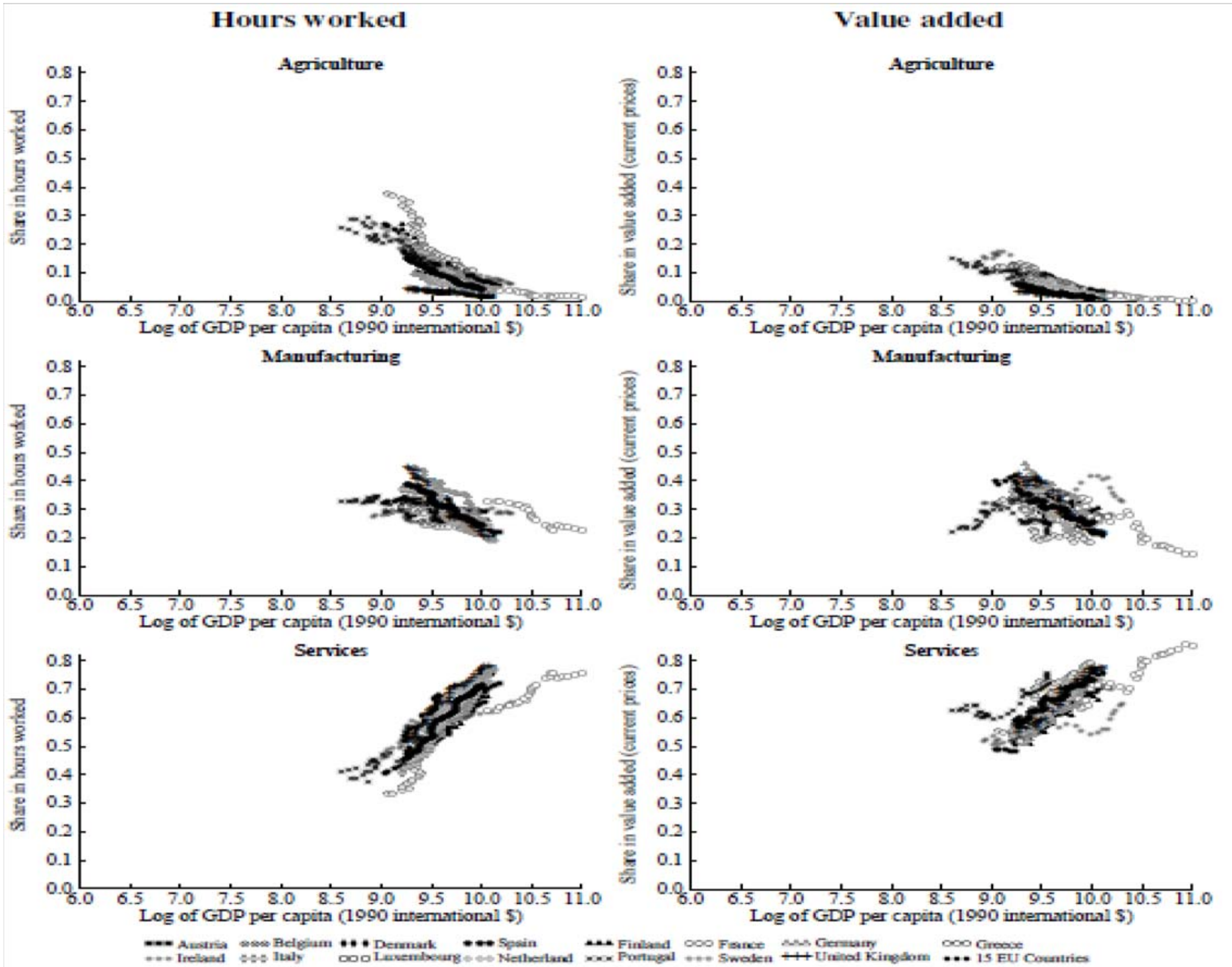
- **Developed countries: 1800-2000**



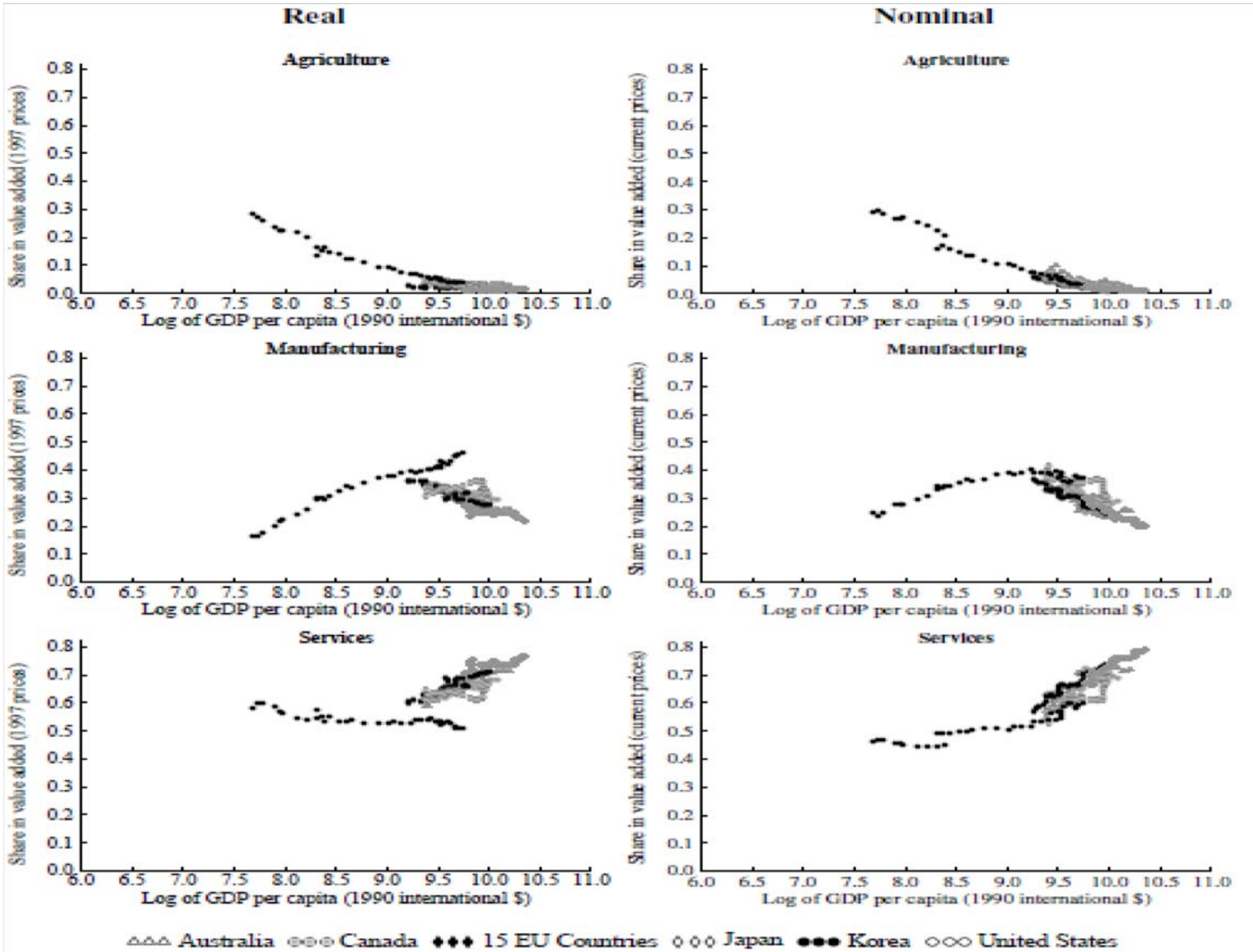
- **5 Non-EU and aggregate of 15 EU: 1970-2007**



- **15 EU: 1970-2007**

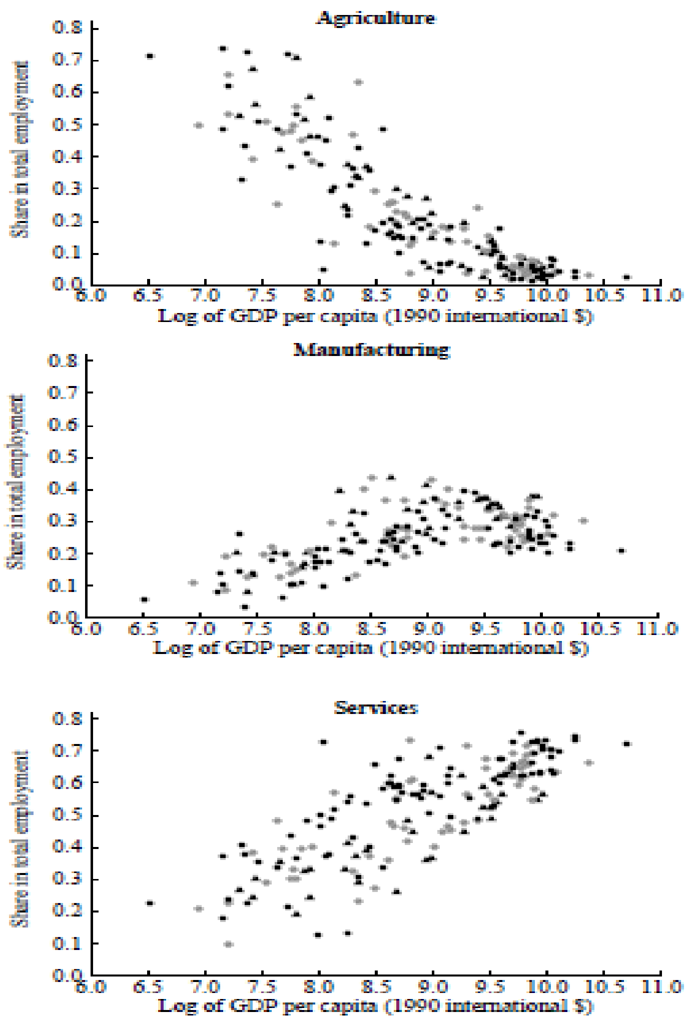


- **Real vs. Nominal: 5 Non-EU and aggregate of 15 EU (1970-2007)**

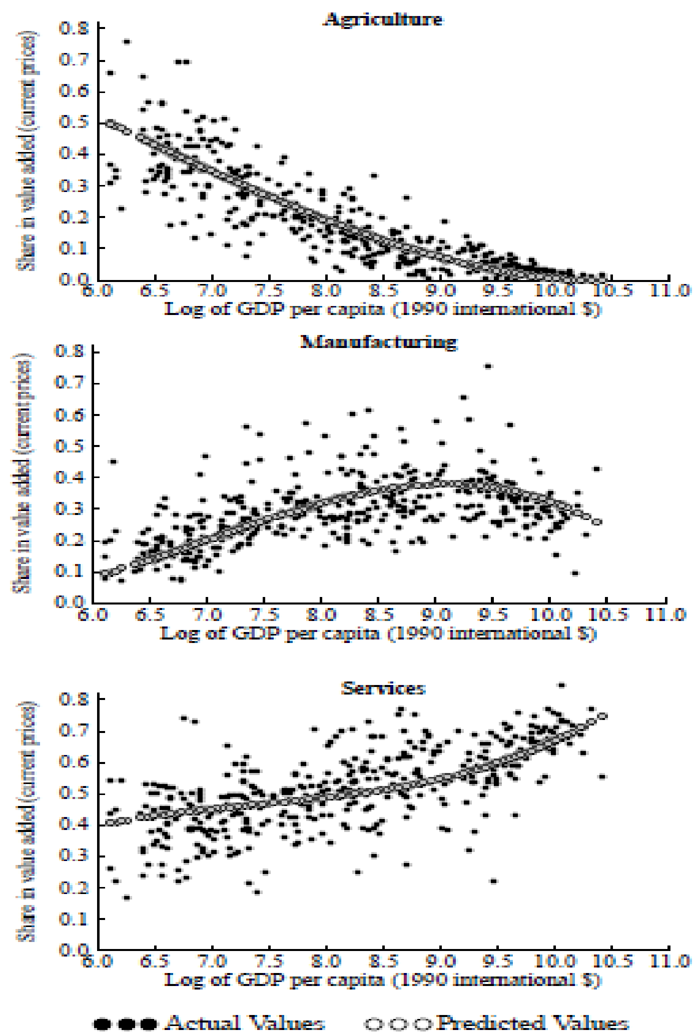


- **World Bank vs. UN-PWT 6.3**

World Bank

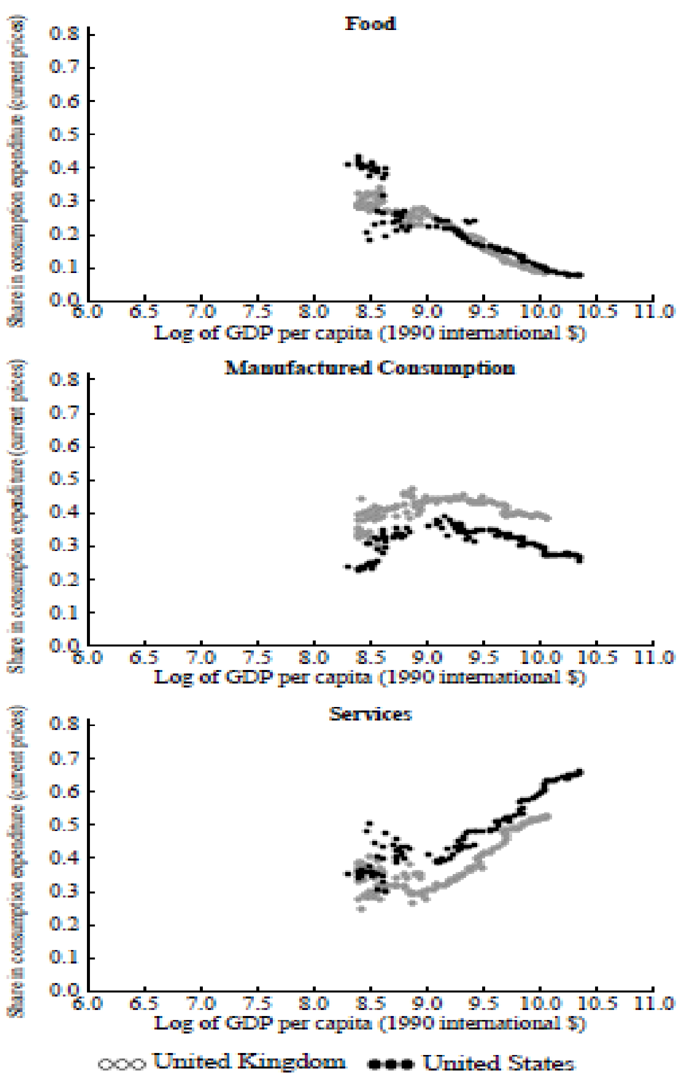


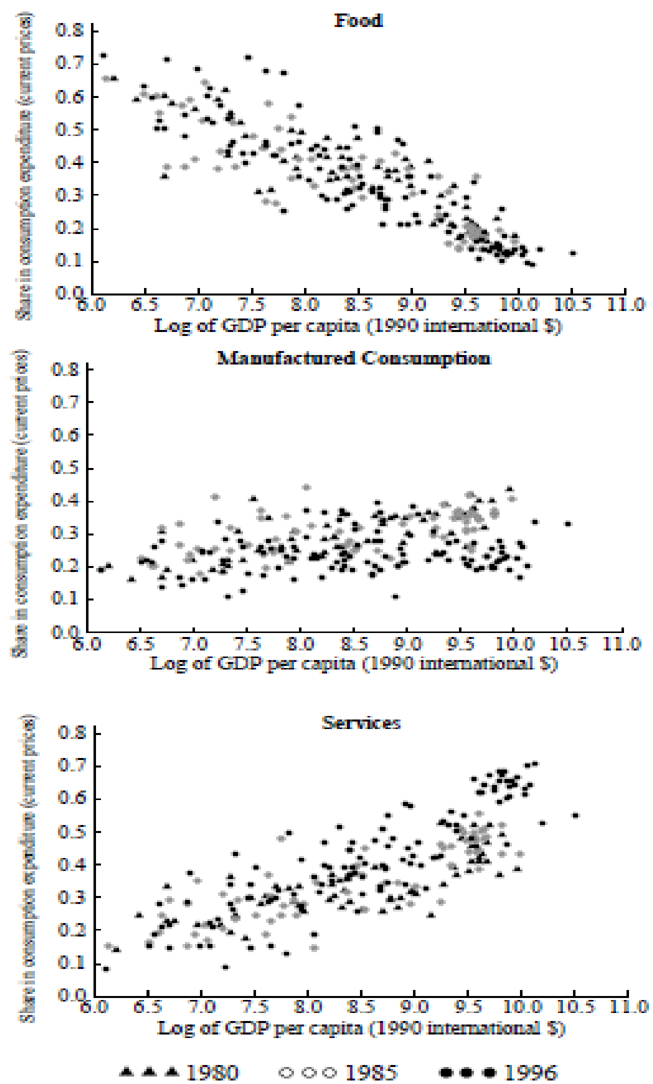
UN-PWT 6.3



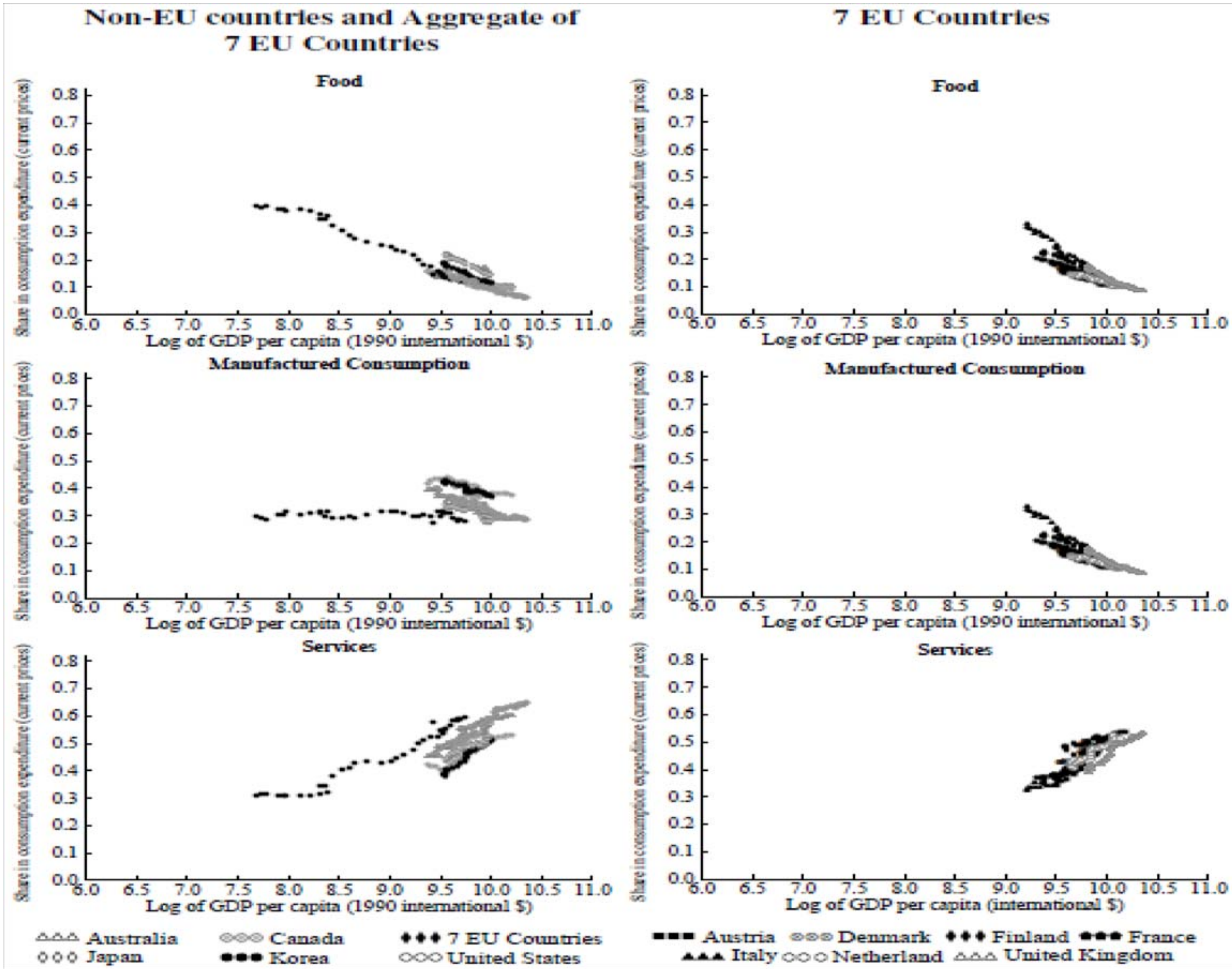
- **Consumption measures:**

US/UK **ICP-PWT 6.3**





OECD: 1970-2007



2. The Basic Model

- **Extending the two-sector growth model of Uzawa (1963) and Greenwood-Hurcowitz-Krussell (1997)**

- **Production**

  - **Production of consumption and investment goods:** $$C_t = k_{ct}^{\theta}(A_{ct}n_{ct})^{1-\theta}$$ $$X_t = k_{xt}^{\theta}(A_{xt}n_{xt})^{1-\theta}$$

  - **Capital evolution:** $$K_{t+1} = (1-\delta)K_t + X_t$$

  - **Factor allocation:** $$K_t = k_{ct} + k_{xt}$$ $$1 = n_{ct} + n_{xt}$$

  - **Relative factor demand:** $$\frac{k_{it}}{n_{it}} = \frac{\theta}{1-\theta}\frac{W_t}{R_t} = \mathbf{K_t} \quad \forall\ \mathbf{i = c, x}$$

  - **Relative price and factor prices:** $$P_t = \left(\frac{A_{xt}}{A_{ct}}\right)^{1-\theta};$$ $$R_t = \theta K_t^{\theta-1}A_{xt}^{1-\theta}$$ $$W_t = (1-\theta)K_t^{\theta}A_{xt}^{1-\theta}$$

- Aggregate output: $Y_t = X_t + P_t C_t = K_t^{\theta}(A_{xt})^{1-\theta}(n_{xt} + n_{ct}) = K_t^{\theta} A_{xt}^{1-\theta}$

- **Households**
  - **maximization:** $\max_{\{C_t, K_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \log C_t \quad \text{s.t.} \quad P_t C_t + K_{t+1} = (1-\delta+R_t)K_t + W_t$
  - **Euler:** $\frac{1}{\beta}\frac{P_t C_t}{P_{t-1}C_{t-1}} = 1-\delta+R_t$

- **Technological progress:** $\frac{A_{it+1}}{A_{it}} = 1+\gamma_i \qquad \forall$ **i = c, x**
- **Economic growth:** $\frac{Y_{t+1}}{Y_t} = (1+\gamma_x)^{\theta}(1+\gamma_x)^{1-\theta} = 1+\gamma_x$ **(no common growth)**
- **BGP rental rate:** $\frac{1}{\beta}(1+\gamma_x) = 1-\delta+R$
- **Unique initial factor proportion:** $K_0 = \left[\frac{\beta\theta}{(1+\gamma_x)-\beta(1-\delta)}\right]^{\frac{1}{1-\theta}} A_{x0}$

3. The General Model

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

- **4 sectors:**

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

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

- **Factor allocation:**

$$K_t = k_{at} + k_{mt} + k_{st} + k_{xt}$$

$$1 = n_{at} + n_{mt} + n_{st} + n_{xt}$$

- **Relative factor demand:**

$$\frac{k_{it}}{n_{it}} = K_t$$

- **Relative price:**

$$p_{it} = \left(\frac{A_{xt}}{A_{it}}\right)^{1-\theta}, \quad i = a, m, s$$

- **Aggregate output:**

$$Y_t = p_{at}c_{at} + p_{mt}c_{mt} + p_{st}c_{st} + X_t = K_t^{\theta}A_{xt}^{1-\theta}$$

- **Household maximization:**
  - $$\max_{\{c_{at}, c_{mt}, c_{st}, K_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \log\left[\omega_a^{\frac{1}{\varepsilon}}(c_{at} - \bar{c}_a)^{\frac{\varepsilon-1}{\varepsilon}} + \omega_m^{\frac{1}{\varepsilon}}(c_{mt})^{\frac{\varepsilon-1}{\varepsilon}} + \omega_s^{\frac{1}{\varepsilon}}(c_{st} + \bar{c}_s)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

    s.t. $p_{at}c_{at} + p_{mt}c_{mt} + p_{st}c_{st} + K_{t+1} = (1 - \delta + R_t)K_t + W_t$

  - **atemporal condition:**

$$\frac{1}{C_t} = \lambda_t\left[\omega_a(p_{at})^{1-\varepsilon} + \omega_m(p_{mt})^{1-\varepsilon} + \omega_s(p_{st})^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

  - **price aggregator:**

$$P_t \equiv \left[\omega_a(p_{at})^{1-\varepsilon} + \omega_m(p_{mt})^{1-\varepsilon} + \omega_s(p_{st})^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

  - **budget allocation:**

$$p_{at}c_{at} + p_{mt}c_{mt} + p_{st}c_{st} = P_tC_t + p_{at}\bar{c}_a - p_{st}\bar{c}_s$$

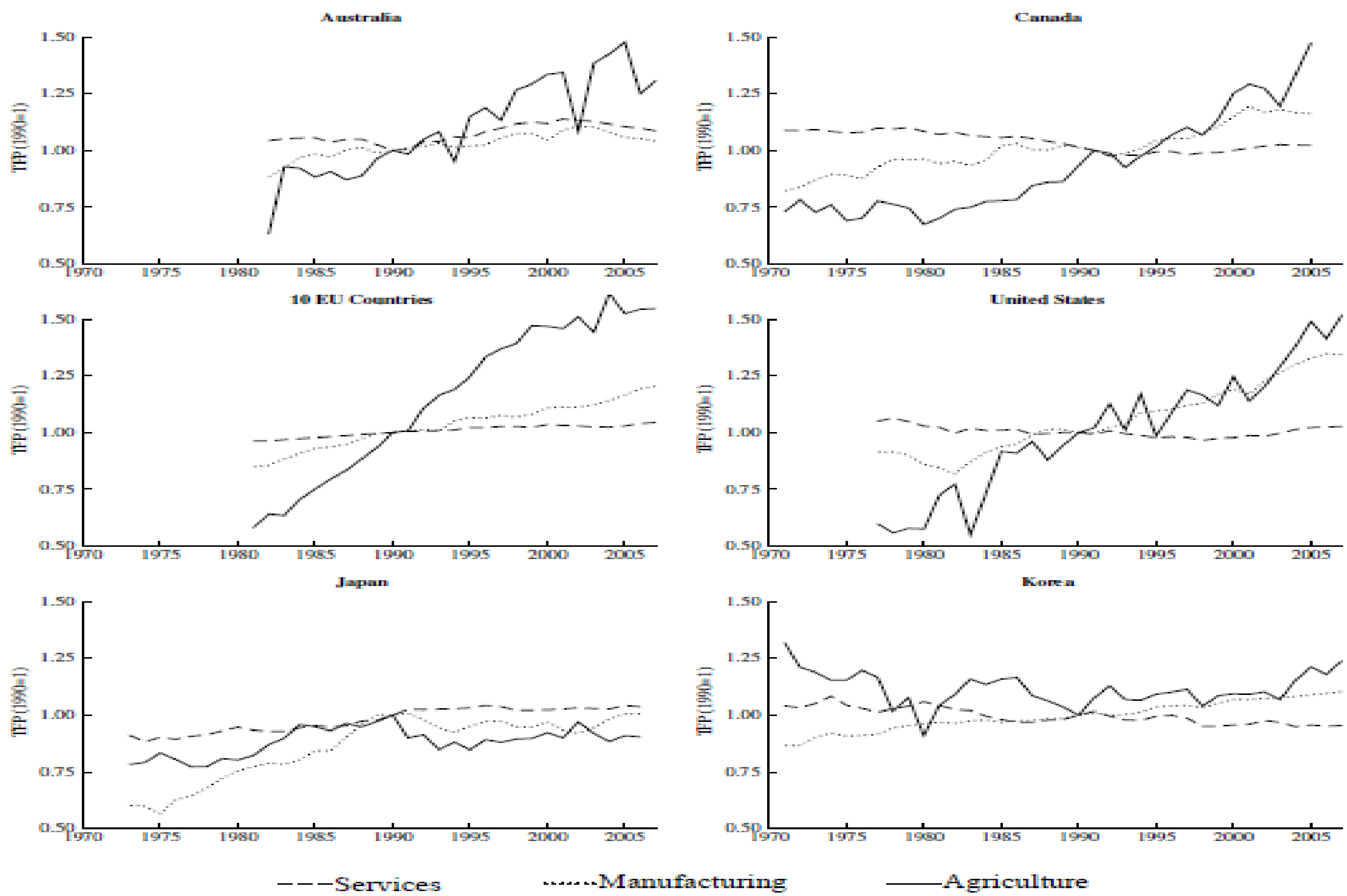
- **Trick: dividing optimization into two separate steps**
  - **intertemporal:** $\max_{\{C_t, K_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \log C_t \quad \text{s.t.} \quad P_t C_t + K_{t+1} = (1-\delta+r_t)K_t + w_t - p_{at}\bar{c}_a + p_{st}\bar{c}_s$
  - **atemporal:** $\max_{c_{at}, c_{mt}, c_{st}} \left[\omega_a^{\frac{1}{\varepsilon}} (c_{at} - \bar{c}_a)^{\frac{\varepsilon-1}{\varepsilon}} + \omega_m^{\frac{1}{\varepsilon}} (c_{mt})^{\frac{\varepsilon-1}{\varepsilon}} + \omega_s^{\frac{1}{\varepsilon}} (c_{st} + \bar{c}_s)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$

    s.t. $p_{at}c_{at} + p_{mt}c_{mt} + p_{st}c_{st} = P_t C_t + p_{at}\bar{c}_a - p_{st}\bar{c}_s$
  - **optimizing conditions:**
    - **atemporal tradeoff:** $\left(\frac{p_{at}}{p_{mt}}\right)^{\varepsilon} \frac{c_{at} - \bar{c}_a}{c_{mt}} = \frac{\omega_a}{\omega_m}$

      $\left(\frac{p_{st}}{p_{mt}}\right)^{\varepsilon} \frac{c_{st} + \bar{c}_s}{c_{mt}} = \frac{\omega_s}{\omega_m}$
    - **relative expenditure:** $\frac{P_t C_t}{p_{mt} c_{mt}} = \left[\frac{\omega_a}{\omega_m} \left(\frac{A_{mt}}{A_{at}}\right)^{(1-\theta)(1-\varepsilon)} + 1 + \frac{\omega_s}{\omega_m} \left(\frac{A_{mt}}{A_{st}}\right)^{(1-\theta)(1-\varepsilon)} \right]$
- **Special cases:**
  - **Kongsamut-Rebelo-Xie (2001):** $\gamma_i = \gamma_j$ for all $i, j = a, m, s$ **and** $\varepsilon = 1$
  - **Ngai-Prescott (2007):** $\bar{c}_a = \bar{c}_s = 0$

4. Quantitative Analysis

- **Cross country differences: TFPs, capital shares, elasticities of substitution, degrees of necessity/luxury, relative incomes, relative prices**
- **Sectoral TFP**



- **Key relationship: declines in agricultural employment shares captured by,**

$$1 - n_{at} = \frac{1 - s_a(c_{at})}{1 + p_R(A_{at}, A_{nt}) s_k(k_{at}, k_{nt}) s_X(c_{nt}, X_t)}$$

  - **$1 - s_a(c_{at}) = 1 - \frac{\bar{c}_a}{c_{at}}$ captures the income effect**
  - $p_R(A_{at}, A_{nt}) = \frac{\omega_a}{\omega_n}\left(\frac{A_{nt}}{A_{at}}\right)^{1-\varepsilon}$ **captures the relative price/productivity effect**
  - $s_k(k_{at}, k_{nt}) = \left(\frac{1-\theta_a}{1-\theta_n}\right)^{\varepsilon}\left(\frac{k_{nt}^{\theta_n}}{k_{at}^{\theta_a}}\right)^{1-\varepsilon}$ **captures the capital deepening effect**
  - $s_X(c_{nt}, X_t) = \frac{X_t}{c_{nt} + X_t}$ **captures the saving/investment effect a la Laitner**

- **Key parametrization: follow Dennis-Iscan (2009) and Buera-Kaboski (2009)**
- **Results:**
  - **overall good fitness with data especially with a uptrend in $\bar{c}_a$**
  - **income effect matters most prior to 1950, but afterward relative price/productivity and capital deepening effects become important**
- **Question: insufficient analysis on the transition to service society with accelerated shares in many advanced economies during the post-WWII period**

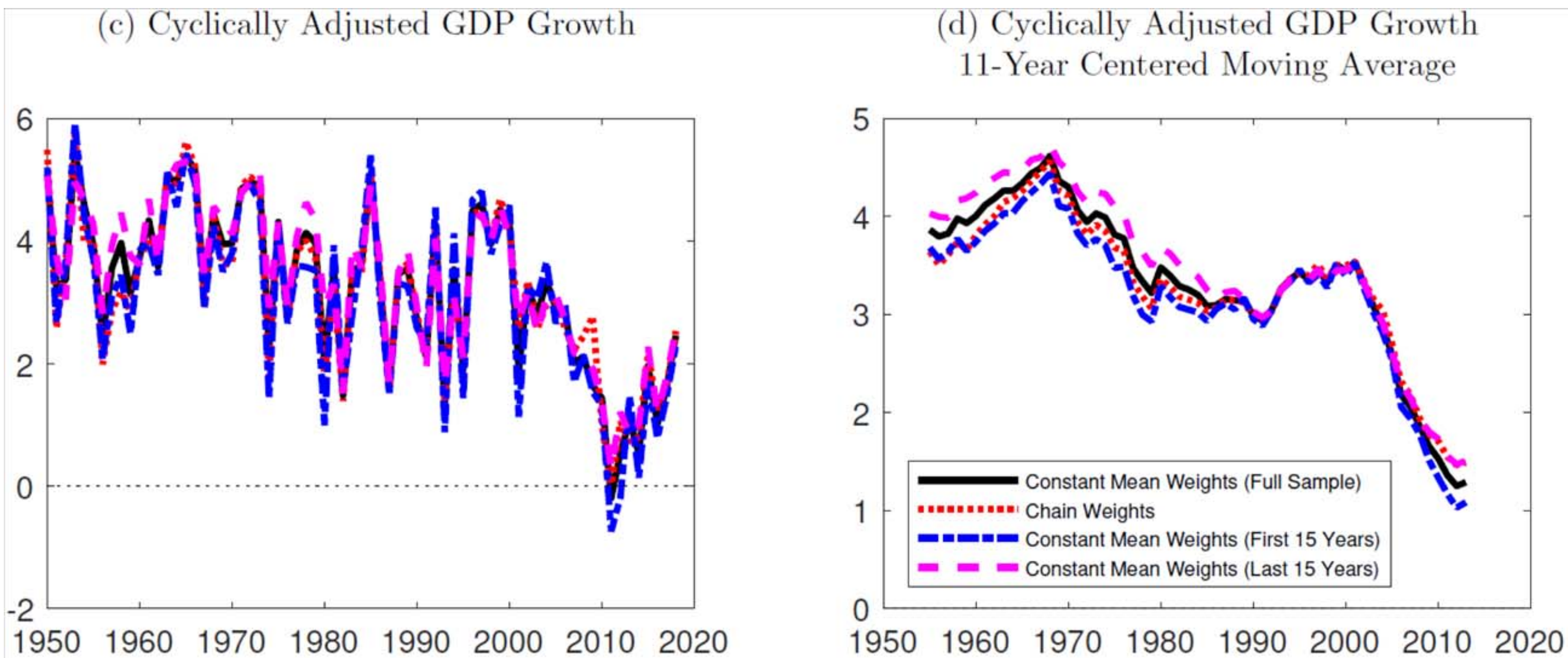
5. Extensions

- **International trade: Matsuyama (2009) 2-country iceberg model of structural transformation, but abstracting from capital**
- **Labor mobility:**
  - **labor composition:**
    - **skill vs. unskilled (Acemoglu, Laing-Palivos-Wang & others)**
    - **manual vs. nonmanual (Autor & others)**
  - **occupational mobility vs. sectoral mobility: changing sectors could incur a cost as large as 75% of annual wage income (Lee-Wolpin 2006), but within sector occupational switch is much less costly**
  - **migration frictions: Lucas (2004), Michaels-Rauch-Redding (2014), Bond-Riezman-Wang (2016), Liao-Wang-Y. Wang-Yip (2016)**
- **Labor intensity:**
  - **labor hours: Prescott-McGrattan-Rogerson (2004), Rogerson (2008) – EU 5% higher than US in 1956, but 30% lower in 2003 due to higher taxes**
  - **leisure preferences: Aguiar-Hurst (2007), Yurdagul (2015)**
- **Goods mobility:**
  - **transport costs: Collin-Rogerson (2010), Adamopoulos (2011)**
  - **tariff: Adamopoulos-Restuccia (2014), Riezman-Lai-Wang (2016), Riezman-Lai-Peng-Wang (in progress).**

F. Sectoral Structural Changes: Foerster-Hornstein-Sarte-Watson (2022)

- **During the post-WWII period, there were different sectoral trends in the US**
- **What are the aggregate implications for the long run development, especially the decline in aggregate real GDP over 1950-2018?**

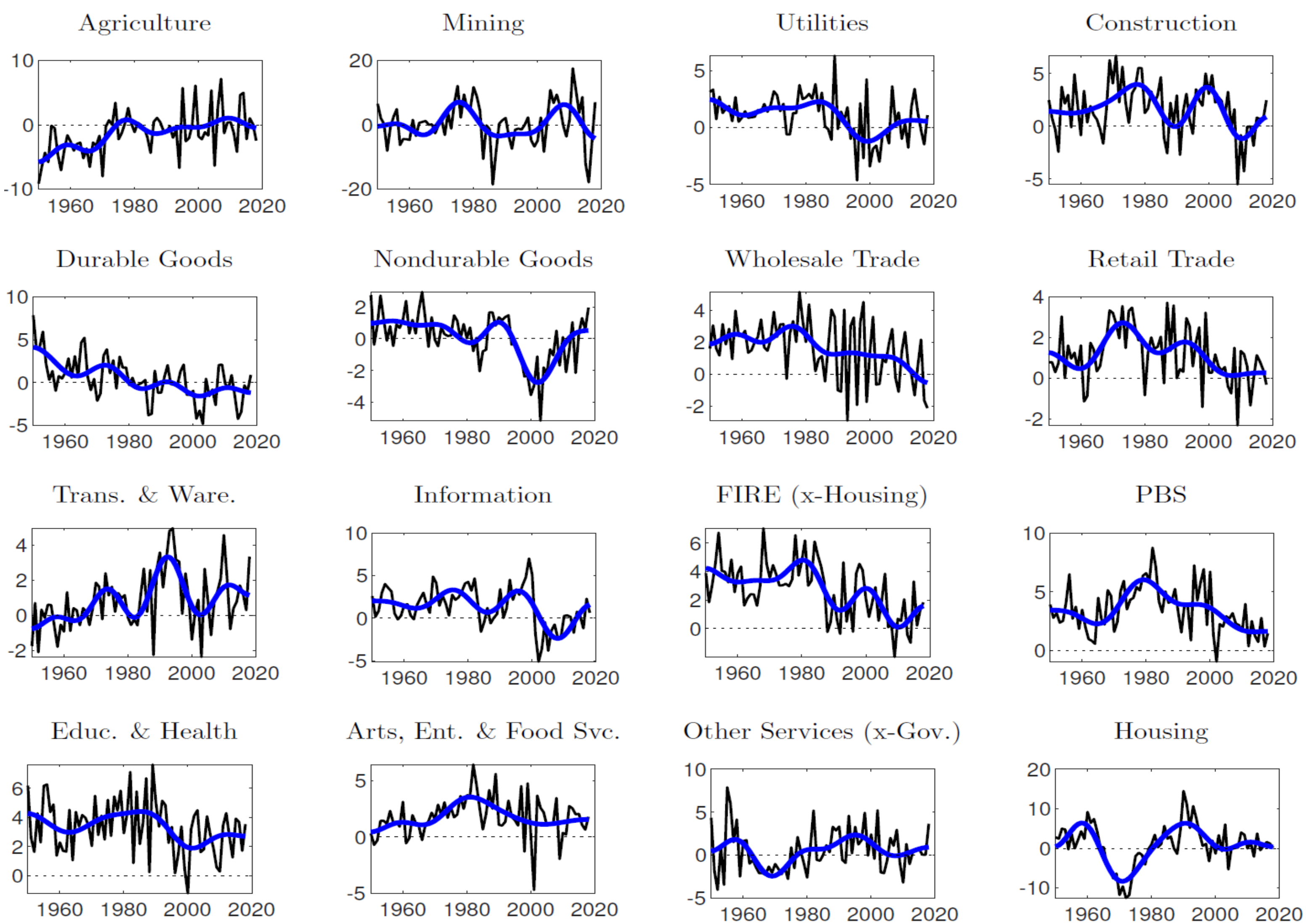
1. Stylized Facts



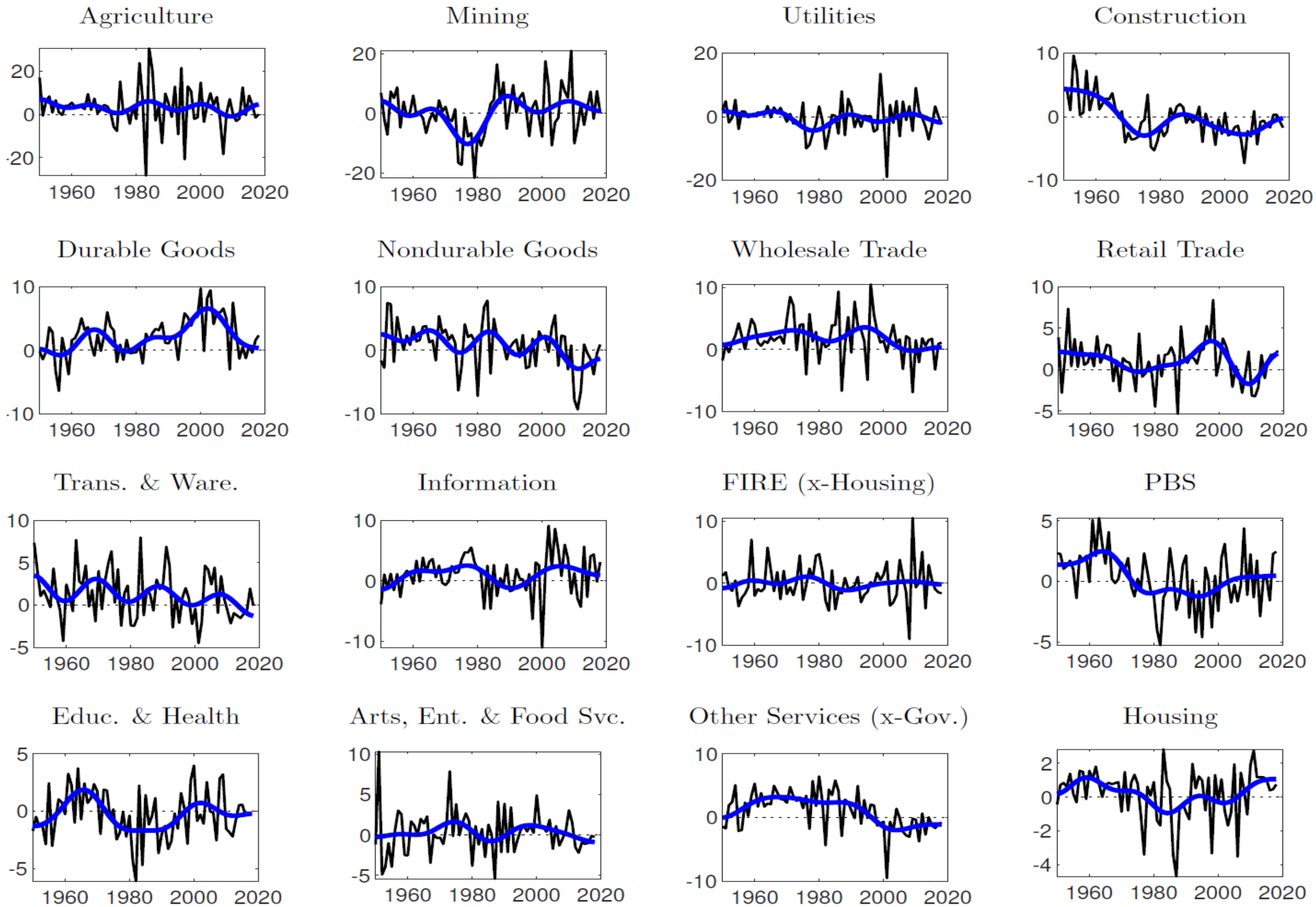
- **Sectoral growth and shares**

Sectors		Average growth rate Cyclically adjusted data (Percentage points at an annual rate)			Average share (Percentage points)	
		Value Added	Labor	TFP	Value Added	Labor
1	Agriculture	2.41	-1.29	3.12	2.69	3.23
2	Mining	1.38	0.37	0.39	2.11	1.55
3	Utilities	2.09	1.00	-0.42	2.37	1.04
4	Construction	1.69	1.76	-0.23	4.99	7.62
5	Durable Goods	3.65	0.54	2.10	13.32	15.5
6	Nondurable Goods	2.27	0.14	0.83	9.20	8.80
7	Wholesale Trade	4.61	1.67	1.81	7.15	6.63
8	Retail Trade	3.13	1.19	1.07	8.18	9.61
9	Trans. & Ware.	2.58	0.91	1.27	4.16	5.03
10	Information	4.93	1.35	1.04	4.97	3.74
11	FIRE (x-Housing)	3.88	2.77	-0.03	9.97	7.53
12	PBS	4.45	3.51	0.36	8.79	11.25
13	Educ. & Health	3.43	3.34	-0.29	6.22	9.35
14	Arts, Ent., & Food Svc.	2.48	1.79	0.36	3.74	4.56
15	Other Services (x-Gov)	1.99	0.52	1.04	2.94	4.37
16	Housing	3.45	0.86	0.24	9.20	0.20
	Aggregate	3.32	1.55	0.82	100	100

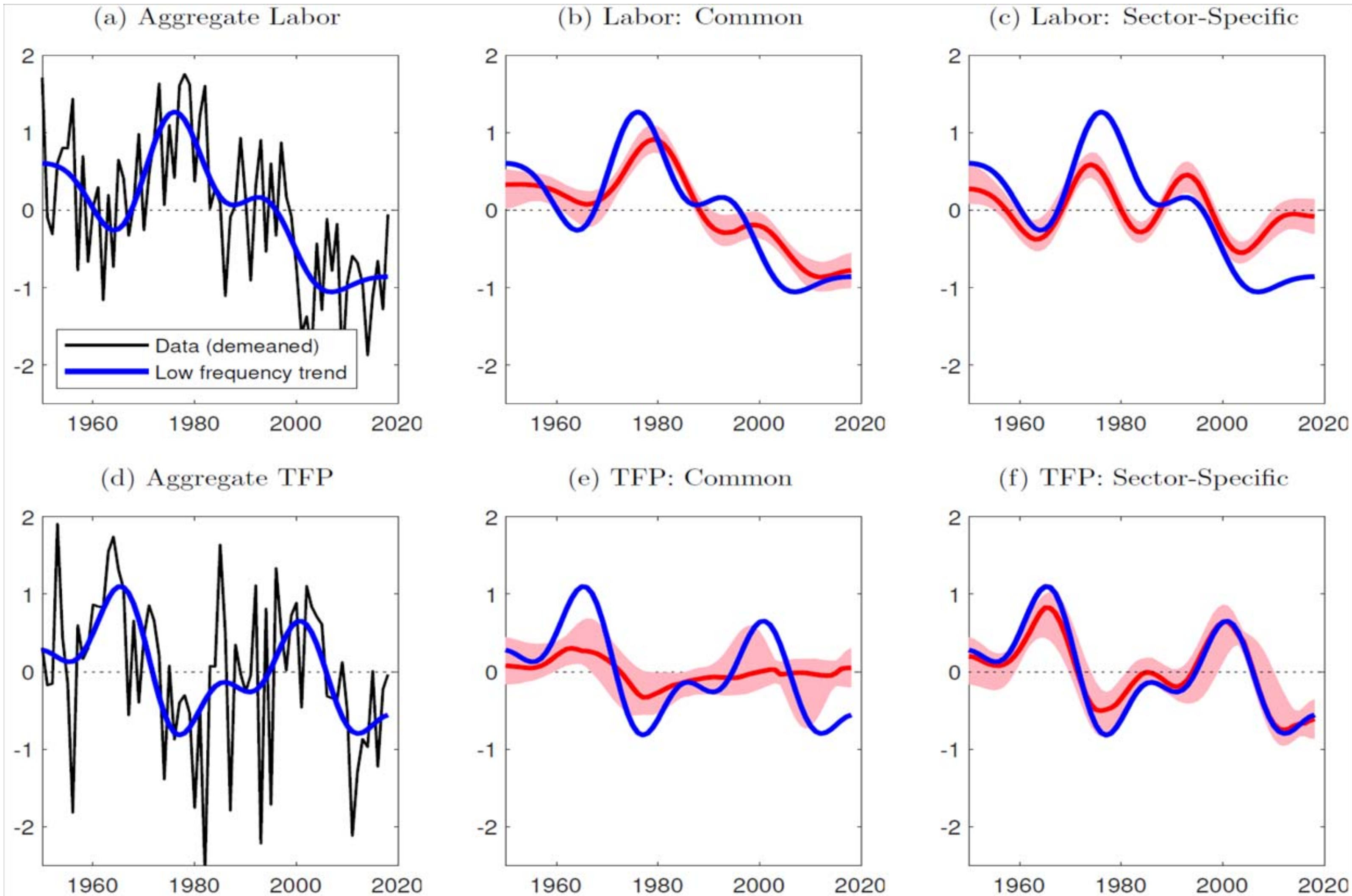
- **Sectoral labor growth**



- **Sectoral TFP growth**



- **Common vs. sector-specific trends (red = posterior median with 68% confidence interval)**

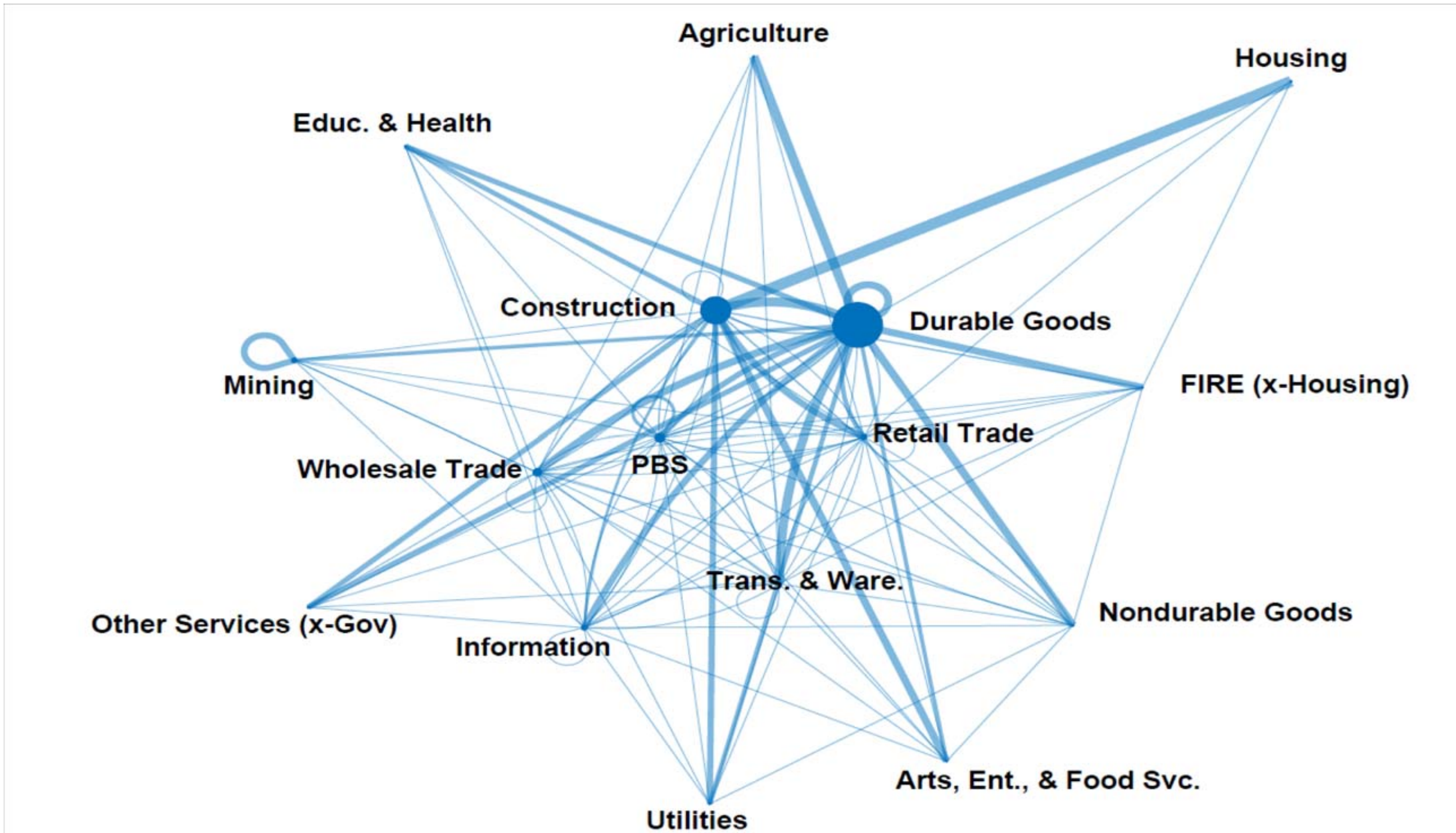


2. Simple Illustrative Model

- **Utility:** $\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \prod_{j=1}^{n} \left(\frac{c_{j,t}}{\theta_j}\right)^{\theta_j}, \ \sum_{j=1}^{n} \theta_j = 1, \ \theta_j \geq 0$
- **Sectoral production depends on a value-added and an intermediate/material components:** $y_{j,t} = \left(\frac{v_{j,t}}{\gamma_j}\right)^{\gamma_j} \left(\frac{m_{j,t}}{1-\gamma_j}\right)^{(1-\gamma_j)}, \ \gamma_j \in [0,1]$
- **Value-added:** $v_{j,t} = z_{j,t} \left(\frac{k_{j,t}}{\alpha_j}\right)^{\alpha_j} \left(\frac{\ell_{j,t}}{1-\alpha_j}\right)^{1-\alpha_j}$
- **Intermediate:** $m_{j,t} = \prod_{i=1}^{n} \left(\frac{m_{ij,t}}{\phi_{ij}}\right)^{\phi_{ij}}, \ \sum_{i=1}^{n} \phi_{ij} = 1, \ \phi_{ij} \geq 0$
- **Capital investment:** $x_{j,t} = \prod_{i=1}^{n} \left(\frac{x_{ij,t}}{\omega_{ij}}\right)^{\omega_{ij}}, \ \sum_{i=1}^{n} \omega_{ij} = 1, \ \omega_{ij} \geq 0$
- **Resource constraint:** $c_{j,t} + \sum_{i=1}^{n} m_{ji,t} + \sum_{i=1}^{n} x_{ji,t} = y_{j,t}$

3. Quantitative Results

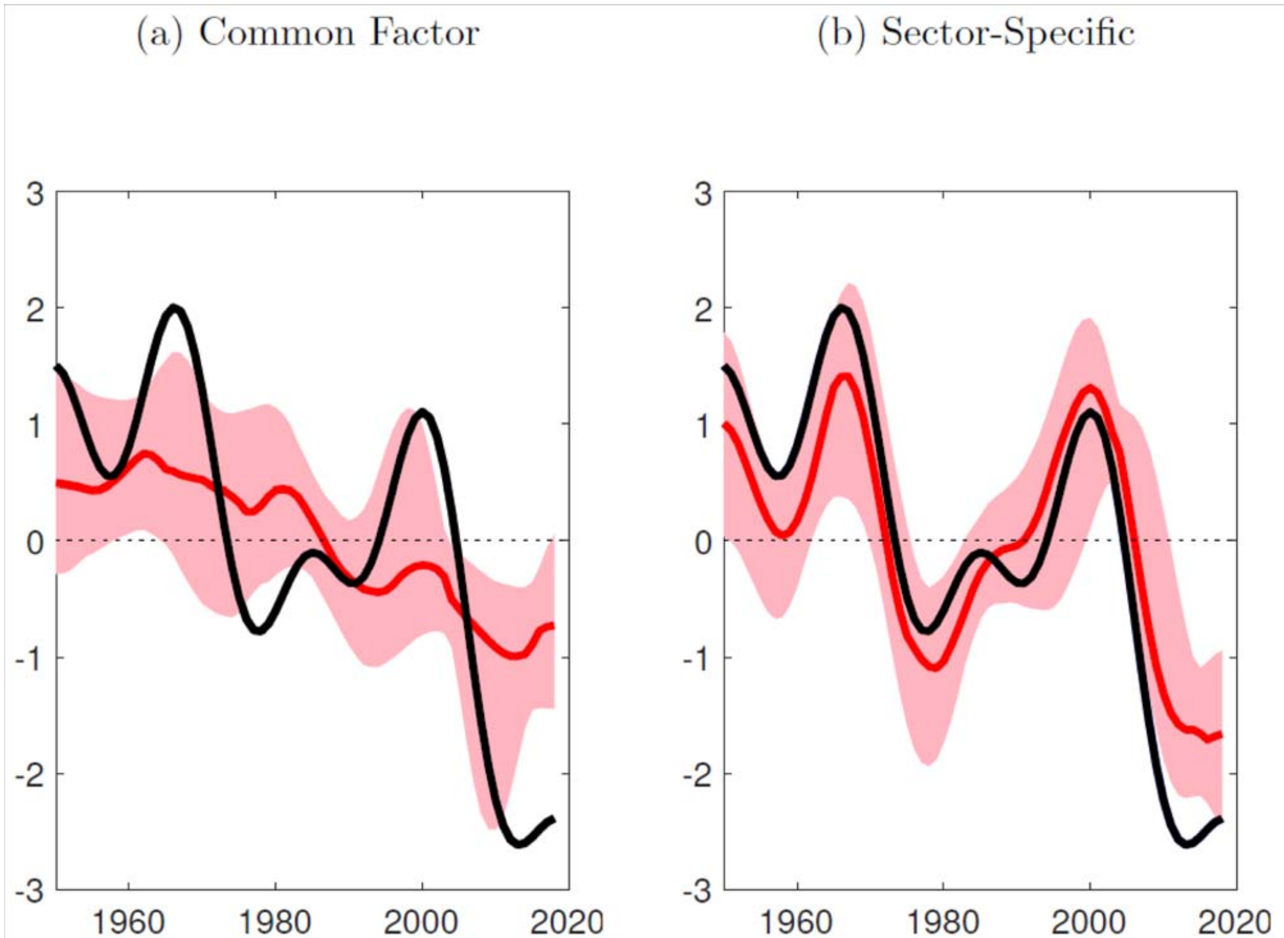
- **Investment networks based on capital flow data**



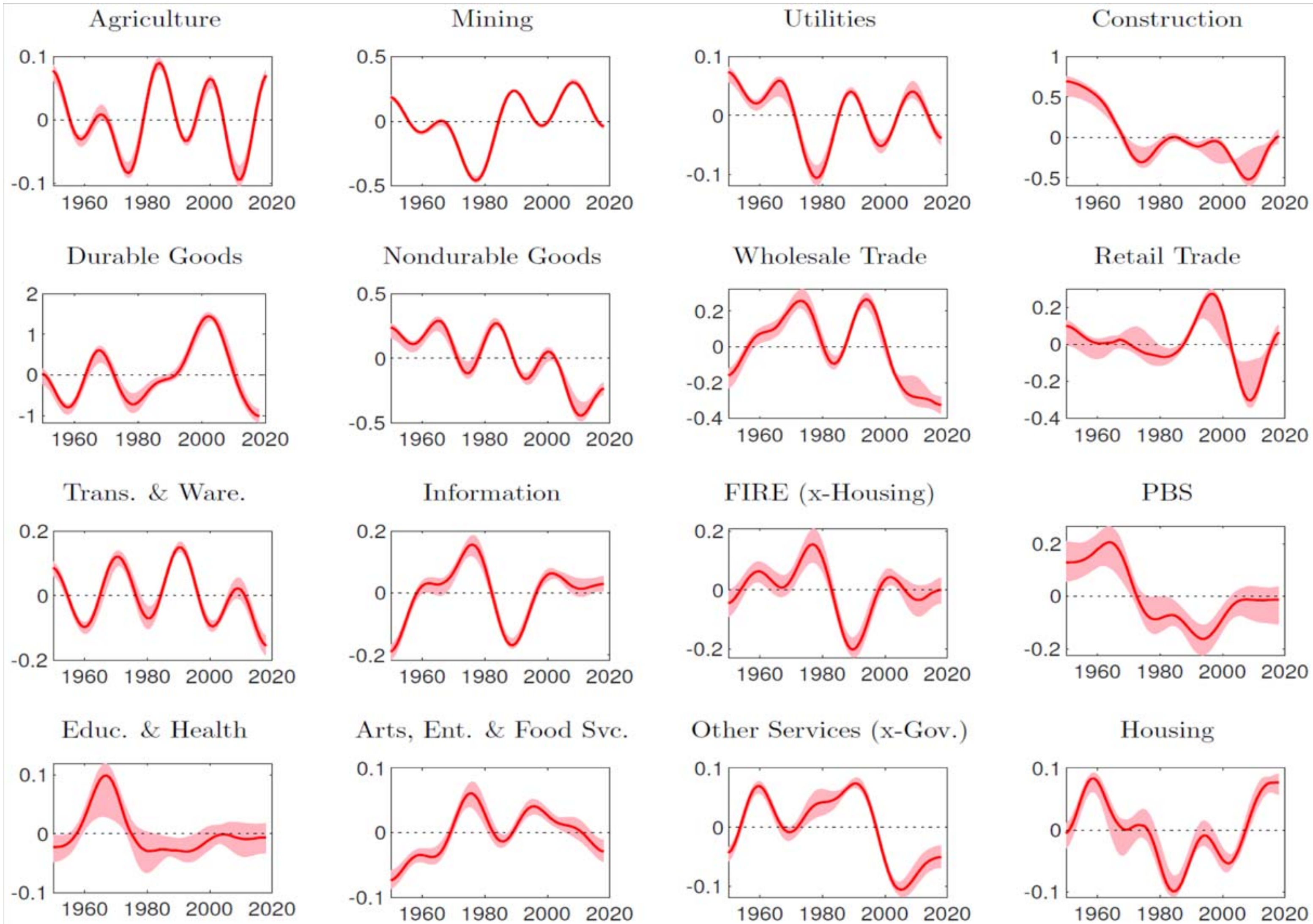
- **Sectoral multipliers (direct + indirect network connections)**

Sector	s^v	$\Xi\Omega\alpha_d s^v$	$(I + \Xi\Omega\alpha_d)s^v$
Agriculture	0.03	0.01	0.03
Mining	0.02	0.03	0.05
Utilities	0.02	0.01	0.03
Construction	0.05	0.12	0.17
Durable Goods	0.13	0.28	0.42
Nondurable Goods	0.09	0.03	0.13
Wholesale Trade	0.07	0.08	0.15
Retail Trade	0.08	0.02	0.11
Trans. & Ware.	0.04	0.03	0.07
Information	0.05	0.03	0.08
FIRE (x-Housing)	0.10	0.03	0.14
PBS	0.09	0.16	0.25
Educ. & Health	0.06	0.00	0.06
Arts, Ent., & Food Svc.	0.04	0.01	0.04
Other Services (x-Gov)	0.03	0.01	0.04
Housing	0.09	0.00	0.09

- **Historical decomposition of trend GDP growth**



- **Sector-specific contribution to trend GDP growth**

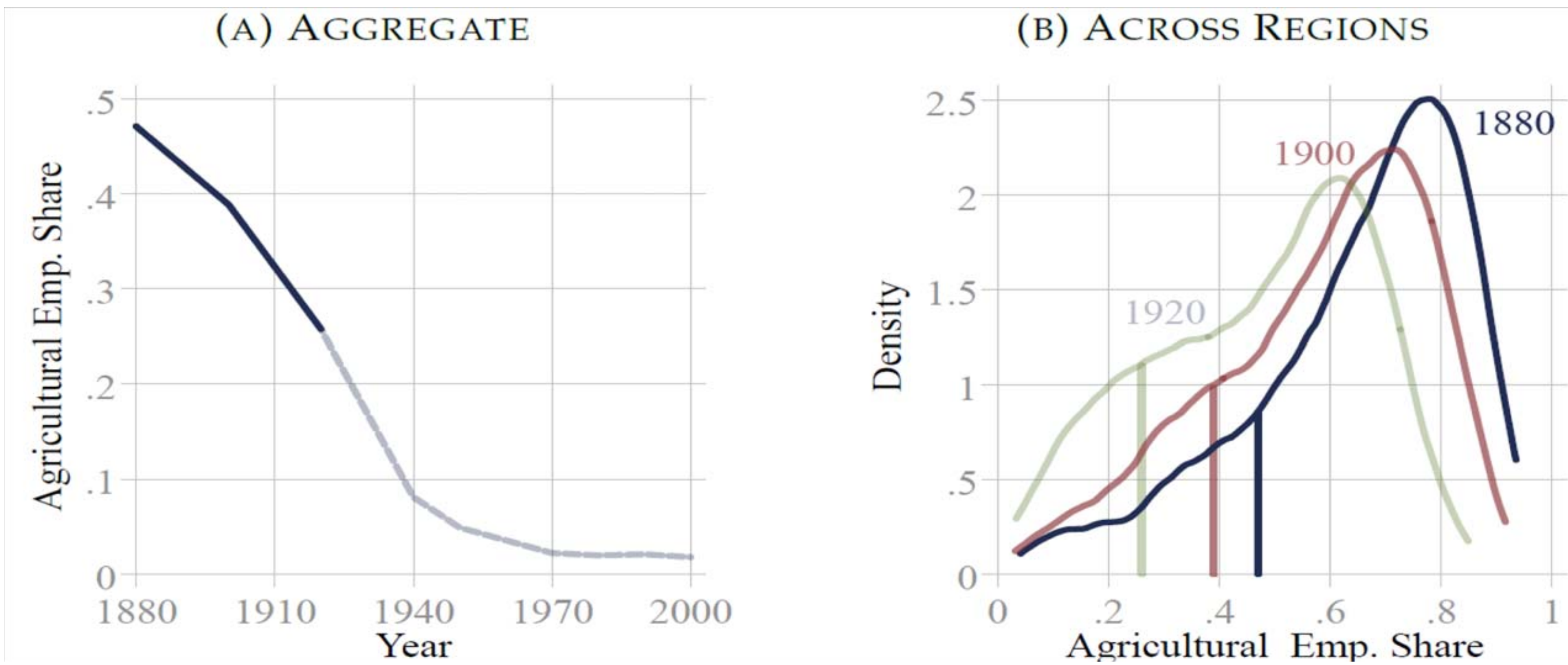


- **Main findings:**
  - **long-run amplification measured by sectoral multipliers are quantitatively large**
  - **historically over the past 70 years, sector-specific factors account for 3/4 of long-run changes of GDP growth, whereas common trends only account for 1/4**
  - **over 1950-1980, 1/3 of the 3 percentage point downward trend in GDP growth is due to Construction**
  - **over 2000-2018, Durable Goods can account for 2 percentage points decline in GDP growth**
  - **no sector contributes significantly to steady increase to trend growth in GDP over the past 70 years**

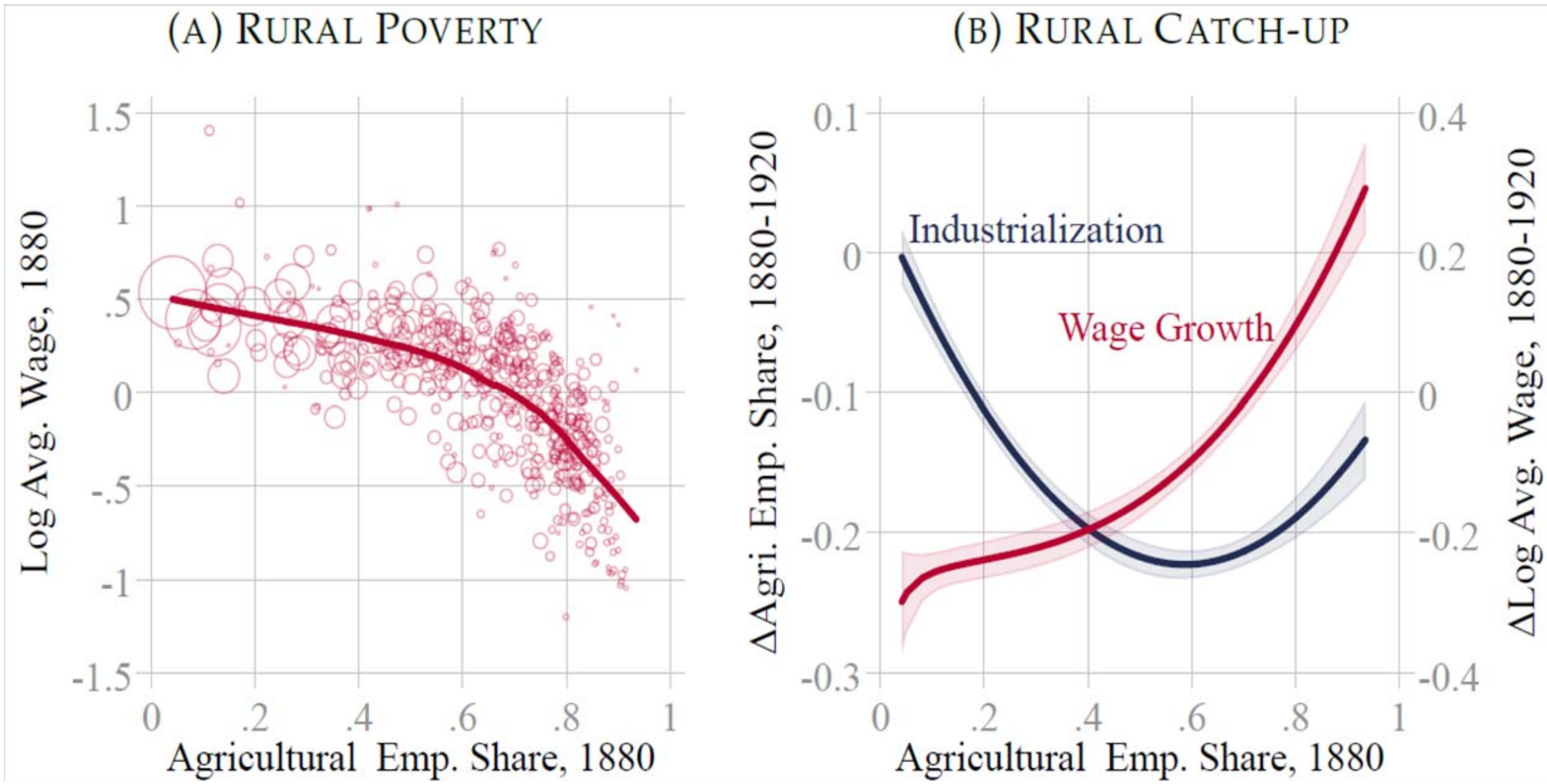
G. Spatial Structural Changes: Eckert-Peters (2022)

- **From 1880 to 1920, U.S. experienced rapid structural transformation with agricultural employment share declining from 1/2 to 1/4.**
- **During the same time, rural labor markets experienced faster wage growth and industrialization than non-rural areas.**

1. Stylized Facts



- **Spatial structural change:**



  - **across locations (commuting zones), places with higher agricultural employment shares suffered lower average wages**
  - **places with higher agricultural employment shares experienced faster wage growth and relatively faster transformation to non-agriculture**

2. The Model

- **Combining spatial sorting (Redding & Rossi-Hansberg 2017) with macro structural transformation (Herrendorf-Rogerson-Valentinyi 2013)**
- **Numeraire: $P_{rA} = 1$ whose transport cost is assumed to be zero**
- **Non-homothetic Price-Independent Generalized Linear (PIGL) indirect utility at location r:** $V(y, P_{rA}, P_{rM}) = \frac{1}{\eta}\left(\frac{y}{P_{rA}^{\phi} P_{rM}^{1-\phi}}\right)^{\eta} - \nu \ln\left(\frac{P_{rA}}{P_{rM}}\right)$
- **Roy's identity gives expenditure share on agriculture:**

$$\vartheta_A(y, P_M) \;=\; \phi + \nu\left(y/P_{rM}^{1-\phi}\right)^{-\eta}$$

  - **φ > 0 is the expenditure share asymptote and** $y/P_{rM}^{1-\phi}$ **is "real income"**
  - **so η is the Engel Curve elasticity**
  - **elasticity of substitution between value-added generated by the two goods is then captured by** $\varrho = 1 + \eta\frac{(\vartheta_A - \phi)^2}{\vartheta_A(1-\vartheta_A)}$**, which is location and income dependent with** $\lim_{\vartheta_A \to \phi} \varrho = 1$
    - **higher for the poor**
    - **approaching one as income rises (Cobb-Douglas utility)**

- **Agricultural production:** $Y_{rA} = Z_{rA} H_{rA}^{1-\alpha} T_r^{\alpha}$
- **Manufacturing production:** $Y_{rM} = \left(\int_0^N y(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}} = \left(\sum_{j=1}^{R} \int_0^{N_j} y(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}$
- **Spatial productivity ladder for location r and sector s:**

  $$d \ln Z_{rst} = g_s + \lambda_s \ln \left(\frac{\overline{Z}_{st}}{Z_{rst}} \right) \quad \text{for } s = A, M$$

  where λ_s > (or <) 0 => regional convergence (divergence)
- **Roy model of sectoral labor supply with worker i in region r supplying z_s^i efficiency unit to sector s drawn from a Fréchet distribution:**

  $P\left(z_s^i \leq z\right) = F_s(z) = e^{-z^{-\zeta}}$**, where ζ is the shape parameter**
- **Worker's sectoral choice:** $y_r^i = \max\left\{ z_A^i w_{rA}, z_M^i w_{rM} \right\}$
- **Income distribution:** $F_r(y) = e^{-(y/\overline{w}_r)^{-\zeta}} \quad \text{where} \quad \overline{w}_r = \left(w_{rA}^{\zeta} + w_{rM}^{\zeta} \right)^{1/\zeta}$
- **Sectoral employment share:** $s_{rs} = \left(w_{rs} / \overline{w}_r \right)^{\zeta}$ **with elasticity depending only on the worker productivity shape parameter ζ**
- **Labor supply:** $H_{rs} = \Gamma_{\zeta} L_r \left(w_{rs} / \overline{w}_r \right)^{\zeta-1}$, $\Gamma_x \equiv \Gamma(1 - 1/x)$ **is a gamma function**

- **Indirect utility of worker i from location r in location r′ at time t:**

$$\mathcal{U}^i_{rr't} \equiv \mathcal{V}_{rt}\mathcal{B}_{rt}\mu_{rr'}u^i_{rt}, \text{ where } \mathcal{V}_{rt} \equiv \int V(y, p_{rt})\, dF_{rt}(y) \text{ and } \mathcal{B}_{rt} = B_r L_{rt}^{-\rho}$$

  - **amenity *B* takes into account of congestion externality with strength ρ**
  - **μ captures migration cost (> 1 if r′ ≠ r)**
  - **u^i_{rt} is a utility shifter drawn prior to moving from a Fréchet distribution with shape parameter ε**

- **So the share of workers migrating from r to r′ is:** $m_{rr't} = \dfrac{(\mu_{rr'}\mathcal{V}_{r't}\mathcal{B}_{r't})^{\varepsilon}}{\sum_j (\mu_{rj}\mathcal{V}_{jt}\mathcal{B}_{jt})^{\varepsilon}}$

- **Law of motion of population in location r:**

$$L_{rt} = \sum_{r'} m_{r'rt} L^Y_{r't} = \sum_{r'} m_{r'rt} n_{r't-1} L_{r't-1}$$

3. Equilibrium

- **Aggregate expenditure share:**

$$\vartheta_{rA} \equiv \frac{\int \vartheta_A(y, p_r)\, y dF_r(y)}{\int y dF_r(y)} = \phi + \nu^{RC}\left(\overline{w}_r / P_{rM}^{1-\phi}\right)^{-\eta}, \nu^{RC} = \nu \frac{\Gamma_{\zeta/(1-\eta)}}{\Gamma_\zeta}$$

depending negatively on average real wage

- **Consumption value in region r:** $\mathcal{V}_r = \int V(y, p_r)\, dF_r(y) = \frac{1}{\eta}\Gamma_{\frac{\zeta}{\eta}}\left(\overline{w}_r / P_{rM}^{1-\phi}\right)^{\eta} - \nu \ln(1/P_{rM})$**, depending on average real wage, relative price $1/P_{rM}$ and critically the shape parameter of worker's productivity distribution**
- **Non-agricultural revenue:** $\mathcal{R}_{rM} = \tilde{f}_E \mathcal{D}_r^{\frac{1}{\sigma}} Z_{rM}^{\frac{\sigma-1}{\sigma}} H_{rM}$, where $\mathcal{D}_r \equiv \sum_j \tau_{rjM}^{1-\sigma} P_{jM}^{\sigma-1} \vartheta_{jM} \Gamma_\zeta L_j \overline{w}_j$**, implying revenue TFP is a combination of physical TFP and local demand *D_r***
- **Effective sectoral productivity:** $\mathscr{Z}_{rM} \equiv \tilde{f}_E^{-1} \mathcal{D}_r^{\frac{1}{\sigma}} Z_{rM}^{\frac{\sigma-1}{\sigma}}$ *and* $\mathscr{Z}_{rA} \equiv Z_{rA}\left(\Gamma_\zeta \ell_r\right)^{-\alpha}$
- **Local wages, w_{rA} and w_{rM}, and sectoral employment share s_{rA} jointly solve:**

$$w_{rM} = \mathscr{Z}_{rM}; \qquad \left(\left(\frac{\mathscr{Z}_{rM}}{w_{rA}}\right)^{\zeta} + 1\right)^{\frac{\zeta-1}{\zeta}} \left(\frac{\mathscr{Z}_{rA}}{w_{rA}}\right)^{\frac{1}{\alpha}} = 1; \qquad \frac{s_{rA}^{1+(\zeta-1)\alpha}}{1 - s_{rA}} = \left(\frac{\mathscr{Z}_{rA}}{\mathscr{Z}_{rM}}\right)^{\zeta}$$

  - **two crucial sufficient statistics,** $\mathscr{Z}_{rM}$ and $\mathscr{Z}_{rA}$**, but distribution matters**
  - **manufacture wage depends only on its own effective productivity**
  - **agricultural wage depends on both effective productivities**
  - **s_{rA} only depends on effective productivity ratio (comparative advantage)**

- **Rural locations have comparative advantage in agriculture (high productivity ratio, $\mathscr{Z}_{rA} / \mathscr{Z}_{rM}$), thus specializing in agriculture (high s_{rA}) – thus, their low income is due to low agricultural productivity and even lower manufacturing productivity**
- **Changes in effective productivities much be key drivers for changes in wage and industrialization**
- **Local wage growth and industrialization:**

$$\begin{aligned} d\ln \overline{w}_{rt} &= \phi(s_{rA})\, d\ln \mathscr{Z}_{rMt} + (1-\phi(s_{rA}))\, d\ln \mathscr{Z}_{rAt} \\ ds_{rAt} &= \psi(s_{rA})\,(d\ln \mathscr{Z}_{rAt} - d\ln \mathscr{Z}_{rMt}), \end{aligned}$$

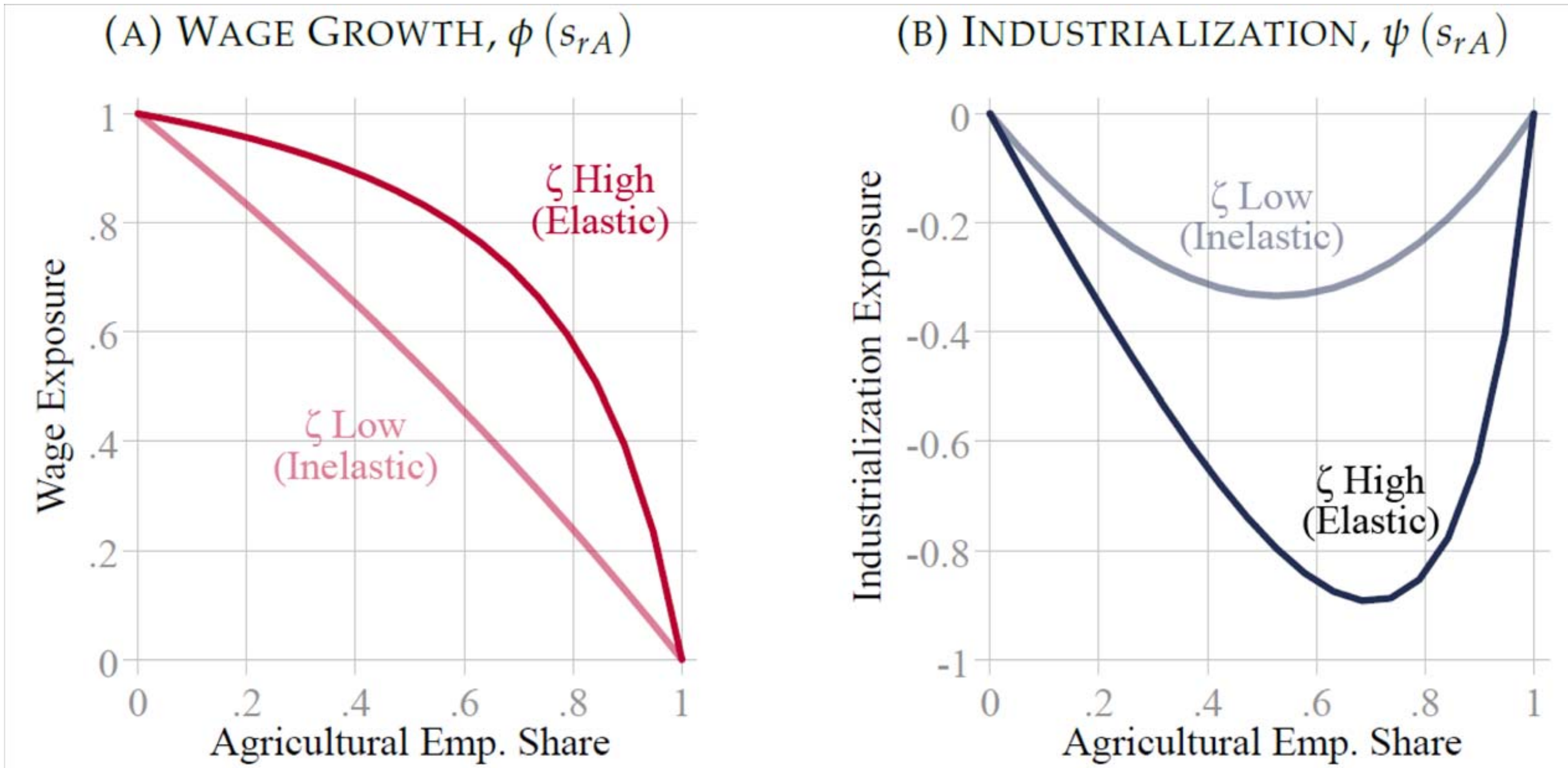
where $\phi_r \equiv \phi(s_{rA}) = \dfrac{(\gamma+1)(1-s_{rA})}{\gamma(1-s_{Ar})+1}$ **and** $\psi_r \equiv \psi(s_{rA}) = -\dfrac{s_{rAt}(1-s_{rAt})\zeta}{\gamma(1-s_{rAt})+1}$

are wage and industrialization exposure elasticities

  - **local wage growth is weighted average of local sectoral effective productivities**
  - **local industrialization change is driven by relative effective productivity**
  - **changes in effective productivity can be decomposed into physical TFP and local demand:**

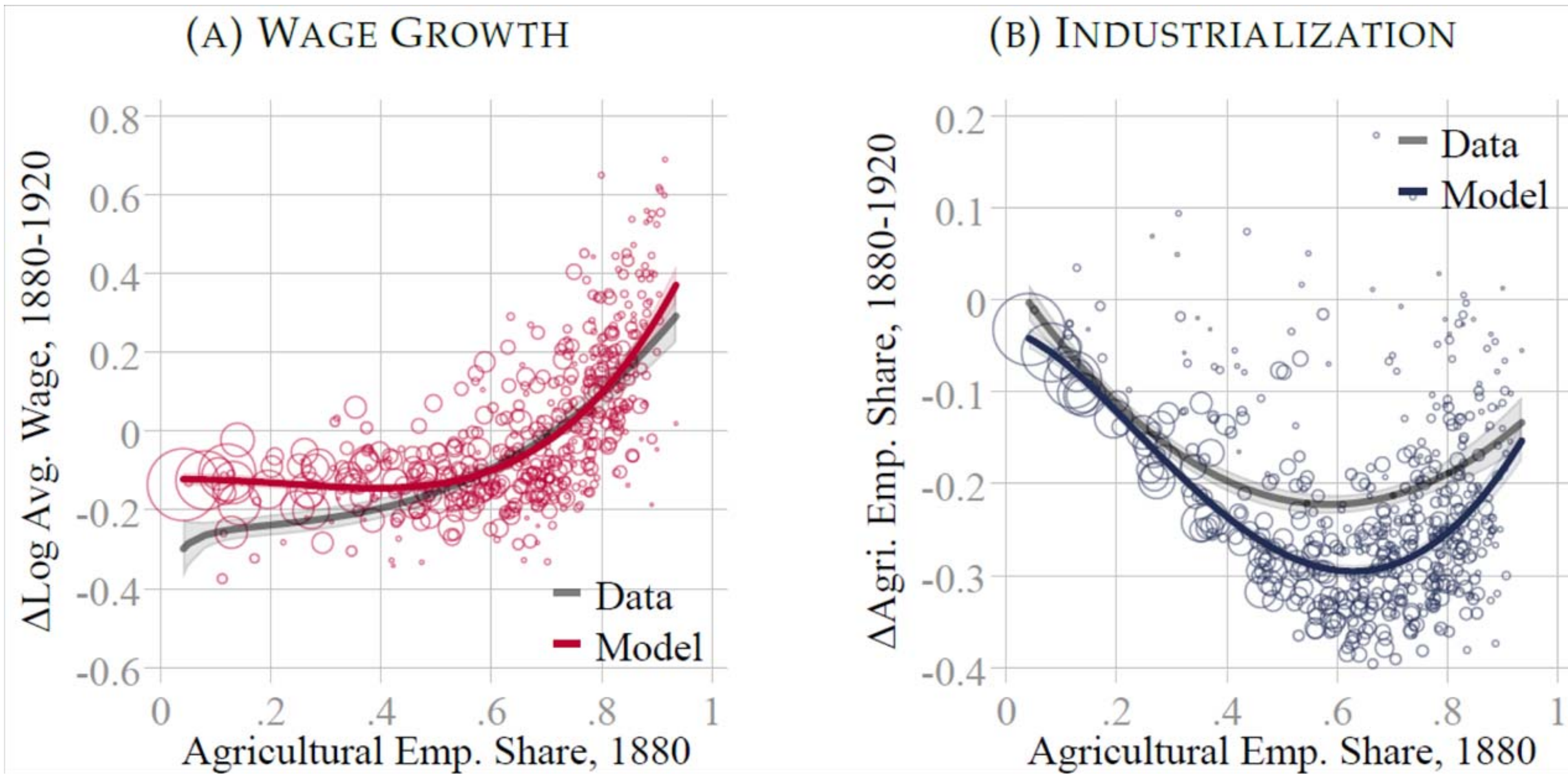
$$d\ln \mathscr{Z}_{rMt} = \frac{\sigma-1}{\sigma} d\ln Z_{rMt} + \frac{1}{\sigma} d\ln \mathcal{D}_{rt}; \qquad d\ln \mathscr{Z}_{rAt} = d\ln Z_{rAt} - \alpha d\ln \ell_{rt}$$

- **The role of the worker productivity shape parameter ζ (labor supply elasticity):**



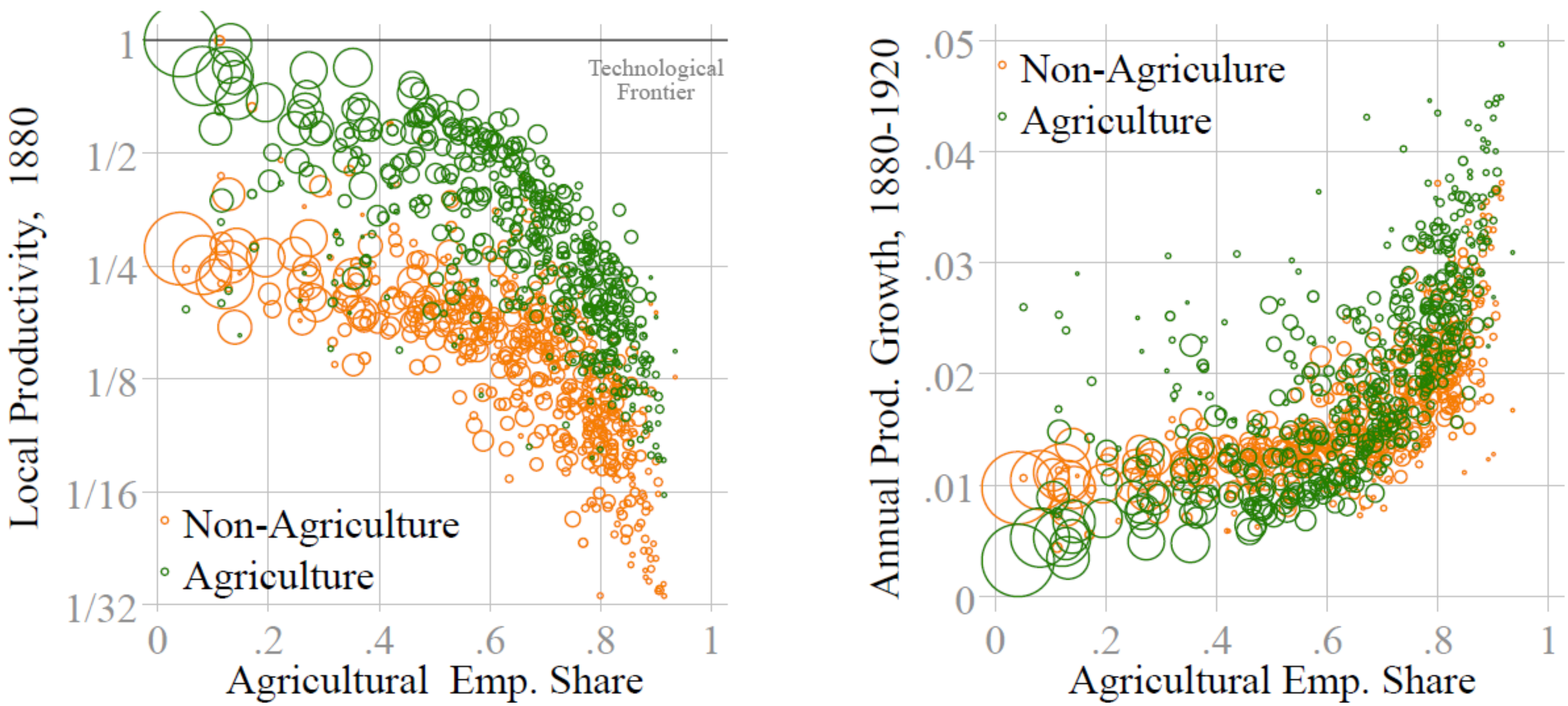
4. Quantitative Results

- **Model fit:**



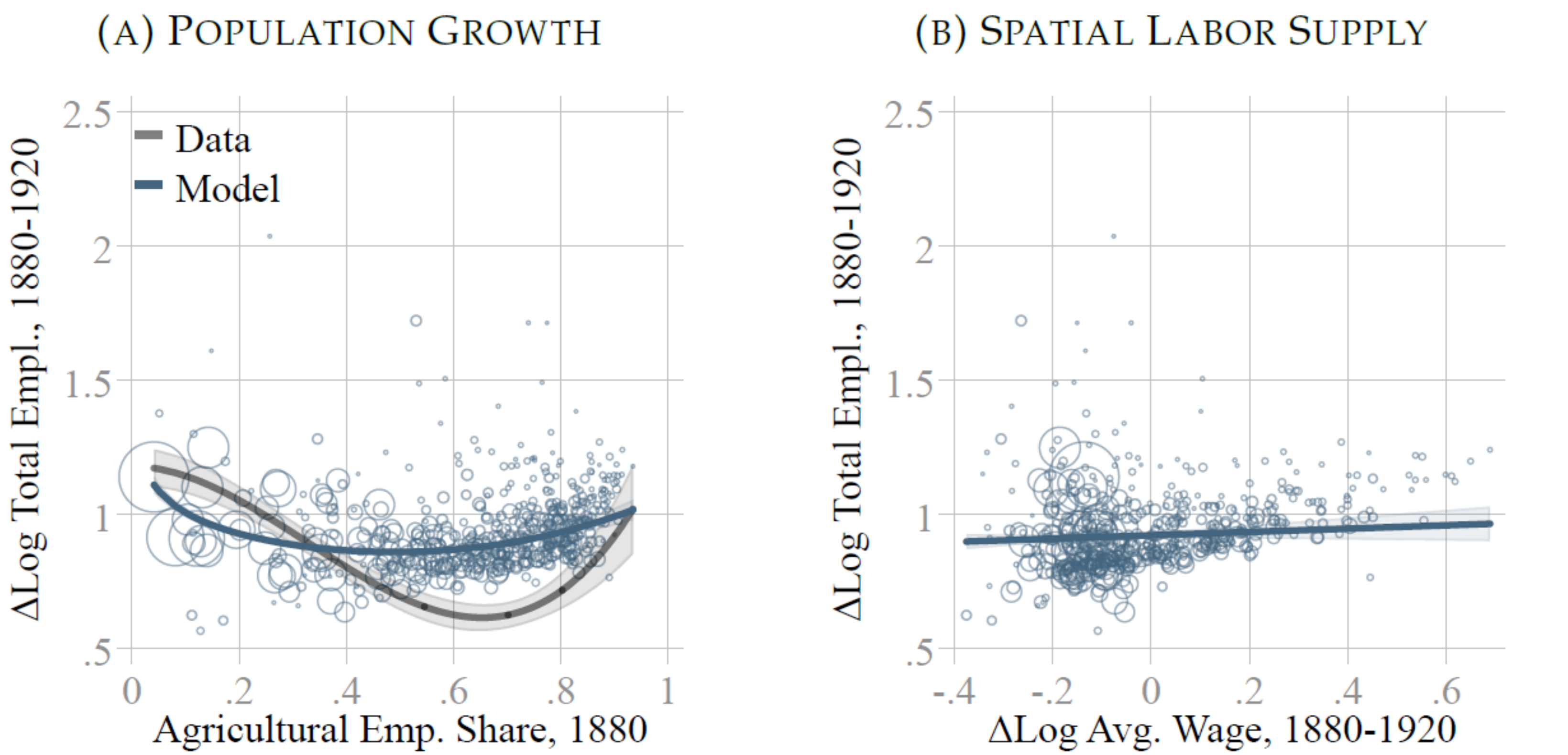
- **Implications for spatial mobility: spatial productivity ladder and local catch-up**

(A) THE PRODUCTIVITY LADDER IN 1880 (B) CATCH-UP GROWTH: 1880-1920



    - **places with very high initial agricultural employment shares have low agricultural productivity and even lower non-agricultural productivity, but have a catch even in the non-agricultural productivity**

- **Population growth and spatial labor supply**



  - **overall correlation of local population growth and initial agricultural employment share is small due to nonmonotonicity**

H. Flying Geese or Middle Income Trap: Hu-Kunieda-Nishimura-Wang (2022)

- **After take-off but before reaching a sustained growth path, countries may experience in flying geese pattern of development (Akamatsu 1962; Baumol 1991) or fall into middle income traps a certain periods of time**
- **Empirical evidence for the existence of middle income trap has been provided by Eichengreen, Park and Shin (2013) among others:**
    - **Mddle income trap is identified as a substantive fall (2% or more) in per capita real income growth of a previously fast growing (3.5% or higher) middle income country (with per capita real income exceeding US$10,000 in 2005 constant PPP prices) for a considerable duration (7 year before and after the structural break)**
    - **Upon checking a number of possible drivers, they find that more educated at secondary and higher education levels is a robust factor leading to lower likelihood for a country to fall into the middle income trap**
- **But there is no unified theory under which not only a poverty trap but a middle income trap may also exist**
- **This paper fills the gap by proposing human capital/knowledge capital to play a key role in the possibility of falling into a middle income trap**

Model

Economy

- Identical infinitely lived agents.
  - The population is normalized to one.
- Time is discrete from 0 to ∞.
- A representative agent produces general goods.
  - Technology: Cobb-Douglas production function
  - Inputs: physical capital, labor, and human capital (more generally including knowledge capital and know-how)
  - The general goods are consumed or used for investments by the representative agent.

Model (cont.)

Investment projects

- The representative agent is endowed with two types of investment projects
  - To produce physical capital. A one-for-one simple linear technology produces capital from general goods.
  - To produce human capital. The human capital is also produced from general goods, but its formation is subject to technology choice: the representative agent chooses the best technology among a number of technologies for the human capital formation.

Agents

A representative agent solves the following maximization problem for her lifetime utility:

$$\max \sum_{\tau=t}^{\infty} \delta^{\tau-t} \ln c_\tau$$

subject to

$$\begin{aligned} y_\tau \quad &: \quad = A h_{\tau-1}^{\alpha} k_{\tau-1}^{\beta} l_\tau^{\gamma} = c_\tau + i_\tau^h + i_\tau^k && (1) \\ k_\tau \quad &= \quad g_0(i_\tau^k) && (2) \\ h_\tau \quad &= \quad \max_{m=1,2,\ldots,M} \{ g_m(i_\tau^h; \bar{h}_{\tau-1}, \bar{y}_\tau) \}, && (3) \end{aligned}$$

for $\tau \geq t$, where $\delta \in (0,1)$ is the subjective discount factor and c_τ is consumption. In Eq. (1), $\alpha, \beta, \gamma \in (0,1)$ and $\alpha + \beta + \gamma = 1$.

Agents (cont.)

- $y_\tau = Ah^{\alpha}_{\tau-1} k^{\beta}_{\tau-1} l^{\gamma}_{\tau}$: the production function of general goods.
  - $h_{\tau-1}$: human capital, $k_{\tau-1}$: physical capital, l_τ: labor.
  - The production takes one gestation period (time-to-build).
- In Eqs. (1)-(3), i^h_τ and i^k_τ are investments for production of human capital and physical capital, respectively.
- Both physical and human capital depreciates entirely in one period.

Physical capital production

In Eq. (2), the production function for physical capital, $g(i^k_\tau)$, is given by

$$g_0(i^k_\tau) = i^k_\tau, \tag{4}$$

which implies that physical capital is produced from the general goods with a one-for-one technology.

Agents (cont.)

Human capital production

In Eq. (3), $g_m(i^h_\tau; \bar{h}_{\tau-1}, \bar{y}_\tau)$ is a production function for human capital when the representative agent applies the *m*th technology.

The agent chooses the best technology for human (or knowledge) capital formation and solves her maximization problem, exogenously given the externalities from the (average) past human capital, $\bar{h}_{\tau-1}$, and the (average) current-period output, $\bar{y}_\tau$, in the economy.

Agents (cont.)

Assumption

(i) $\partial g_m(i^h_\tau; \bar{h}_{\tau-1}, \bar{y}_\tau)/\partial i^h_\tau > 0$ *(ii)* $\partial^2 g_m(i^h_\tau; \bar{h}_{\tau-1}, \bar{y}_\tau)/\partial i^h_\tau \partial \bar{h}_{\tau-1} > 0$, *(iii)* $\partial^3 g_m(i^h_\tau; \bar{h}_{\tau-1}, \bar{y}_\tau)/\partial i^h_\tau \partial \bar{h}^2_{\tau-1} < 0$, *and (iv)* $\partial^2 g_m(i^h_\tau; \bar{h}_{\tau-1}, \bar{y}_\tau)/\partial \bar{h}_{\tau-1} \partial \bar{y}_\tau < 0$.

- Assumption 1-(i) guarantees the positive marginal product of human capital investment, i^h_τ.
- Assumption 1-(ii) implies that the past knowledge accumulation, which is condensed into the past human capital formation $\bar{h}_{\tau-1}$, has a positive external effect on the marginal product promoting the human capital formation.
- Assumption 1-(iii) implies that the effect of the positive externality diminishes as the past knowledge more accumulates.
- Assumption 1-(iv) mitigates the scale effect of human capital investment, i^h_t. We assume that the past knowledge accumulation more significantly contributes to the human capital formation than the scale expansion of an economy.

Agents (cont.)

To make the following analysis concrete, we specify $g_m(i_\tau^h; \bar{h}_{\tau-1}, \bar{y}_\tau)$ as

$$g_m(i_\tau^h; \bar{h}_{\tau-1}, \bar{y}_\tau) = \frac{B_m(\bar{h}_{\tau-1})}{\bar{y}_\tau} i_\tau^h, \tag{5}$$

where $B_m(\bar{h}_{\tau-1}) := \theta_m(\bar{h}_{\tau-1} - \eta_m)^\sigma$ for $\bar{h}_{t-1} \geq \eta_m$, with $\alpha < \sigma \in (0,1)$, $\theta_m \in [1, \infty)$, and $\eta_m \in [0, \infty)$.

Agents (cont.)

- Human or knowledge capital accumulation depends on the society's existing stock in the spirit of the knowledge spillovers in Romer (1986).
- However, the externality of $\bar{h}_{t-1}$ is effective only when it exceeds a certain border, η_m.
- Thus, one may view the presence of η_m as a result of scale barrier in knowledge accumulation.
  - The scale barrier in human capital considered here also captures the argument in Buera and Kaboski (2012) where higher skill is required for production of goods with greater complexity.
  - Our scale barrier setup generates similar implication to the appropriate technology model in Caselli and Coleman (2006) where skilled labor abundant rich countries tend to choose technologies more efficient to skilled workers.

Agents (cont.)

Assumption

(i) $1 = \theta_1 < \theta_2 < \cdots < \theta_M$ *and (ii)* $0 = \eta_1 < \eta_2 < \cdots < \eta_M$.

We assume that there is a trade-off between the productivity, θ_m, and the scale barrier, η_m.

Equilibrium

Transformed system:

$$q_t^k = \frac{1}{\delta(1-\gamma)} q_{t-1}^k - \frac{\beta}{1-\gamma}, \tag{E1}$$

where $q_t^k := p_t^k k_t = \lambda_t k_t$, which is the value of physical capital in t.

$$q_t^h = \frac{1}{\delta(1-\gamma)} q_{t-1}^h - \frac{\alpha}{1-\gamma}, \tag{E2}$$

where $q_t^h := p_t^h h_t$, which is the value of human capital in period t.

From FOCs & Tech Choice, we have

$$h_t = \alpha \max_m \{B_m(h_{t-1})\} \left[\frac{1}{1-\gamma} - \frac{\beta\delta}{1-\gamma}\left(\frac{1}{q^k_{t-1}}\right)\right], \tag{E3}$$

which can then be used to obtain

$$k_t = \beta A h^{\alpha}_{t-1} k^{\beta}_{t-1} \left[\frac{1}{1-\gamma} - \frac{\beta\delta}{1-\gamma}\left(\frac{1}{q^k_{t-1}}\right)\right]. \tag{E4}$$

Technology choice

Define such cutoffs as w_1 and w_2 so that $B_1(w_1) = B_2(w_1)$ and $B_2(w_2) = B_3(w_2)$. It is straightforward to show that w_1 and w_2 satisfy

$$w_1^\sigma = \theta_2(w_1 - \eta_2)^\sigma$$

and

$$\theta_2(w_2 - \eta_2)^\sigma = \theta_3(w_2 - \eta_3)^\sigma,$$

respectively, from which w_1 and w_2 are uniquely determined as $w_1 = \theta_2^{\frac{1}{\sigma}}\eta_2/(\theta_2^{\frac{1}{\sigma}} - 1)$ and $w_2 = (\theta_3^{\frac{1}{\sigma}}\eta_3 - \theta_2^{\frac{1}{\sigma}}\eta_2)/(\theta_3^{\frac{1}{\sigma}} - \theta_2^{\frac{1}{\sigma}})$.

Proposition

Suppose that Assumption 2 holds. Then, in $\max_m\{B_m(h_{t-1})\}$, *the representative agent optimally chooses the first technology* ($m = 1$) *if* $0 \leq h_{t-1} < w_1$, *the second technology* ($m = 2$) *if* $w_1 < h_{t-1} < w_2$, *and the third technology* ($m = 3$) *if* $w_2 < h_{t-1}$.

Steady states

Eqs. (E1)-(E4) form the dynamical system in equilibrium (D):

$$
\begin{cases}
q_t^h = \frac{1}{\delta(1-\gamma)} q_{t-1}^h - \frac{\alpha}{1-\gamma} \\
q_t^k = \frac{1}{\delta(1-\gamma)} q_{t-1}^k - \frac{\beta}{1-\gamma} \\
h_t = \alpha \max_m \{B_m(h_{t-1})\} \left[\frac{1}{1-\gamma} - \frac{\beta\delta}{1-\gamma} \left(\frac{1}{q_{t-1}^k} \right) \right] =: J_1(q_{t-1}^k, h_{t-1}, k_{t-1}) \\
k_t = \beta A h_{t-1}^{\alpha} k_{t-1}^{\beta} \left[\frac{1}{1-\gamma} - \frac{\beta\delta}{1-\gamma} \left(\frac{1}{q_{t-1}^k} \right) \right] =: J_2(q_{t-1}^k, h_{t-1}, k_{t-1}).
\end{cases}
$$

Steady states

The values of human and physical capital in the steady state, q^{h*} and q^{k*}, are given by

$$q^{h*} = \frac{\alpha\delta}{1-\delta(1-\gamma)} \text{ and } q^{k*} = \frac{\beta\delta}{1-\delta(1-\gamma)}.$$

Steady states

Since $B_j(h_{t-1})$ is concave, we can "potentially" obtain at most two steady states, say, $h^*_{j,1}$ and $h^*_{j,2}$, from each technology.

Summary

Propositions 2-4 imply that six steady states (including a trivial one) exist in the dynamical system if the following inequalities (IN) hold:

$$(\delta\alpha)^{\frac{1}{1-\sigma}} < \eta_2 < (1-\sigma)\sigma^{\frac{\sigma}{1-\sigma}}(\delta\alpha\theta_2)^{\frac{1}{1-\sigma}}$$
$$(\delta\alpha\theta_2)^{\frac{1}{1-\sigma}} < \eta_3 < (1-\sigma)\sigma^{\frac{\sigma}{1-\sigma}}(\delta\alpha\theta_3)^{\frac{1}{1-\sigma}},$$

in which each technology yields two steady states.

Steady states

It is straightforward to extend the analysis to the case in which the number of technologies is M with $1 = \theta_1 < \cdots < \theta_M$ and $0 = \eta_1 < \cdots < \eta_M$. In this case, $2M$ steady states appear if the following inequalities hold:

$$
\begin{aligned}
(\delta\alpha)^{\frac{1}{1-\sigma}} &< \eta_2 < (1-\sigma)\sigma^{\frac{\sigma}{1-\sigma}}(\delta\alpha\theta_2)^{\frac{1}{1-\sigma}} \\
(\delta\alpha\theta_2)^{\frac{1}{1-\sigma}} &< \eta_3 < (1-\sigma)\sigma^{\frac{\sigma}{1-\sigma}}(\delta\alpha\theta_3)^{\frac{1}{1-\sigma}} \\
&\vdots \\
(\delta\alpha\theta_{M-1})^{\frac{1}{1-\sigma}} &< \eta_M < (1-\sigma)\sigma^{\frac{\sigma}{1-\sigma}}(\delta\alpha\theta_M)^{\frac{1}{1-\sigma}}.
\end{aligned}
$$

Local dynamics

Linearization of the dynamical system (D) with the jth technology around one of the steady states, $(q^{h*}, q^{k*}, h_{j\ ,s}^{*}, k_{j\ ,s}^{*})$ $(s = 1$ or $2)$, obtains the Jacobian as follows:

$$\begin{pmatrix} \frac{1}{\delta(1-\gamma)} & 0 & 0 & 0 \\ 0 & \frac{1}{\delta(1-\gamma)} & 0 & 0 \\ 0 & J_{1,\lambda}(q^{k*}, h_{j,s}^{*}, k_{j,s}^{*}) & \alpha\delta B_j'(h_{j,s}^{*}) & 0 \\ 0 & J_{2,\lambda}(q^{k*}, h_{j,s}^{*}, k_{j,s}^{*}) & J_{2,k}(q^{k*}, h_{j,s}^{*}, k_{j,s}^{*}) & \beta \end{pmatrix},$$

where $J_{n,q^k}(q^k, h, k) := \partial J_n(q^k, h, k)/\partial\lambda$ and $J_{n,k}(\lambda, h, k) := \partial J_n(\lambda, h, k)/\partial k$ for $n = 1, 2$.

The eigenvalues of this dynamical system are given by $\rho_1 := 1/(\delta(1-\gamma))$, $\rho_2 := 1/(\delta(1-\gamma))$, $\rho_3 := \alpha\delta B_j'(h_{j,s}^{*})$, and $\rho_4 = \beta$.

Local dynamics

Proposition

Under Assumption 2, suppose that inequalities (IN) are satisfied. Consider the jth technology. Then, the following hold:

- *There exists no equilibrium sequence,* $\{q_t^h, q_t^k, h_t, k_t\}$, *around the lower steady state,* $(q^{h*}, q^{k*}, h_{j,1}^*, k_{j,1}^*)$, *that converges to this steady state.*
- *There exists a unique equilibrium sequence,* $\{q_t^h, q_t^k, h_t, k_t\}$, *around the higher steady state,* $(q^{h*}, q^{k*}, h_{j,2}^*, k_{j,2}^*)$, *that converges to this steady state.*

Global analysis

In the local analysis, it is still unclear whether an equilibrium sequence exists around the higher steady state. Moreover, even if an equilibrium sequence exists around the higher steady state, the local analysis does not clarify where it goes.

Global analysis

It follows from the transversality condition, $\lim_{u\to\infty}\delta^u q^k_{t+u} = \lim_{u\to\infty}\delta^u q^h_{t+u} = 0$, that $\lim_{u\to\infty}[\delta(1-\gamma)]^u q^k_{t+u} = \lim_{u\to\infty}[\delta(1-\gamma)]^u q^h_{t+u} = 0$. Therefore, we obtain $q^k_t = \beta\delta/(1-\delta(1-\gamma))$ and $q^h_t = \alpha\delta/(1-\delta(1-\gamma))$, respectively, which implies that the equilibrium sequences of $\{q^k_t, q^h_t\}$ are uniquely determined, being equal to $\{q^k_t, q^h_t\} = \{q^{k*}, q^{h*}\}$.

Then, from Proposition 1,

$$h_t = \begin{cases} \alpha\delta h_{t-1}^{\sigma} & \text{if } 0 \leq h_{t-1} < w_1 \\ \alpha\delta\theta_2 (h_{t-1} - \eta_2)^{\sigma} & \text{if } w_1 \leq h_{t-1} < w_2 \\ \alpha\delta\theta_3 (h_{t-1} - \eta_3)^{\sigma} & \text{if } w_2 \leq h_{t-1} \end{cases} \tag{h}$$

and

$$k_t = \beta\delta A h_{t-1}^{\alpha} k_{t-1}^{\beta}. \tag{k}$$

Global analysis

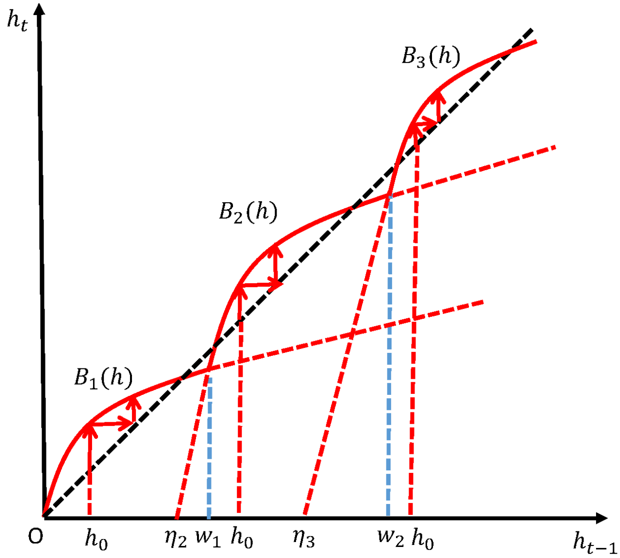


Figure 1. Phase diagram of h_t

Global analysis

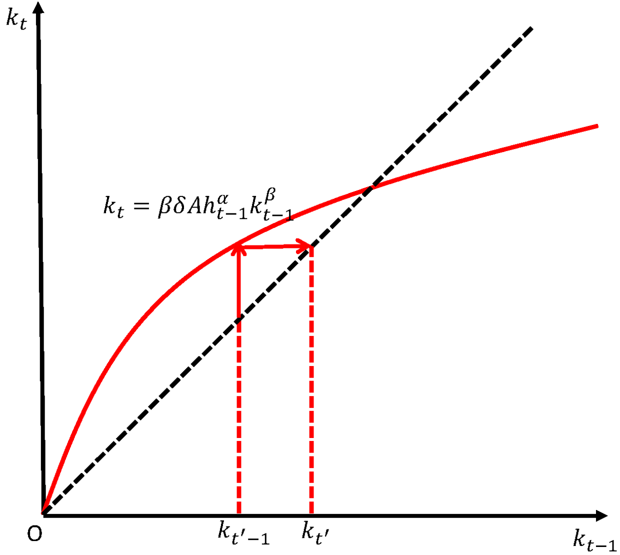


Figure 2. Conditional phase diagram of k_t given h_{t-1}

Proposition

Suppose that Assumption 2 holds. Then, there exist only two steady states in the dynamical system, which are a trivial one and the high steady state of the third technology if and only if the following parameter condition holds:

$$(\delta\alpha)^{\frac{1}{1-\sigma}} > \max\{\Phi_1, \Phi_2\},$$

where

$$\Phi_i := \frac{\left(\theta_{i+1}^{\frac{1}{\sigma}}\eta_{i+1} - \theta_i^{\frac{1}{\sigma}}\eta_i\right)^{\frac{1}{1-\sigma}}}{\theta_i^{\frac{1}{1-\sigma}}\theta_{i+1}^{\frac{1}{1-\sigma}}\left(\theta_{i+1}^{\frac{1}{\sigma}} - \theta_i^{\frac{1}{\sigma}}\right)(\eta_{i+1} - \eta_i)^{\frac{\sigma}{1-\sigma}}}.$$

Take-off and flying geese

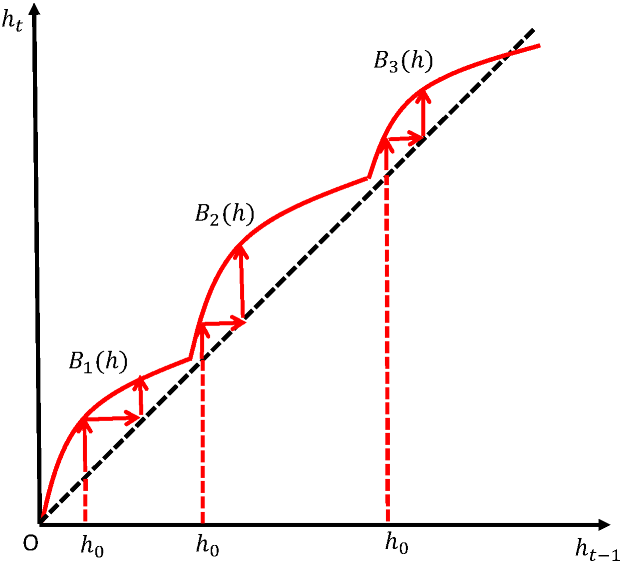


Figure 3. Flying geese pattern

Middle income trap

Define the set of all globally available technogies as $T := \{1, \cdots, M\}$ and the set of "interior" technologies as $I := \{2, \cdots, M-1\}$.

Proposition

Suppose that Assumption 2 holds. Then, there exist nontrivial steady states in the dynamical system, featuring middle income trap at various technologies in $J \subseteq I$ if and only if the following parameter condition holds:

$$\min_{j \in J}\{\Phi_j\} > (\delta\alpha)^{\frac{1}{1-\sigma}} > \max_{m \in T \setminus J}\{\Phi_m\}. \tag{C}$$

Middle income trap

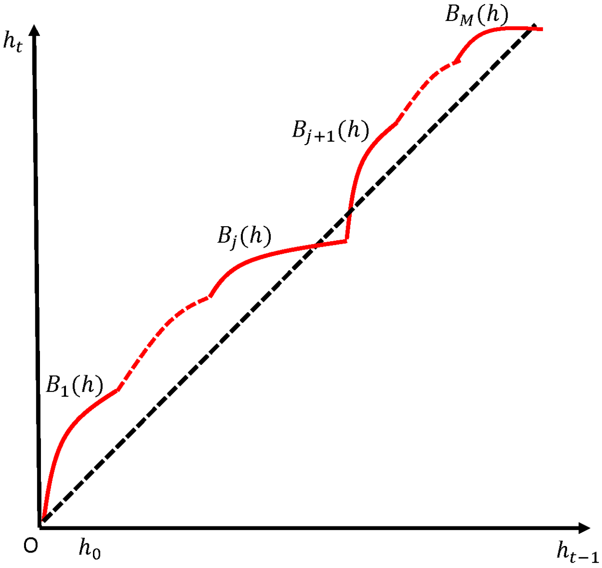


Figure 4. Trap in the jth technology

Middle income trap

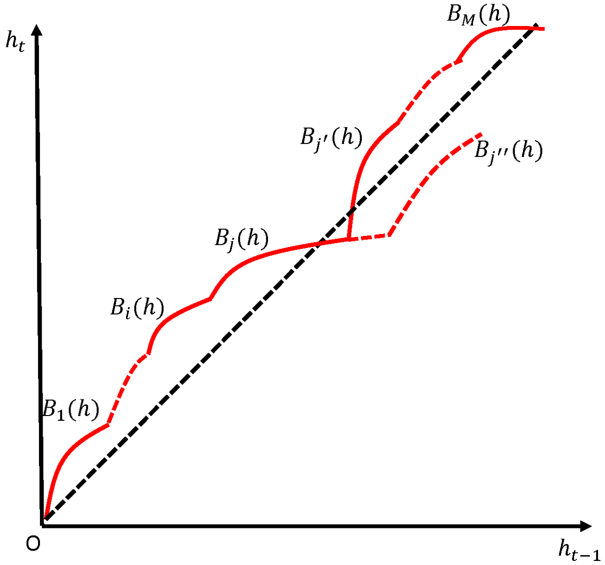


Figure 5. Restricted middle income trap

Middle income trap

The necessary condition for trap at the *j*th technology is:

$$\frac{\left(\theta_{j+1}^{\frac{1}{\sigma}}\eta_{j+1}-\theta_{j}^{\frac{1}{\sigma}}\eta_{j}\right)^{\frac{1}{1-\sigma}}}{\theta_{j}^{\frac{1}{1-\sigma}}\theta_{j+1}^{\frac{1}{1-\sigma}}\left(\theta_{j+1}^{\frac{1}{\sigma}}-\theta_{j}^{\frac{1}{\sigma}}\right)\left(\eta_{j+1}-\eta_{j}\right)^{\frac{\sigma}{1-\sigma}}}>\left(\delta\alpha\right)^{\frac{1}{1-\sigma}}$$

Middle income trap

Let $g_{\theta_j} = \frac{\theta_{j+1}}{\theta_j}$ and $g_{\eta_j} = \frac{\eta_{j+1}}{\eta_j}$ capture, respectively, the productivity gap and the barrier gap between the $j+1$th and the jth technologies. Then the above inequality reduces to

$$\frac{(\eta_j)^{1-\sigma}\left[\left(g_{\theta_j}\right)^{\frac{1}{\sigma}} g_{\eta_j} - 1\right]}{\theta_j \left(g_{\theta_j}\right)^{\frac{1}{\sigma}} \left(g_{\eta_j} - 1\right)^{\sigma}} > \delta\alpha$$

It is straightforward to show that the left-hand side of this inequality is strictly decreasing in θ_j and strictly increasing in η_j and g_{θ_j}.

Proposition

Suppose that Assumption 2 holds. Then, a middle income trap of the jth technology for $1 < j < M$ is likely to arise if the productivity of the jth technology is not too large, the scale barrier of the jth technology is sufficiently high and the productivity gap between the $j+1$th and the jth technologies is sufficiently big.

Calibration

Solving (θj,ηj) from:

$$\left(\frac{y_{t+1}}{A_{t+1}}\right)^{\frac{1}{\alpha}}(\beta\delta y_t)^{-\frac{\beta}{\alpha}} = \alpha\delta\theta_j\left(\left(\frac{y_t}{A_t}\right)^{\frac{1}{\alpha}}(\beta\delta y_{t-1})^{-\frac{\beta}{\alpha}} - \eta_j\right)^{\sigma}$$

and

$$\eta_j = \frac{(\beta\delta y_{t-1})^{-\frac{\beta}{\alpha}}\left(y_{t-1}/A_{t-1}\right)^{\frac{1}{\alpha}}\left(\frac{y_t/A_t}{y_{t-1}/A_{t-1}}\right)^{\frac{1}{\alpha}}\left(\left(\left(\frac{y_{t+2}/A_{t+2}}{y_{t+1}/A_{t+1}}\right)^{\frac{1}{\alpha}}\left(\frac{y_{t+1}}{y_t}\right)^{-\frac{\beta}{\alpha}}\right)^{\frac{1}{\sigma}} - \left(\frac{y_{t+1}/A_{t+1}}{y_t/A_t}\right)^{\frac{1}{\alpha}}\left(\frac{y_t}{y_{t-1}}\right)^{-\frac{\beta}{\alpha}}\right)}{\left(\left(\frac{y_{t+2}/A_{t+2}}{y_{t+1}/A_{t+1}}\right)^{\frac{1}{\alpha}}\left(\frac{y_{t+1}}{y_t}\right)^{-\frac{\beta}{\alpha}}\right)^{\frac{1}{\sigma}} - 1}$$

Use data from PWT9.0, with 3 year MA and examine in 5 year intervals to identify flying geese periods and middle income trap

Calibration Result

- **Advanced countries**
  - **US: trapped mid 60s/early 70s/early 80s/early 2000s; flying otherwise**
  - **UK: trapped late 70s-late 80s/2000s; flying otherwise**
  - **Germany: trapped late 70s-early 80s/mid-late 2000s; flying otherwise**
  - **Japan: trapped early 70s/early 80s/late 90s; flying otherwise**
- **Fast growing economies:**
  - **Hong Kong: trapped late 1990s; flying otherwise**
  - **Singapore: trapped late 70s-early 80s/late 90s; flying otherwise**
  - **South Korea: trapped early 70s/late 2000s; flying otherwise**
  - **Taiwan: trapped late 70s-early 80s; flying otherwise**
- **Emerging growing economies:**
  - **China: trapped late 50s-early 80s/mid 90s; flying mostly after mid 80s**
  - **Malaysia: trapped early 70s/late 90s; flying otherwise**
  - **Mexico: trapped late 60s/late 70s-80s/early 2000s; flying before mid 60s**
- **Development laggards:**
  - **Argentina: trapped early 60s/most of 70s and 80s; not much flying**
  - **Greece: trapped late 70s-early 90s/most of 2000s; flying before early 70s**
  - **Philippines: trapped mid 60s/mid 70s/mid 80s/mid 90s/late 2000s; not much flying**

Growth Accounting:

$$1=\beta\frac{\Delta\ln k_{t-1}}{\Delta\ln y_t}-\alpha\frac{\Delta\ln n_t}{\Delta\ln y_t}+\frac{\Delta\ln A_t}{\Delta\ln y_t}+\alpha\frac{\Delta\ln\theta_j^*}{\Delta\ln y_t}+\alpha\sigma\frac{\Delta\ln\left(h_{t-2}-\eta_j^*\right)}{\Delta\ln y_t}$$

cap accum pop TFP H upgrading H barrier reduction

- **In advanced countries, on average, human capital technology upgrading and human capital barrier reduction account for 51% of economic growth during the first 30-year window and for 39% during the second 30-year window**
- **In the fast-growing economies except Korea, human capital technology and human capital barriers are more important drivers; in Korea, physical capital accumulation is the main driver; on average, human capital technology upgrading and human capital barrier reduction, on average, contribute to 55% and 45% over the two 30-year windows, respectively**
- **In emerging growing economies, on average, human capital technology upgrading and human capital barrier reduction account for 41% and 38% of economic growth over the two 30-year windows, respectively**
- **In the development laggards, by excluding outliers, human capital technology upgrading and human capital barrier reduction on average contribute to 56% and 25% of economic growth over the two 30-year windows, respectively**

I. Foreign Technology Adoption and Flying Geese: Hu-Kunieda-Nishimura-Wang (2024)

- **During the post-WWII era, we have observed widening world income disparity accompanied by a mixture of**
  - **poverty/middle income trap (MIT, à la Eichengreen-Park-Shin 2013)**
  - **flying geese paradigm (FGP, à la Akamatsu 1962)**

- **Meanwhile, it has been argued by development economists that FDI played an important role in the rapid development of many small open economies, particularly in East Asia and Southeast Asia (Wan 2004; Wang-Wong-Yip 2018; Kunieda-Okada-Sawada-Shibata 2021).**

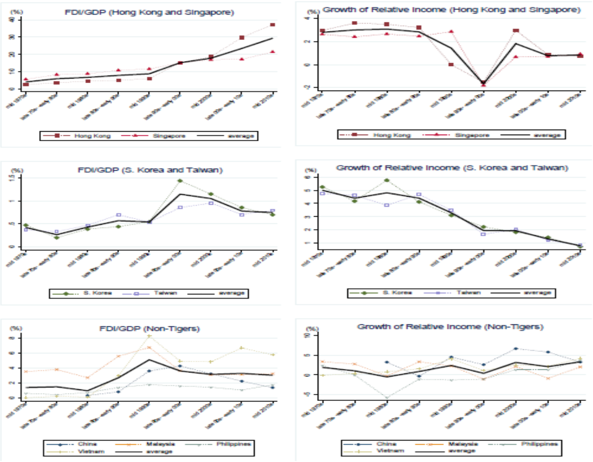
- **Questions:**

1. **What is the role of foreign technology adoption via FDI played in economic growth?**

2. **What are the underlying drivers for foreign technology adoption and for technology adoption-led growth?**

Motivation

- FDI intensity and relative income to the US:



Motivation

- Crowding-in effect of the net inflow of FDI: Borensztein-De Gregorio-Lee (1998) find that "the main channel through which FDI contributes to economic growth is by **stimulating technological progress**, rather than by increasing total capital accumulation in the host economy" (p.118).
- Empirically, FDI have been found to
  - induce firm-embodied technologies to be transferred globally (Alviarez-Cravino-Ramondo 2019)
  - enable upgrading product quality (Bajgar-Javorcik 2020) or producing complex products (Javorcik-Turco-Maggioni 2018)
  - escape from a middle-income trap (Bajgar-Javorcik 2020).
- Empirically, such gains of FDI depend on a host country's
  - absorptive capability of the advanced technologies (Borensztein-De Gregorio-Lee 1998),
  - institutional quality (Jude-Levieuge 2017),
  - other costs and barriers (Alfaro 2017).

What we do

- To address the two research questions, we develop an optimal growth framework with endogenous technology choice – foreign vs. domestic – incorporating the key features identified by empirical studies:
  1. the **trade-off** between more productive advanced foreign technology and cost of adoption barriers
  2. uncompensated foreign technology spillovers
  3. distance to technology frontier
  4. artificial scale effect removal
  5. world price wedge.
- The technology choice offers a novel story of **endogenous TFP**.
- To quantify, we fit the model to data from 8 Asian economies at different development stages (4 Asian Tigers and 4 emerging economies).

Literature

- FGP: Matsuyama (2002), Hu-Kunieda-Nishimura-Wang (2023)
- MIT: Wang-Wong-Yip (2018), Hu-Kunieda-Nishimura-Wang (2023)
- Distance to the technological frontier: Acemoglu-Aghion-Zilibotti (2006)
- Technology spillovers: Buera-Oberfield (2020)
- Absorptive capability of FDI: Borensztein-De Gregorio-Lee (1998).

Basic Structure

- Discrete-time with a continuum of infinitely lived agents whose population is normalized to one
- Small open economy with a single traded good produced by two factor inputs, labor and capital, where capital can be accumulated by domestic or foreign investments:

$$Y_t := (A_t K_{t-1})^{\beta} L_t^{1-\beta} = Z_{t-1}^{\beta} L_t^{1-\beta}, K_{t-1} := K_{t-1}^{d} + K_{t-1}^{f}$$

- Optimization problem (all in per worker form):

$$\begin{array}{rl} \max & \sum_{s=t}^{\infty} \delta^{s-t} \ln c_s \\ \text{subject to} & \begin{array}{l} y_s = z_{s-1}^{\beta} = c_s + i_s^d + p_s i_s^f \\ n_{s+1} k_s^d = h(i_s^d) = \Omega \cdot i_s^d \\ n_{s+1} k_s^f = g(i_s^f; \bar{z}_{s-1}, \bar{z}_{s-1}^{*}, \bar{y}_s). \end{array} \end{array}$$

Foreign Technology Conversion

- Foreign capital formation: depends on a conversion multiplier $\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)$ and foreign FDI (i^f_s) scaled down by average domestic output ($\bar{y}_s$) (to remove scale effect)

$$g(i^f_s; \bar{z}_{s-1}, \bar{z}^*_{s-1}, \bar{y}_s) = \underbrace{\chi_s\left(\bar{z}_{s-1}; \theta, \eta\right) \cdot \left(\bar{z}^*_{s-1}\right)^{\varsigma} \cdot \left(\frac{\bar{z}^*_{s-1} - \eta^*}{\bar{z}_{s-1} - \eta}\right)^{\varepsilon}}_{\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)} \cdot \frac{i^f_s}{\bar{y}_s},$$

where $0 \leq \varsigma < 1$ and $\varepsilon > 0$ and $\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)$ consists of

  - foreign technology adoption: $\chi_s\left(\bar{z}_{s-1}; \theta, \eta\right)$
  - international technological spillover: $\left(\bar{z}^*_{s-1}\right)^{\varsigma}$
  - technology gap: $\left[\left(\bar{z}^*_{s-1} - \eta^*\right) / \left(\bar{z}_{s-1} - \eta\right)\right]^{\varepsilon}$.

- Assume $\chi_s\left(\bar{z}_{s-1}; \theta, \eta\right) := \theta(\bar{z}_{s-1} - \eta)^{\sigma}, \forall \bar{z}_{s-1} \geq \eta$, where $\theta > 0$ (efficacy), $\eta > 0$ (barrier), and hence $\Gamma := \theta(\bar{z}_{s-1} - \eta)^{\sigma - \varepsilon}\left(\bar{z}^*_{s-1}\right)^{\varsigma + \varepsilon}, \beta < \sigma - \varepsilon < 1$.

Technology Choice

- Optimization: total investment $\tilde{\imath}_t := i_t + p_t i_t^f$ and capital

$$n_{t+1} z_t = A_{t+1} \max\left\{\Omega, \frac{\Gamma\left(\bar{z}_{t-1}, \bar{z}^*_{t-1}; \theta, \eta\right)}{p_t \bar{y}_t}\right\} \tilde{\imath}_t$$

- Capital evolves according to:

$$z_t = \frac{A_{t+1}\Omega\delta\beta}{\min\left\{1, \frac{p_t \Omega y_t}{\Gamma\left(z_{t-1}, z^*_{t-1}; \theta, \eta\right)}\right\} n_{t+1}} z_{t-1}^{\beta}$$

- Technology choice ($\tilde{p}_t := \theta\left(z_{t-1} - \eta\right)^{\sigma-\varepsilon}\left(z^*_{t-1}\right)^{\varsigma+\varepsilon} / \Omega z^{\beta}_{t-1}$):

$$z_t = \begin{cases} \frac{\delta\beta\Omega}{n_{t+1}} A_{t+1} z_{t-1}^{\beta} := h^D\left(z_{t-1}\right) \text{ (if } p_t \geq \tilde{p}_t\text{)} \\ \frac{\delta\beta\left(z^*_{t-1}\right)^{\varsigma+\varepsilon}}{n_{t+1} p_t} A_{t+1} \theta\left(z_{t-1} - \eta\right)^{\sigma-\varepsilon} := h^F\left(z_{t-1}\right) \text{ (if } p_t < \tilde{p}_t\text{).} \end{cases}$$

Technology Choice

Theorem

Under $\beta < \sigma - \varepsilon < 1$ and given the relative price of FDI (p), the more advanced foreign technology is more likely to be adopted

(i) *the higher the FDI conversion efficacy (θ),*

(ii) *the lower the FDI barrier (η),*

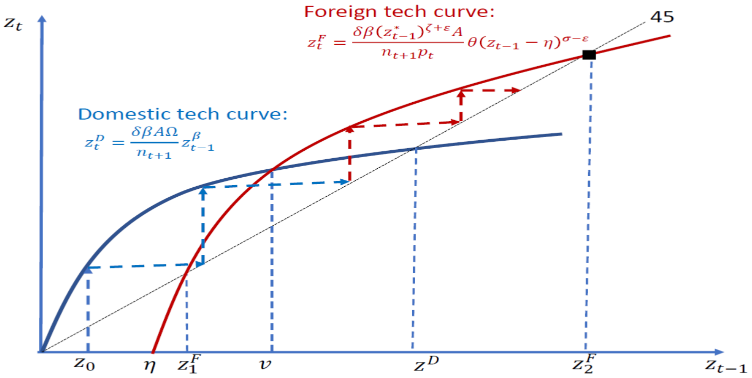
(iii) *the larger technology gap ($[\bar{z}^* / (\bar{z} - \eta)]^{\varepsilon}$), or,*

(iv) *the stronger the international technology spillover ($\bar{z}^{*\varsigma}$) is.*

Flying or Trapped

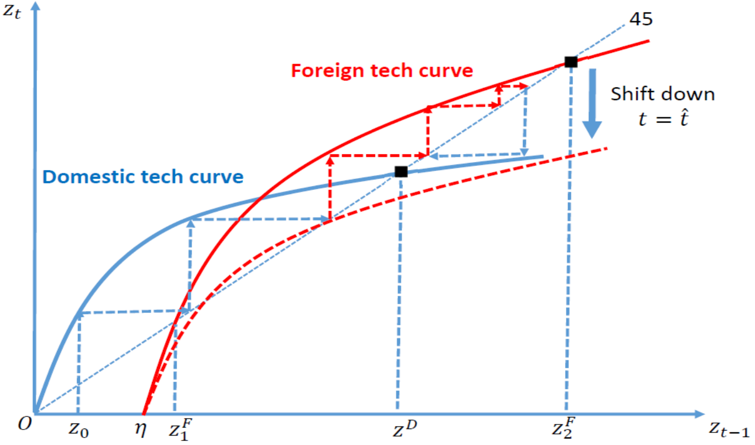
- Assume $\eta < (1-\sigma+\varepsilon)(\sigma-\varepsilon)^{\frac{\sigma-\varepsilon}{1-(\sigma-\varepsilon)}}\left(\frac{\delta\beta A\Theta}{np}\right)^{\frac{1}{1-(\sigma-\varepsilon)}} := \eta_1$
- Flying with advanced foreign technology:

$$\eta < \eta_2 := \left(\frac{\delta\beta\Omega A}{n}\right)^{\frac{1}{1-\beta}} - \left(\Omega\left(\frac{A\delta\beta}{n}\right)^{\beta}\right)^{\frac{1}{(1-\beta)(\sigma-\varepsilon)}}\left(\frac{p}{\Theta}\right)^{\frac{1}{\sigma-\varepsilon}}$$



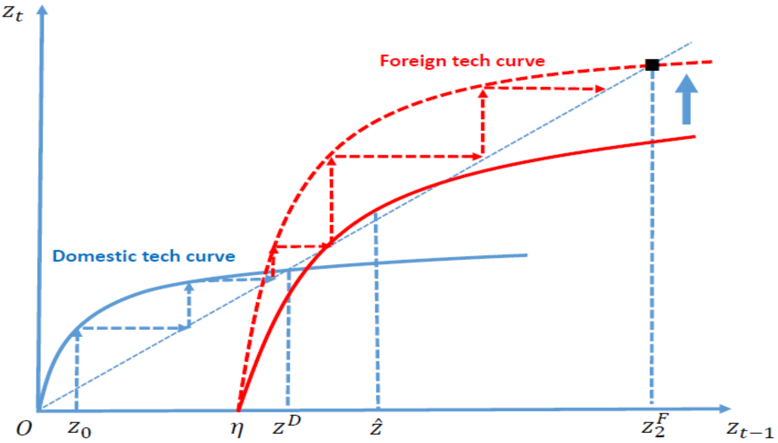
Flying or Trapped

- Trapped in domestic low technology: $\eta_2 < \eta < \eta_1$



Small Push

- A small push can enable an economy to escape from a middle income trap:



FDI and Growth

Theorem

Under $\beta < \sigma - \varepsilon < 1$ and $\eta < \eta_1$, a higher FDI conversion efficacy (θ), a lower FDI barrier (η), or a stronger international technology spillover ($\bar{z}^{*\varsigma}$), in conjunction with a lower relative price of FDI (p) can propel the economy to exhibit a flying geese paradigm and to escape from a middle income trap.

- The role played by adoption efficacy and barrier echoes Borensztein-De Gregorio-Lee (1998), Alfaro (2017), and Jude-Levieuge (2017)
- The escape from a middle-income trap lends theoretical support to Bajgar-Javorcik (2020)
- The role of FDI played in flying geese complements the stories of technology assimilation by Wang-Wong-Yip (2018) and human capital upgrading by Hu-Kunieda-Nishimura-Wang (2023).

Calibration

- 4 Asian Tigers plus 4 LDCs (China/Malaysia/Philippines/Vietnam), differing in growth, sizes, openness and FDI intensities.
- Annual data over 1973-2018 whenever available.
- Foreign set to the US (benchmark).
- Preset $\delta = 0.95$ and $\beta = 1/3$ (literature).
- Letting $\eta_\tau(z_{t-1}) := \tilde{\eta}_\tau z_{t-1}$, we have:

$$\ln\left(\frac{n_{t+1}k_t}{i_t^f/y_t}\right) = \ln\theta_\tau + (\sigma\text{-}\varepsilon)\left[\ln(1\text{-}\tilde{\eta}_\tau)\text{-}\ln z_{t-1}\right] + (\varsigma\text{+}\varepsilon)\ln z_{t-1}^*.$$

By estimating country-by-country $\ln\left(\frac{n_{t+1}k_t}{i_t^f/y_t}\right) = \sum_{\tau=1}^{Y}\gamma_\tau d_\tau + \alpha_1 \ln z_{t-1} + \alpha_2 \ln z_{t-1}^* + \xi_t$, we obtain: $\hat{\alpha}_1 = \sigma - \varepsilon$ and $\hat{\alpha}_2 = \varsigma + \varepsilon$.

Calibration

- To recover $(\sigma, \varsigma, \varepsilon)$, we use the estimate of ς by Buera-Oberfield (2020) and the estimate of ε by Peters-Zilibotti (2021) to obtain $\varsigma/\varepsilon = 1.5$.
- Estimation/calibration results:

	$\hat{\alpha}_1$	$\hat{\alpha}_2$	ε	σ	ς
China	0.3298	0.1210	0.0484	0.3782	0.0726
Hong Kong	0.1317	0.2970	0.1188	0.2505	0.1782
S. Korea	0.1746	0.3132	0.1253	0.2999	0.1879
Malaysia	0.2635	0.1762	0.0705	0.3340	0.1057
Philippines	0.3483	0.1247	0.0499	0.3982	0.0748
Singapore	0.1614	0.2492	0.0997	0.2611	0.1495
Taiwan	0.1837	0.3049	0.1220	0.3057	0.1829
Vietnam	0.1753	0.2342	0.0937	0.2690	0.1405

Calibration

- Calibrate $\{\theta_\tau, \eta_\tau\}$ based on the model: We obtain the $100,000$ sets of $(\theta_\tau, \tilde{\eta}_\tau)$ for each technological interval. Then, we will pair $\tilde{\eta}_\tau$ with the randomly chosen z_{t-1} from the set of capital stock values within each interval and create $100,000$ of $\tilde{\eta}_\tau z_{t-1}$. By taking the average of $\tilde{\eta}_\tau z_{t-1}$, we obtain the calibrated η_τ. The algorithm is:

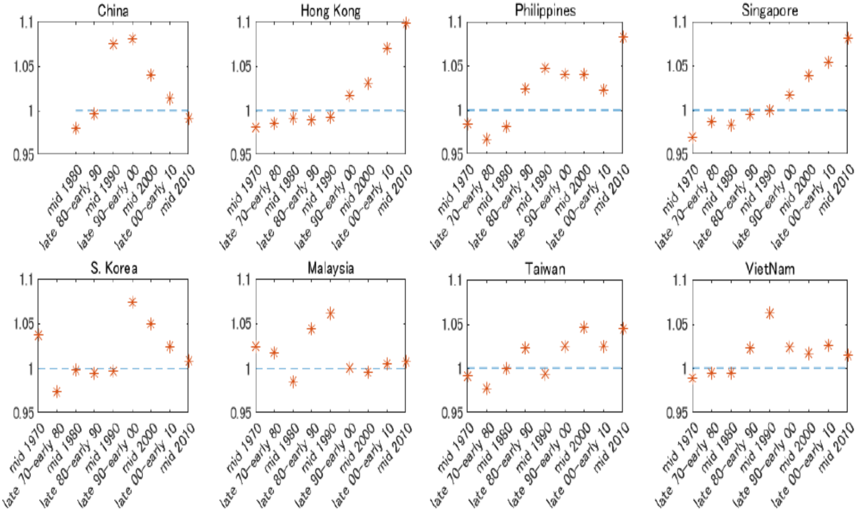
$$\min_{\theta_\tau, \tilde{\eta}_\tau} \left\{ \sum_{t \in T_\tau} \left[\ln \theta_\tau + \tilde{\alpha}_{1,t} \ln(1 - \tilde{\eta}_\tau) - \tilde{\gamma}_t \right]^2 \right\} \text{ s.t. } \theta_\tau, \tilde{\eta}_\tau \geq 0$$

- Estimation/calibration results:
  - The extent of such barriers relative to domestic effective capital $(\tilde{\eta}_\tau)$ is approximately 20% on average and relatively stable over time.
  - The degrees of FDI conversion efficacy (θ_τ) are relatively stable in China, South Korea, Malaysia, and Taiwan but declining in Hong Kong, the Philippines, Singapore, and Vietnam.

Simulated Technology Choice

- $\Gamma(z_{t-1}, z^*_{t-1}; \theta, \eta)\left(i^f_t / (y_t n_{t+1} k_t)\right) < 1 \Longrightarrow$ domestic technology.
- $\Gamma(z_{t-1}, z^*_{t-1}; \theta, \eta)\left(i^f_t / (y_t n_{t+1} k_t)\right) > 1 \Longrightarrow$ adopting foreign technology.
- By regressing $\Gamma(z_{t-1}, z^*_{t-1}; \theta, \eta)\left(i^f_t / (y_t n_{t+1} k_t)\right)$ on the technological duration dummies (d_τ) using the Bayesian method, we obtain its simulated distribution for each technological episode.
- Based on the simulated distribution, we judge that the foreign technology becomes more likely to be adopted if the likelihood for adopting the foreign technology is greater than 50%.

Simulated Technology Choice: Likelihood Ratio



Counterfactual Analysis

- Differing from the benchmark y_t, the counterfactual y_t^C starts from the same $y_0^C = y_0$ but with only domestic technology after the initial year 0:

$$y_t = \underbrace{(A_t \Xi_t)^\beta}_{\text{(TFP)}} \times \underbrace{\left(\frac{\delta \beta y_{t-1}}{n_t}\right)^\beta}_{\text{(input)}} \quad \text{and} \quad y_t^C = \underbrace{(A_t \Omega)^\beta}_{\text{(TFP)}} \times \underbrace{\left(\frac{\delta \beta y_{t-1}^C}{n_t}\right)^\beta}_{\text{(input)}}$$

where the endogenous TFP compoent (excluding the power β) is given by,

$$\Xi_t := \frac{\theta_\tau \frac{(z_{t-2}-\eta_\tau)^\sigma}{y_{t-1}} \left(\frac{z_{t-2}^*}{z_{t-2}-\eta_\tau}\right)^\varepsilon (z_{t-2}^*)^\varsigma}{p_{t-1}}.$$

- In counterfactual exercises, mask **endogenous TFP** by setting $\Xi_t = \Omega$ and to pin **input** by setting $y_{t-1} = y_{t-1}^C$.

Decomposition Analysis

- Contribution of FDI to growth: $\triangle =:\text{mean}[\frac{y_T}{y_0}] - \text{mean}[\frac{y_T^C}{y_0}]$ (geometric mean).
- % Contribution of FDI to growth: $\varpi := \triangle/\text{mean}[\frac{y_T}{y_0}]$.
- Compute the time-series geometric mean of the ratio of each factor to Ξ_t:
  - $\rho_1 = \text{mean}\left[\frac{\theta_\tau}{\Xi_t}\right]$, $\rho_2 = \text{mean}\left[\frac{(z_{t-2}-\eta_\tau)^\sigma/y_{t-1}}{\Xi_t}\right]$,
  - $\rho_3 = \text{mean}\left[\frac{(z^*_{t-2}/(z_{t-2}-\eta_\tau))^\varepsilon}{\Xi_t}\right]$, $\rho_4 = \text{mean}\left[\frac{(1/p_{t-1})}{\Xi_t}\right]$,
  - $\rho_5 = \text{mean}\left[\frac{(z^*_{t-2})^\varsigma}{\Xi_t}\right]$, $\sum_{i=1}^5 \rho_i = 1$.

Decomposition Analysis

- We then compute 6 counterfactual output growth mean$[\frac{y_T^{C_i}}{y_0}]$ by masking each factor driving the TFP gaps and the input gap by setting:
  - (adoption efficacy) $\theta_\tau = \Omega^{\rho_1}$
  - (barrier mitigation) $\frac{(z_{t-2}-\eta_\tau)^\sigma}{y_{t-1}} = \Omega^{\rho_2}$
  - (technology gap) $(\frac{z^*_{t-2}}{z_{t-2}-\eta_\tau})^\varepsilon = \Omega^{\rho_3}$
  - (price wedge) $1/p_{t-1} = \Omega^{\rho_4}$
  - (technology spillover) $(z^*_{t-2})^\varsigma = \Omega^{\rho_5}$
  - (input gap) $(y_{t-1})^\beta = (y^C_{t-1})^\beta$.
- The contribution of each factor driving the TFP gaps $\triangle_i :=$mean$[\frac{y_T}{y_0}]-$mean$[\frac{y_T^{C_i}}{y_0}]$ and the % contribution $\varpi_i := \triangle_i/\triangle$, after normalizating $\sum_i \triangle_i = \triangle$ (total contribution by FDI).

Quantitative Findings

Contribution to Growth	FDI (%)	Decomposition of Contribution by FDI (%)						
		endogenous TFP gap					input	
		efficacy	barrier	tech gap	price	spillover	gap	total
China	45.8	20.9	27.2	-1.3	6.4	44.8	2.0	100
Hong Kong	42.4	15.8	-63.2	-6.5	11.4	115	27.5	100
S. Korea	54.3	14.7	-18.8	-7.8	-0.3	91.5	20.7	100
Malaysia	31.2	25.8	1.0	-1.5	-24.1	90.1	8.7	100
Philippines	52.1	13.1	41.0	-0.3	-13.0	51.0	8.2	100
Singapore	25.6	28.2	-92.3	-4.2	-30.1	170	28.4	100
Taiwan	45.7	16.1	-17.7	-9.7	-10.3	101	20.6	100
Vietnam	28.7	19.6	-45.0	3.7	4.2	96.4	21.1	100
Four Tigers	40.2	18.1	-44.7	-7.2	-6.1	116	23.9	100
a) KOR&TWN	49.6	15.4	-18.2	-8.7	-5.3	96.5	20.3	100
b) HKG&SGP	32.8	21.3	-76.1	-5.5	-7.0	139	28.3	100
Four LDCs	38.0	20.7	14.2	-0.7	-10.9	68.8	7.9	100
a) CHN&PHL	48.7	17.0	34.0	-0.8	-3.3	47.9	5.2	100
b) MYS&VTN	30.7	24.7	-7.2	-0.6	-19.1	91.2	11.0	100

- FDI does matter for growth, especially via the Endogenous TFP channel.
- Adoption efficacy and spillover are key drivers, partly offset by slowdown in barrier mitigation.

Takeaways

- A higher FDI conversion efficacy, a lower adoption barrier, or a stronger international technology spillover, together with a lower relative price of FDI, can propel an economy to exhibit **flying geese growth**, escaping from a **middle income trap** and catching up with the world frontier.
- By calibrating to eight representative Asian economies, including 4 Tigers and 4 less-developed countries, and performing counterfactual analysis, we find that **technology-embodied FDI serves as a key flying propeller**, explaining 25.6% (Singapore) to 54.3% (South Korea) of their average growth.
- Overall,
  - **adoption efficacy** and **technology spillover** are most important, jointly accounting for a lion's share of the contribution of FDI to growth, about 20% and 80%, respectively;
  - contribution of input gap reduction is **far less important than endogenous technical progress** and is largely offset by slowdown in barrier mitigation and shrinking price advantages;
  - technology gap is inessential.