OPENNESS, TECHNOLOGY CAPITAL, AND DEVELOPMENT

Ellen McGrattan and Edward Prescott

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Why Did the EU-6 Catch Up?

EU-6 Labor Productivity as % of US
Why is Asia Starting to Catch Up?

Asian Labor Productivity as % of US
While South America Is Losing Ground?

South American Labor Productivity as % of US
Questions

- Why did the EU-6 catch up?

- Why is Asia starting to catch up?

- Why is South America losing ground?

Answer: Open countries gain, closed countries lose
Our Notion of Openness

- Openness can mean many things

- We mean foreign multinationals’ technology capital permitted

- We find big gains to openness
Technology Capital

- Is accumulated know-how from investments in
  - R&D
  - Brands
  - Organization know-how

which can be used in as many *locations* as firms choose
**New Avenue for Gains**

- Countries are measures of locations

- Technology capital can be used in multiple locations

- Implying gains to openness
  
  - Without increasing returns

  - Without factor endowment differences
Theory
Closed-Economy Aggregate Output

\[ Y = A(NM)^{1-\phi}Z^\phi \]

- \( M \) = units of *technology capital*
- \( Z \) = composite of other factors, \( K^\alpha L^{1-\alpha} \)
- \( N \) = number of production *locations*
- \( A \) = the technology parameter
- \( \phi \) = the income share parameter

which is the result of maximizing plant-level output
• $n \in \{1, \ldots, N\}$, $m \in \{1, \ldots, M\}$

$$F(N, M, Z) = \max \sum_{z_{nm}} g(z_{nm})$$

subject to $\sum_{n,m} z_{nm} \leq Z$

We assume $g(z) = A z^\phi$, increasing and strictly concave
A Micro Foundation for Aggregate Function

- \( n \in \{1, \ldots, N\}, \ m \in \{1, \ldots, M\} \)

\[
F(N, M, Z) = \max \sum_{n,m} g(z_{nm})
\]

subject to \( \sum_{n,m} z_{nm} \leq Z \)

\[ \Rightarrow \text{optimal to split } Z \text{ evenly across location-technologies} \]
A Micro Foundation for Aggregate Function

- \( n \in \{1, \ldots, N\} \), \( m \in \{1, \ldots, M\} \)

\[
F(N, M, Z) = \max_{z_{nm}} \sum_{n,m} g(z_{nm})
\]

subject to
\[
\sum_{n,m} z_{nm} \leq Z
\]

\(\Rightarrow\) \( F(N, M, Z) = NMg(Z/NM) = A(NM)^{1-\phi}Z^\phi \)
A Micro Foundation for Aggregate Function

- \( n \in \{1, \ldots, N\} \), \( m \in \{1, \ldots, M\} \)

\[
F(N, M, Z) = \max \sum_{n,m} g(z_{nm})
\]

subject to \( \sum_{n,m} z_{nm} \leq Z \)

\[ \Rightarrow F(N, \lambda M, \lambda Z) = \lambda F(N, M, Z) \]
The degree of openness of country $i$ is $\sigma_i$

Aggregate output in $i$ is

$$\max_{z_d, z_f} M_i N_i A_i z_d^\phi + \sigma_i \sum_{j \neq i} M_j N_i A_i z_f^\phi$$

subject to

$$M_i N_i z_d + \sum_{j \neq i} M_j N_i z_f \leq Z_i$$

$d, f$ indexes allocations to domestic and foreign operations
Production in Open Economy

- The degree of openness of country $i$ is $\sigma_i$

- Aggregate output in $i$ is

$$Y_i = A_i N_i^{1-\phi} (M_i + \omega_i \sum_{j \neq i} M_j)^{1-\phi} Z_i^\phi$$

where

$$Z_i = K_i^\alpha L_i^{1-\alpha}$$

$$\omega_i = \sigma_i^{1-\phi} = \text{fraction of foreign T-capital permitted}$$
Production in Open Economy

- The degree of openness of country $i$ is $\sigma_i$

- Aggregate output in $i$ is

$$Y_i = A_i N_i^{1-\phi} (M_i + \omega_i \sum_{j \neq i} M_j)^{1-\phi} Z_i^\phi$$

- Key result:

Each $i$ has constant returns, but summing over $i$ results in a bigger aggregate production set.
Production in Open Economy

- The degree of openness of country \( i \) is \( \sigma_i \)

- Aggregate output in \( i \) is

\[
Y_i = A_i N_i^{1-\phi} (M_i + \omega_i \sum_{j \neq i} M_j)^{1-\phi} Z_i^\phi
\]

- Key result:

It is as if there were increasing returns, when in fact there are none.
Advantages to Our Technology

- Standard welfare analysis
- Standard national accounting
- Standard parameter selection
Advantages to Our Technology

- Standard welfare analysis
- Standard national accounting
- Standard parameter selection

Next, we describe the rest of the model
Introduce Population

• $N_i =$ number of production locations in $i$

• $N_i \propto$ population in $i$

• Interpretation: expanding markets requires more consumers

• Implication: Canada is like Taiwan, not China
Country $i$ Household’s Problem

$$\max \sum_t \beta^t U(C_{it}/N_{it}, L_{it}/N_{it}) N_{it}$$

s.t. \hspace{1cm} C_{it} + X_{ikt} + X_{imt} + NX_{it} = Y_{it}$$
Country $i$ Household’s Problem

$$\max \sum_t \beta^t U(C_{it}/N_{it}, L_{it}/N_{it}) N_{it}$$

s.t.

$$C_{it} + X_{ikt} + X_{imt} + NX_{it} = Y_{it}$$

$$K_{i,t+1} = (1 - \delta_k)K_{it} + X_{ikt}$$

$$M_{i,t+1} = (1 - \delta_m)M_{it} + X_{imt}$$
Country $i$ Household’s Problem

$$\max \sum_t \beta^t U(C_{it}/N_{it}, L_{it}/N_{it}) N_{it}$$

s.t. $$C_{it} + X_{ikt} + X_{imt} + NX_{it} = Y_{it}$$

$$K_{i,t+1} = (1 - \delta_k) K_{it} + X_{ikt}$$

$$M_{i,t+1} = (1 - \delta_m) M_{it} + X_{imt}$$

$$NX_{it} + \sum_{j \neq i} r^j_{it} M_{it} - \sum_{j \neq i} r^i_{jt} M_{jt} = 0$$
Country $i$ Household’s Problem

$$\text{max} \quad \sum_t \beta^t U(C_{it}/N_{it}, L_{it}/N_{it}) N_{it}$$

s.t.  $$C_{it} + X_{ikt} + X_{imt} + NX_{it} = Y_{it}$$

$$K_{i,t+1} = (1 - \delta_k)K_{it} + X_{ikt}$$

$$M_{i,t+1} = (1 - \delta_m)M_{it} + X_{imt}$$

$$NX_{it} + \sum_{j \neq i} r^j_{it} M_{it} - \sum_{j \neq i} r^i_{jt} M_{jt} = 0$$

$$N_{it} = (1 + \gamma_N)^t N_{i0}$$
Country $i$ Household’s Problem

$$\text{max} \quad \sum_t \beta^t U\left(C_{it}/N_{it}, L_{it}/N_{it}\right) N_{it}$$

s.t. 

$$C_{it} + X_{ikt} + X_{imt} + NX_{it} = Y_{it}$$

$$K_{i,t+1} = (1 - \delta_k) K_{it} + X_{ikt}$$

$$M_{i,t+1} = (1 - \delta_m) M_{it} + X_{imt}$$

$$NX_{it} + \sum_{j \neq i} r_{ij}^j M_{it} - \sum_{j \neq i} r_{ij}^i M_{jt} = 0$$

$$N_{it} = (1 + \gamma_N)^t N_{i0}$$

$$X_{imt}, X_{ikt} \geq 0$$
**Country $i$ Household’s Problem**

$$\max \sum_t \beta^t U(C_{it}/N_{it}, L_{it}/N_{it}) N_{it}$$

s.t. \begin{align*}
C_{it} + X_{ikt} + X_{imt} + NX_{it} &= Y_{it} \\
K_{i,t+1} &= (1 - \delta_k) K_{it} + X_{ikt} \\
M_{i,t+1} &= (1 - \delta_m) M_{it} + X_{imt} \\
NX_{it} + \sum_{j \neq i} r_{jt}^i M_{it} - \sum_{j \neq i} r_{jt}^i M_{jt} &= 0 \\
N_{it} &= (1 + \gamma_N)^t N_{i0} \\
X_{imt}, X_{ikt} &\geq 0
\end{align*}$$

$K_{i0}, M_{i0}, \{A_{it}, \omega_{it}\} \forall i, t; \{M_{jt}\} \forall j \neq i, t; \{r_{jt}^i\} \forall i, j, t$ given
How do Countries Differ?
Differences Across Countries

- Degree of openness

- Size = $A_i N_i$
  
  - $N_i$ is proportional to population
  
  - $A_i$ is augmenting labor & location ($= A_i^{1-\phi\alpha}$)

Results depend only on product $A_i N_i$
Steady State Analysis
A Steady State Exists

- Assume labor is supplied inelastically (w.l.o.g.)

- Proposition. A non-zero steady state exists.

**Sketch of Proof:**

- $K_i/Y_i$ same across $i$
  \[ Y_i = \psi A_i N_i (M_i + \omega_i \sum_{j \neq i} M_j)^\frac{1-\phi}{1-\alpha\phi} \]

- Combined with $\sum_j \partial Y_j / \partial M_i \leq \rho + \delta_m$, $=\text{if } M_i > 0$
  \[ \Rightarrow \text{System for which we apply Kakutani theorem} \]
Algorithm to Compute Steady State

- System for $M = \{M_i\}_{i \in I}$:

$$\sum_{j \in I} \frac{\partial F_j}{\partial M_i} = \rho + \delta_m, \quad i \in J \subseteq I$$

$$M_i = 0 \quad \text{for } i \notin J$$

- Step 1. Set $J = I$.
- Step 2. Solve system. If $M \geq 0$, stop.
- Step 3. Remove $i = \text{argmin}\{M_i\}$ from $J$. Go to 2.
\( I = 2, \text{ Symmetric } \omega \text{ Case} \)

- Country 1 is larger, \( A_1 N_1 \geq A_2 N_2 \)

- Equilibrium conditions are:

\[
\rho + \delta_m \geq (1 - \phi) \frac{Y_1}{M_1 + \omega M_2} + (1 - \phi) \frac{\omega Y_2}{M_2 + \omega M_1} \\
\text{Return on } M_1 \text{ in 1} \quad \text{Return on } M_1 \text{ in 2}
\]

\[
\rho + \delta_m \geq (1 - \phi) \frac{Y_2}{M_2 + \omega M_1} + (1 - \phi) \frac{\omega Y_1}{M_1 + \omega M_2} \\
\text{Return on } M_2 \text{ in 2} \quad \text{Return on } M_2 \text{ in 1}
\]
\[ I = 2, \text{ Symmetric } \omega \text{ Case} \]

- Country 1 is larger, \( A_1 N_1 \geq A_2 N_2 \)

- Equilibrium conditions—if \( M_1, M_2 > 0 \)—are:

\[
M_1 \propto \frac{Y_1 - \omega Y_2}{1 - \omega} \\
M_2 \propto \frac{Y_2 - \omega Y_1}{1 - \omega}
\]

\[
M_i + \omega M_{-i} \propto (1 + \omega)Y_i
\]

if \( \omega \) is not too large so \( M_2 > 0 \)
$I = 2$, Symmetric Case

- Country 1 is larger, $A_1 N_1 \geq A_2 N_2$

- Substitute $M_i + \omega M_{-i}$ into production function

\[
\frac{Y_i}{A_i N_i} \propto (M_i + \omega M_{-i})^{\frac{1-\phi}{1-\alpha \phi}}
\]

\[
\propto [(1 + \omega)A_i N_i]^{\frac{1-\phi}{\phi(1-\alpha)}}
\]
$I = 2$, Symmetric $\omega$ Case

- Country 1 is larger, $A_1 N_1 \geq A_2 N_2$

- Substitute $M_i + \omega M_{-i}$ into production function

\[
\frac{Y_i}{A_i N_i} \propto (M_i + \omega M_{-i})^{\frac{1-\phi}{1-\alpha \phi}}
\]

\[
\propto [(1 + \omega) A_i N_i]^{\frac{1-\phi}{\phi(1-\alpha)}}
\]

Implying an advantage to size when $\omega$ small
$I = 2$, Symmetric Case

- Country 1 is larger, $A_1N_1 \geq A_2N_2$

- Equilibrium conditions—if $M_2 = 0$—are:

$$
\rho + \delta_m = (1 - \phi) \frac{Y_1}{M_1 + \omega 0} + (1 - \phi) \frac{\omega Y_2}{0 + \omega M_1}
$$

- Return on $M_1$ in 1

$$
\rho + \delta_m \geq (1 - \phi) \frac{Y_2}{0 + \omega M_1} + (1 - \phi) \frac{\omega Y_1}{M_1 + \omega 0}
$$

- Return on $M_2$ in 2

- Return on $M_2$ in 1
I = 2, Symmetric Case

• Country 1 is larger, $A_1 N_1 \geq A_2 N_2$

• Equilibrium conditions—if $M_2 = 0$—are:

$$\rho + \delta_m = (1 - \phi) \frac{Y_1 + Y_2}{M_1}$$

Total return on $M_1$

$$M_2 = 0$$
$I = 2$, **Symmetric $\omega$ Case**

- Country 1 is larger, $A_1 N_1 \geq A_2 N_2$

- Substitute $M_1$ into production function

\[
Y_1 \propto A_1 N_1 M_1^{\frac{1-\phi}{1-\alpha\phi}} \\
\quad \propto A_1 N_1 (Y_1 + Y_2)^{\frac{1-\phi}{1-\alpha\phi}} \\
Y_2 \propto A_2 N_2 (\omega M_1)^{\frac{1-\phi}{1-\alpha\phi}} \\
\quad \propto A_2 N_2 (\omega (Y_1 + Y_2))^{\frac{1-\phi}{1-\alpha\phi}}
\]

Implying no advantage to size for $\omega = 1$
I = 2, Symmetric Case

- Country 1 is larger, $A_1 N_1 \geq A_2 N_2$

- Substitute $M_1$ into production function

$$Y_1 \propto A_1 N_1 M_1^{\frac{1-\phi}{1-\alpha\phi}}$$

$$\propto A_1 N_1 (Y_1 + Y_2)^{\frac{1-\phi}{1-\alpha\phi}}$$

$$Y_2 \propto A_2 N_2 (\omega M_1)^{\frac{1-\phi}{1-\alpha\phi}}$$

$$\propto A_2 N_2 (\omega (Y_1 + Y_2))^{\frac{1-\phi}{1-\alpha\phi}}$$

And productivity $\propto total\ world\ output$ to a power
Productivities vs. $\omega$, $A_1N_1 = 10A_2N_2$
Big gains from Forming Unions

- $I =$ number of equal-sized countries forming union

- Then, productivity gain for $I$ in union is

\[
y(I)/y(1) = I \frac{1-\phi}{\phi(1-\alpha)}
\]

- For example, if $\alpha = .3$, $\phi = .94$,

  \[
  \text{gain} = 23\% \quad \text{if} \quad I = 10
  \]

  \[
  \text{gain} = 52\% \quad \text{if} \quad I = 100
  \]
Big Gains from Unilaterally Opening

- $I =$ number of equal-sized countries remaining closed

- Then, productivity gain of $I+1$st opening is

\[
y_o/y_c = I^{\frac{1-\phi}{1-\phi\alpha}}
\]

- For example, if $\alpha = .3$, $\phi = .94$,

  \[
gain = 21\% \text{ if } I = 10
  \]

  \[
gain = 47\% \text{ if } I = 100
  \]
ECONOMIES IN TRANSITION
In Transitions

- Allow for

  - Labor to be elastically supplied with

    \[ u(c, l) = \log c + \psi \log(1 - l) \]

  - Growth in population \( \gamma_N \) and technology \( \gamma_A \) so

    \[ \gamma_Y = \left[ (1 + \gamma_A)(1 + \gamma_N) \right]^{(1-\phi\alpha)/(\phi-\phi\alpha)} - 1 \]

- What happens to a country joining an open EU?
Small Country ($\mathcal{A}N = 1$) Opens to Big ($\mathcal{A}N = 10$)

Openness Parameters ($\sigma$)

Big Country

Small Country

Years

0 10 20 30 40 50 60
Small Country Opens to Big

\[ \text{Consumption/ } C_{2,0}(1 + \gamma_Y)^t \]
SMALL COUNTRY OPENS TO BIG

TECHNOLOGY CAPITAL/ $Y_{2,0}(1+\gamma_Y)^t$

Big Country

Small Country

Years

0 10 20 30 40 50 60

0 1 2 3 4 5 6 7
Small Country Opens to Big – Recap

- Large and rapid gains in consumption

- Specialization in technology capital investment
  - Initially takes advantage of new markets
  - Eventually exploits big country’s stock
Small Country Opens to Big – Recap

- Large and rapid gains in consumption

- Specialization in technology capital investment
  - Initially takes advantage of new markets
  - Eventually exploits big country’s stock

- What if there is diffusion of knowledge?
GAINS FROM OPENING WITH DIFFUSION

- Compare small country’s consumption in 2 cases:
  
  - Without diffusion \((A_{2t} = A_{1t})\)
  
  - With diffusion \((A_{2t} = A_{1t}(0.9 + 0.1\sigma_{2,t}))\)
GAINS FROM OPENING WITH DIFFUSION

\[ \frac{C_{2,0}}{(1+\gamma_Y)^t} \]

**Consumption** with and without diffusion

- **With Diffusion**
- **Without Diffusion**

Graph showing consumption over years with and without diffusion.
Summary

- Paper extends neoclassical growth model by adding
  - Locations
  - Technology capital
- Use new theory to assess the gains from openness
- Elsewhere, use theory to study U.S. net asset position