Cross-Country Heterogeneity in Production-Environment Nexus and International Trade

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JSIE Kanto Workshop
April 20, 2024

Overview

Introduction

Basic model

Short-run equilibrium

Transition dynamics & trade steady state

Welfare analysis

Motives

- Local env'tl challenges due to attitude, law, and/or technology
- Primary/ sectors more impacted by env'tl problems
- Sectoral ranking of env't intensity could vary by country

Cross-country heterogeneity

- Who harms the fishery resource more, a fisherman or a chemical worker? It depends ...
  - Abundance of fishery resource
  - Fishing method & equipment
  - Toxicity of factory wast water
  - Abatement equipment & technology
  - Distance b/w factory & fish habitat
- Countries can differ in which sectors are the "dirtier" sectors
  - Sector A can be "dirtier" than Sector B in a country
  - But he opposite may hold in another country

This study

- To understand
  - Implication of the presence of cross-country heterogeneity
  - Key factors driving the welfare effects of trade
- For the purpose
  - Two-country, two-sector trade model w/ an env'tl stock
    - Only resource-good sector is impacted by the env'tl stock
    - Both resource-good and manufacturing impact the env'tl stock
  - Cross-country heterogeneity in two-sector setting
    - Country 1 has a dirtier resource-good sector
      (LDCs w/ unsustainable farming, excessive resource use)
    - Country 2 has a dirtier manufacturing sector
      (Emerging economies w/ pollution intensive manufacturing)

Main findings

Presence of cross-country heterogeneity

- Nonconvexity arises in one country's production technology
- This has little impact on the equilibrium in autarky
- But it may induce multiple steady-state equilibra under trade

Welfare effects of trade

- Factor #1: Pr-trade comparative advantage
- Factor #2: Env'tl deterioration in resource-exporting country
- Specialization patterns & transition path also matter
- All countries may lose from trade in the long run
- Moving from one trade equilibrium to another (if any) has opposite welfare effects for the two countries

Env'tl consequences of trade

- Env'tl deterioration in all countries $\leftarrow$ our assumption
- Possible env'tl improvement during transition in one country

Literature

- Renewable resources & trade: Brander and Taylor (1997, 1998)
  - Resource management: Brander and Taylor (1997), Jinji (2007), Copeland and Taylor (2009)
  - International shared resource: Takarada et al. (2013)
  - Endogenous carrying capacity: Jinji (2006)
- Industrial pollution & trade: Copeland and Taylor (1999)
  - Pollution control: Copeland and Taylor (1997),
  - Transboundary pollution: Unteroberdoerster (2001), Benarroch and Thille (2001), Suga (2007)
  - Migration/capital movement: Kondoh (2006), Beladi et al. (2001),
- Hybrid model: Rus (2016), Li and Yanase (2022)
- Property rights for env'tl resources & trade: Chichilnisky (1994), Karp et al. (2001)
- Empirical studies on trade (policy) & carbon emission: Shapiro (2016), Larch and Wanner (2017)

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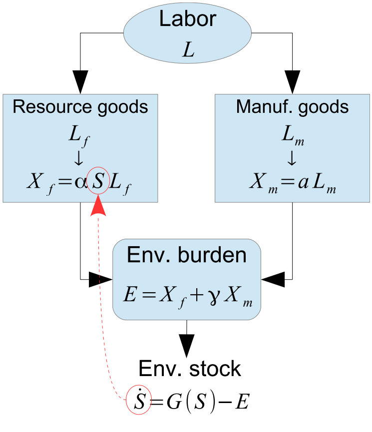
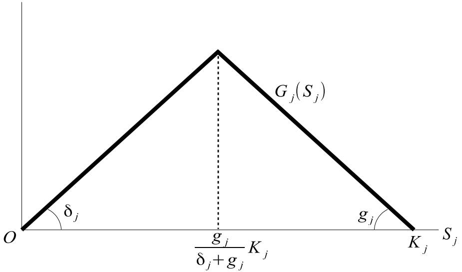
Model setting



- Two countries
  - Country 1 & country 2
- Within each country
  - Two sectors: Resource good (f) & manufacturing (m)
  - A single factor of production: Labor (L)
  - A non-transboundary env't: Env'tl stock (S)
- Production-environment nexus
  - Both sectors cause env'tl burdens, lowering S
  - The level of S only affects f-sector productivity

Model setting (cont'd)

- Growth function of the env'tl stock: Tent-shaped



$$G_j(S_j) = \begin{cases} \delta_j S_j & \text{if } S_j \le \frac{g_j}{\delta_j+g_j}K_j \\ g_j(K_j - S_j) & \text{if } S_j > \frac{g_j}{\delta_j+g_j}K_j \end{cases}$$

- Cobb-Douglas preference: $u(C_f, C_m) = b \ln C_f + (1-b) \ln C_m$

A microfoundation of env'tl stock

- Take env'tl stock S as a combination of resource stock (R) & pollution stock (Z):

$$S = R - \psi Z$$

- Then we have

$$\dot{S} = g\left(K - S\right) - E$$

if the equations of motion of R and Z satisfy

$$\dot{R} = g\left(K - R\right) - H$$
$$\dot{Z} = P - gZ$$

where

- Harvest $H = \alpha\left(R - \psi Z\right) L_f$
  - i.e. pollution stock also harms harvest (think about the quality of resource may be lower due to pollution)
- Pollution flow $P = \frac{\gamma}{\psi} a L_m$

Assumptions

A1: Positive env'tl stock for all possible steady states:

$$\alpha_j L_j \leq \delta_j \text{ and } \gamma_j a_j L_j \leq \frac{\delta_j g_j K_j}{\delta_j + g_j}$$

A2: F-sector is dirtier than m-sector in country 1 and the opposite holds in country 2 (cross-country heterogeneity):

$$\frac{\gamma_1 a_1}{\alpha_1} < \frac{g_1}{g_1 + \alpha_1 L_1} K_1 \text{ and } \frac{\gamma_2 a_2}{\alpha} > \frac{g_2}{g_2 + \alpha_2 L_2} K_2$$

A3: Country 2's opportunity cost of m is lower than country 1 for all possible steady states:

$$\frac{\alpha_2 S_2}{a_2} < \frac{\alpha_1 S_1}{a_1} \text{ for } \forall (S_1, S_2) \in (\Gamma_1, \Gamma_2)$$

where $\Gamma_j = \left\{ S_j \mid S_j = \frac{g_j K_j - \gamma_j a_j L_{jm}}{g_j + \alpha_j L_{jf}}, L_{jf} + L_{jm} = L_j \right\}$

- A2 & A3 $\rightarrow$ Countries 1 & 2 will export their respective "dirtier" goods to each other under trade

Autarky

- At every point in time
  - Labor allocation (b: expenditure share on f)

$$L_{jf} = bL_j, \quad L_{jm} = (1-b)\,L_j$$

  - Env'tl stock motion

$$\dot{S}_j = G_j(S_j) - [\alpha_j S_j b L_j + \gamma_j a\,(1-b)\,L_j]$$

- Autarkic steady-state equilibrium is determined uniquely
  - Env'tl stock

$$S_j^{*\mathrm{A}} = \frac{g_j K_j - \gamma_j a_j (1-b)\,L_j}{g_j + \alpha_j b L_j}$$

  - Relative price of m to f

$$P_j^{*\mathrm{A}} = \alpha_j S_j^{*\mathrm{A}} / a_j$$

  - Utility level

$$V_j^{*\mathrm{A}} = B + \ln L_j + (1-b)\ln a_j + b\ln \alpha_j S_j^{*\mathrm{A}}$$

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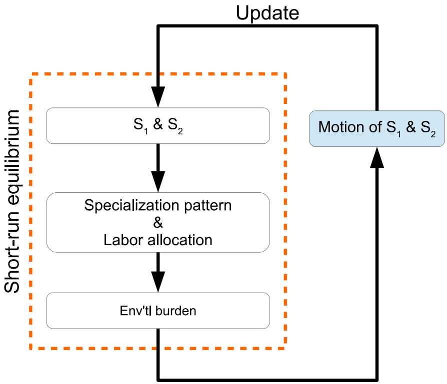
Model solving & short-run equilibrium

Given (S_1, S_2) at the moment, we can obtain the short-run equilibrium

- Specialization pattern & Labor allocation
- Env'tl burden

$\rightarrow$ Update (S_1, S_2)



Specialization patterns

- Trade pattern (determined by A3)
  - Country 1 exports resource goods (f)
  - Country 2 exports manufactured goods (m)
- The short-run Ricardian structure (i.e. single factor of production & constant productivity) and A3 imply that at least one country completely specializes

  $\rightarrow$ Three possible specialization patterns

Country 1	Country 2	
Diversifies	Specializes in m	$\rightarrow$ Pattern DM
Specializes in f	Specializes in m	$\rightarrow$ Pattern FM
Specializes in f	Diversifies	$\rightarrow$ Pattern FD

  - Which arises depends on the preference and env'tl stocks

Conditions for specialization pattern

- Case i (Strong preference on m): Only DM arises

$$q < z$$

  - $q \equiv \frac{b}{1-b}$: relative expenditure share of f
  - $z \equiv \frac{a_1 L_1}{a_2 L_2}$: relative size (in terms of m production capacity)
- Case ii (Strong preference on f): FM or FD arises

$$q \geq z$$

  - Which arises further depends on comparative advantage index $v(S_1, S_2) \equiv \frac{\alpha_2 S_2}{a_2} / \frac{\alpha_1 S_1}{a_1}$ (<1)
    1. Relatively insufficient env'tl stock in country 2: $v(S_1, S_2) \leq z/q \Rightarrow$ FM
    2. Relatively insufficient env'tl stock in country 1: $v(S_1, S_2) > z/q \Rightarrow$ FD

Short-run trade equilibrium

- World relative price of m

$$P_w = \begin{cases} \frac{\alpha_1 S_1}{a_1} & \text{in pattern DM,} \\ \frac{z}{q}\frac{\alpha_1 S_1}{a_1} & \text{in pattern FM,} \\ \frac{\alpha_2 S_2}{a_2} & \text{in pattern FD.} \end{cases}$$

- Country 1's labor allocation

$$L_{1f} = \begin{cases} \left(1 + \frac{1}{z}\right) bL_1 & \text{in pattern DM} \\ L_1 & \text{in pattern FM \& FD} \end{cases}$$

- Country 2's labor allocation

$$L_{2m} = \begin{cases} L_2 & \text{in pattern DM \& FM} \\ \left(1 + \frac{z}{v(S_1,S_2)}\right)(1-b)\, L_2 & \text{in pattern FD} \end{cases}$$

- Env'tl burden follows immediately

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Free-trade equilibrium dynamics

- Motion of env'tl stocks

$$\dot{S}_1 = G_1(S_1) - [\alpha_1 S_1 L_{1f}(S_1, S_2) + \gamma_1 a_1 L_{1m}(S_1, S_2)]$$
$$\dot{S}_2 = G_2(S_2) - [\alpha_2 S_2 L_{2f}(S_1, S_2) + \gamma_2 a_2 L_{2m}(S_1, S_2)]$$

  - $L_{ji}(S_1, S_2)$ (country j's labor in sector i under trade)
- Two cases, depending on parameters
  - Case i (Strong preference on m) $\rightarrow$ DM
  - Case ii (Strong preference on f) $\rightarrow$ FM and/or FD

Case ii

- Motion of env'tl stocks

$$\dot{S}_1 = G_1(S_1) - \alpha_1 S_1 L_1$$

$$\dot{S}_2 = \begin{cases} G_2(S_2) - \gamma_2 a_2 L_2 & \text{in pattern FM} \\ G_2(S_2) - \alpha_2 S_2 \left(1 - \frac{z}{qv(S_1,S_2)}\right) bL_2 & \text{in pattern FD} \\ \qquad -\gamma_2 a_2 \left(1 + \frac{z}{v(S_1,S_2)}\right)(1-b) L_2 & \end{cases}$$

- The (S_1, S_2) plane can be divided into two regions by

$$v(S_1, S_2) = \frac{z}{q} \text{ or } \frac{\alpha_1 S_1 L_1}{\alpha_2 S_2 L_2} = \frac{b}{1-b}$$

  - Below and along the boundary, pattern FM arises $\rightarrow$ FM region
  - Above the boundary, pattern FD arises $\rightarrow$ FD region

- Country 1
  - In both regions, $\dot{S}_1 = 0 \Leftrightarrow$

$$S_1 = \frac{g_1 K_1}{g_1 + a_1 L_1} \equiv \underline{S_1}$$

$\rightarrow$ Vertical line

- Country 2
  - In FM region, $\dot{S}_2 = 0 \Leftrightarrow$

$$S_2 = K_2 - \frac{\gamma_2 a_2 L_2}{g_2} \equiv \underline{S_2}$$

$\rightarrow$ Horizontal line

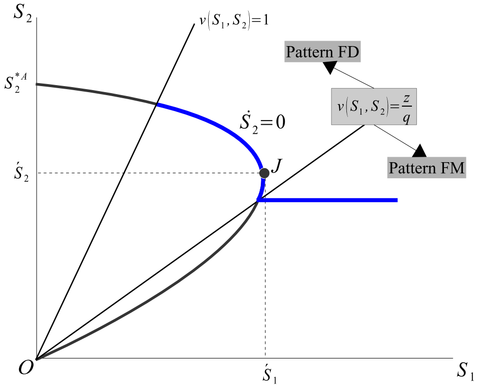
  - In FD region, $\dot{S}_2 = 0 \Leftrightarrow$

$$S_1 = \varphi \frac{\alpha_2}{\alpha_1} \frac{S_2 \left(S_2^{*A} - S_2\right)}{\left(\gamma_2 a_2 - \alpha_2 S_2\right)}$$

    - $\varphi \equiv \frac{g_2 + \alpha_2 b L_2}{(1-b) L_1}$
    - S_2^{*A}: Country 2's autarkic level of env'tl stock

$\rightarrow$ Hump shape toward right

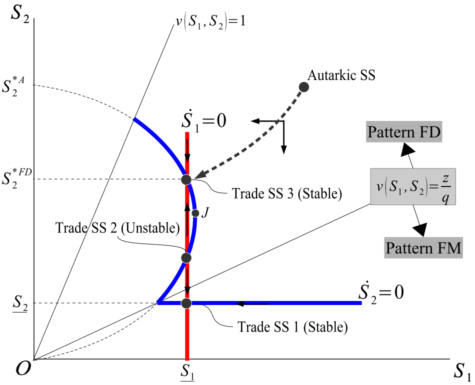
$\dot{S}_2 = 0$ in Case ii



Two sub-cases

- Case ii-a: Point J located in FM region
  - Unique steady-state equilibrium w/ pattern FM
  - Unique steady-state equilibrium w/ pattern FD
- Case ii-b: Point J located in FD region
  - Unique steady-state equilibrium w/ pattern FM
  - Unique steady-state equilibrium w/ pattern FD
  - Multiple steady-state equilibria

Multiple steady-state equilibria



Cross-country heterogeneity & Nonconvexity in production

- The presence of cross-country heterogeneity
  $\rightarrow$ There must be a country (country 2) w/ the env'tlly insensitive sector (m-sector) as the dirtier sector
- This induces nonconvexity & possibility of multiple equilibria:

Country 2 produces more m goods

$\downarrow$

Country 2's env'tl stock declines

$\downarrow$

Opportunity cost of m falls in country 2

$\downarrow$

Nonconvexity in country 2's production technology
(Hump-shaped $\dot{S}_2 = 0$ in FD region)

$\downarrow$

Possibility of multiple equilibria

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Welfare under free trade

- Instantaneous utility levels under trade for given S_1 & S_2:

$$V_1 = B + \ln \alpha_1 S_1 L_1 - (1-b)\ln P_w$$
$$V_2 = B + \ln a_2 L_2 + b \ln P_w$$

- Utility differences b/w autarkic steady state and free trade

$$\Delta V_1 \equiv V_1 - V_1^{*A} = \ln \frac{S_1}{S_1^{*A}} + (1-b)\ln \frac{P_1^{*A}}{P_w}$$
$$\Delta V_2 \equiv V_2 - V_2^{*A} = b \ln \frac{P_w}{P_2^{*A}}$$

Welfare effects of trade (Case ii)

- Country 1: $\frac{P_w}{P_1^{*A}} = \begin{cases} \frac{z}{q}\frac{S_1}{S_1^{*A}} & \text{in FM} \\ v\left(S_1^{*A}, S_2\right) & \text{in FD} \end{cases}$

$$\Rightarrow \Delta V_1 = \begin{cases} \underbrace{\ln \frac{S_1}{S_1^{*A}}}_{\text{Prod.}(\leq 0)} + \underbrace{(1-b)\ln \frac{S_1^{*A}}{S_1}}_{\text{Dynamic ToT}(\geq 0)} + \underbrace{(1-b)\ln \frac{q}{z}}_{\text{Static ToT}(\geq 0)} & \text{in FM} \\ \underbrace{\ln \frac{S_1}{S_1^{*A}}}_{\text{Prod.}(\leq 0)} + \underbrace{(1-b)\ln \frac{S_2^{*A}}{S_2}}_{\text{Dynamic ToT}(\geq 0)} + \underbrace{(1-b)\ln \frac{1}{v\left(S_1^{*A}, S_2^{*A}\right)}}_{\text{Static ToT}(>0)} & \text{in FD} \end{cases}$$

- Country 2: $\frac{P_w}{P_2^{*A}} = \begin{cases} \frac{z}{q}\frac{1}{v\left(S_1, S_2^{*A}\right)} & \text{in FM} \\ \frac{S_2}{S_2^{*A}} & \text{in FD} \end{cases}$

$$\Rightarrow \Delta V_2 = \begin{cases} \underbrace{b \ln \frac{S_1}{S_1^{*A}}}_{\text{Dynamic ToT}(\leq 0)} + \underbrace{b\left[\ln \frac{z}{q} - \ln v\left(S_1^{*A}, S_2^{*A}\right)\right]}_{\text{Static ToT}(\geq 0)} & \text{in FM} \\ \underbrace{b \ln \frac{S_2}{S_2^{*A}}}_{\text{Dynamic ToT}(\leq 0)} & \text{in FD} \end{cases}$$

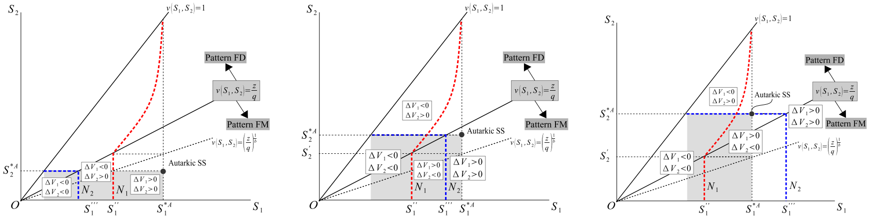
Welfare during the transition (Case ii)

Assume that both countries are initially in autarkic steady state

- On the spot of trade liberalization, $S_j = S_j^{*A}$
  - FM: $\Delta V_1, \Delta V_2 \geq 0$
  - FD: $\Delta V_1 > 0, \Delta V_2 = 0$
- Along the transition path
  - FM: Utility levels depend only on S_1, which declines over time $\rightarrow$ Instantaneous utility declines in both countries
  - FD: S_1 declines along the transition path; S_2 does not necessarily decline
    1. Country 1's utility is increasing in S_1 and decreasing in S_2 $\rightarrow$ Country 1's utility may increase or decrease as S_2 decreases, and necessarily decreases as S_2 increases
    2. Country 2's utility level varies with S_2

Long-run welfare effects (Case ii)

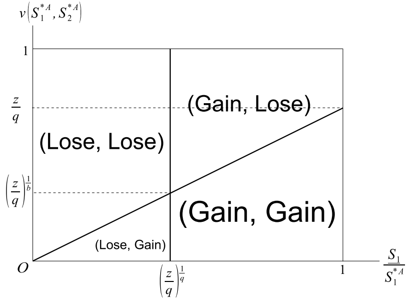
- Long-run welfare effects of trade are affected by pre-trade comparative advantage $v\left(S_1^{*A}, S_2^{*A}\right)$
  (a) Large: $v\left(S_1^{*A}, S_2^{*A}\right) < (z/q)^{1/b}$
  (b) Moderate: $(z/q)^{1/b} < v\left(S_1^{*A}, S_2^{*A}\right) \leq z/q$
  (c) Small: $v\left(S_1^{*A}, S_2^{*A}\right) > z/q$
- Welfare-neutral locus: $\Delta V_1 = 0 \to N_1$, $\Delta V_2 = 0 \to N_2$



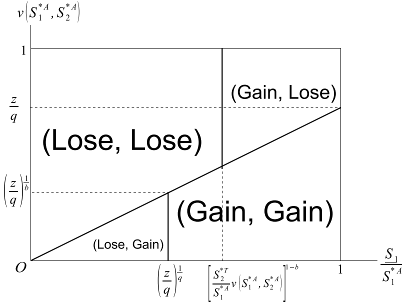
(a) Large $v\left(S_1^{*A}, S_2^{*A}\right)$ (b) Moderate $v\left(S_1^{*A}, S_2^{*A}\right)$ (c) Small $v\left(S_1^{*A}, S_2^{*A}\right)$

Figure: Welfare-neutral locus in Case ii.

Distribution of welfare effects of trade



(c) $S_2^{*T} \leq S_2'$ holds for $v\left(S_1^{*A}, S_2^{*A}\right) > (z/q)^{1/b}$



(d) $S_2^{*T} > S_2'$ holds for $v\left(S_1^{*A}, S_2^{*A}\right) > (z/q)^{1/b}$

Figure: Distribution of welfare gains/losses in trade steady state, where $S_2' \equiv S_2^{*A}\left(\frac{z}{q}\right)^{\frac{1}{b}} v\left(S_1^{*A}, S_2^{*A}\right)^{-1}$ and S_2^{*T} is S_2 in trade steady state

- Smaller pre-trade comparative advantage
- Greater trade-induced environmental deterioration

Concluding remarks

- Two-country, two-sector dynamic model of trade and the env't
  - Both sectors harm the env't
  - One sector's productivity depends on the env'tl quality
  - Countries differ in which sector is dirtier
- Key insights
  - Cross-country heterogeneity induces nonconvexity in production and possibly multiple equilibria under trade
  - Pre-trade comparative advantage & resource-exporting country env'tl deterioration determine long-run welfare effects of trade
- Future agenda
  - Policy analysis
  - Noncooperative game
  - International cooperation
  - Many sectors & countries
  - Numerical analysis w/ calibration