# Capital Mobility, Trade and Induced Technological Change:

# Implications for Modelling a Dynamic Multi-Country model

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- Static analysis (Heckscher-Ohlin): trade in goods vs trade of emission permits
- Capital trade vs. emissions trade in a dynamic model
- Social planner vs. Nash ‚equilibrium', and the dynamic Samuelson-Lindhal rule
- Role of pure time preference rate

# Motivation

- Increasing number of dynamic mitigation cost models take regional approach (e.g. RICE, FEEM-RICE, WITCH, REMIND ...)

- Limited literature on multi-country dynamic growth models (5 entries Web of Science for „endogenous growth AND multi-country“)

- Still less when *endogenous technological change* is to be included (WITCH, REMIND)

# Key Questions

- Role of free trade:
  - Can capital-trade substitute emissions trade?
  - How many goods should be traded in a ‚realistic‘ multi-country model?
- Time preference: uniform rate of time-discounting assumed in many models:
  - What happens in between countries with different rates?

# Free Trade – Static Analysis

- Copeland & Taylor (2005): Cost-efficiency can be achieved mainly by trade in goods, without emissions trading; competition in the good market may limit the power on permit markets.

- Based on Factor Price Equalization Theorem in a Heckscher-Ohlin framework

# Definition of a static Heckscher-Ohlin model:

- 2 goods – X and Y, one ‚dirty' and one less ‚dirty'
- 2 factor inputs – capital K and emissions E
- 2 neo-classical production functions – F and G
- 2 countries, each with given endowments of capital and emissions

$$X = F(K_x, E_x)$$

$$Y = G(K_Y, E_Y)$$

$$K_x + K_Y = K$$

$$E_x + E_Y = E$$

# Free Trade – Static Analysis

Classical results (Samuelson *et al*): if the constant-return-to scale neoclassical production functions are the same (+ some more prerequisites), then

1. Real factor prices – and hence marginal abatement costs – are completely equalized

$$\frac{\partial}{\partial I}F^i = \frac{\partial}{\partial I}F^j = \frac{\partial}{\partial I}G^i = \frac{\partial}{\partial I}G^j$$

{i,j}=country

$I \in \{E,K\}$

2. For a given sector (X or Y), emissions intensities are the same across all countries

# Free Trade – Static Analysis

But: breakdown of cost-efficiency, with, e.g., model specification

Output: $Y = F(K)\,M(\sigma)$

Emissions: $E = \sigma\,F(K)$

$$\Rightarrow \quad Y = F(K)\,M(E/F(K))$$

Neoclassical properties cannot generally be assumed anymore!

# Free Trade – Dynamic Analysis

- J.Stiglitz (1970): Factor price equalization does not generally hold in dynamic economies
- When factor endowmnents are determined by investments in human or in physical capital, a separate market for emission permits is always needed to achieve abatement cost-efficiency

# Definition of dynamic model with ITC

$$\max_{C,Q,IA} \int \left(e^{-\rho t} U[C,Q]\right) dt$$

$s.t.$

$$\dot{K} = F(K) - C - IA$$

$$\dot{KA} = IA$$

$$E = \sigma(KA)\ F(K) \overset{!}{=} Q$$

K – capital

I – investment

KA – abatement capital

IA – investment in KA

C – consumption

σ - emission intensity

Q – emissions cap

E – emissions

P I K

# *Two countries*, global social planner solution:

– Coupled Keynes-Ramsey rule:

$$\rho_1 + \frac{\dot{C}_1}{C_1} = \frac{F_1'}{\left(1 - \frac{\sigma_1 F_1'}{\sigma_1' F_1}\right)} = \rho_2 + \frac{\dot{C}_2}{C_2} = \frac{F_2'}{\left(1 - \frac{\sigma_2 F_2'}{\sigma_2' F_2}\right)}$$

– Abatement-cost efficiency:

$$\sigma_1'(KA)\, F_1(K) = \sigma_2'(KA)\, F_2(K)$$

– Dynamic Samuelson-Lindhal rule (for steady-state):

$$\frac{\partial U_1}{\partial E} + \frac{\partial U_2}{\partial E} = \frac{\partial U_i / \partial C \left[\sigma_i' F_i - F_i'\right]}{\sigma_i F_i'}$$

# Definition of decentralized (Nash) problem:

$$\max_{C_i, Q_i, IA_i} \int \left( e^{-\rho t} U[C_i, Q_i + Q_{-i}] \right) dt$$

$s.t.$

$$\dot{K}_i = F(K_i) - C_i - IA_i + W_i - pQ^T$$

$$\dot{KA}_i = IA_i$$

$$E_i = \sigma(KA_i)\ F(K_i) \overset{!}{=} Q_i + Q^T$$

$$\dot{D}_i = rD_i + W_i$$

K - capital

KA – abatement capital

σ - emission intensity

Q – emissions cap

W – current account

D – accumulated debt

$Q^T$ – emission permits

p – price of permit

# Nash solution (without strategic behavior):

– Keynes-Ramsey rule

$$\rho_1 + \frac{\dot{C}_1}{C_1} = \frac{F_1'}{\left(1 - \frac{\sigma_1 F_1'}{\sigma_1' F_1}\right)} = \rho_2 + \frac{\dot{C}_2}{C_2} = \frac{F_2'}{\left(1 - \frac{\sigma_2 F_2'}{\sigma_2' F_2}\right)} = r$$

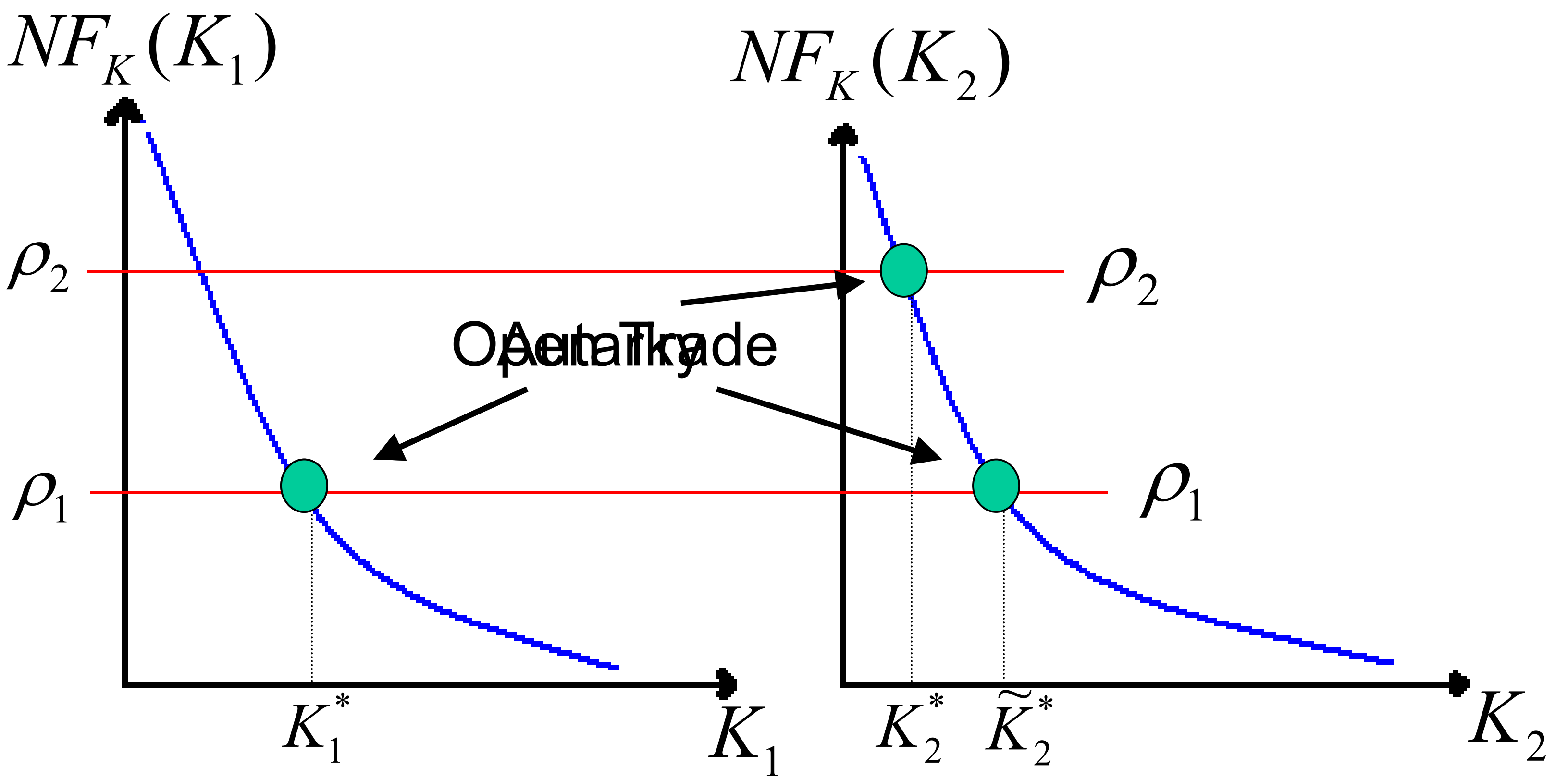
– Abatement-cost efficiency

$$\sigma_1'(KA)\, F_1(K) = \sigma_2'(KA)\, F_2(K) = \frac{r}{p}$$

– Dynamic Samuelson-Lindhal rule ??? No!

$$\frac{U_E^1}{U_C^1} = \frac{U_E^2}{U_C^2} = -p$$

# Nash solution (without strategic behavior):




Capital-Exporting

Capital-Importing

# Public Good Property

- Global social optimum cannot (obviously) be achieved by means of emissions trade alone.

- Can be achieved, e.g., with the following policy instrument, when well-calibrated:

$$F(K_i) + W_i = C_i + I_i + IA_i - t_i Q_i + \beta_i \sum t_j Q_j$$

with: t = carbon tax

β = transfer payment

# Extensions of this Model

- Capital taxation vs. emission taxation – complement or substitute?
- Strategic interactions between countries

# The Impact of Globalization

- Static trade theory analyses welfare effects of factor mobility in a comparative static framework

- In a dynamic framework, welfare effects of international trade can be analyzed as anticipated or non-anticipated shocks.

# Static vs Dynamic Theory

- Static HO model: international capital movement depends on capital (factor) endowments

- Rauscher (1997, p.56) has shown that a country which increases its emissions can attract foreign capital because of an increasing domestic return on investment. This results depends crucially on the fixed factor endowment assumption.

- In a dynamic model, the pure rate of time preference, abatement technology, and preferences for emissions are crucial.

# Free Trade – Dynamic Analysis

Conclusion:

- Straightforward application of Factor Prize Equalization Theorem not possible in dynamic models

- Terms of trade effects were for now neglected; their importance remains an open question

- International trade in at least two goods would be needed to take into account terms of trade effects.

# Discount Rate – Dynamic Analysis

- Let‘s study capital trade between two countries with different rates of time preference
- Warm-up: simple model of debt dynamics. Consider a small country in large rest-of-the-world

Y – constant national income

W – current account

C – consumption

D – stock of external debt

r – interest rate (external)

$$Y + W = C$$

$$\max_{W} \int \left( e^{-\rho t} \ln[C] \right) dt$$

$$s.t.$$

$$\dot{D} = rD + W$$

$$D(0) = 0$$

# Debt-Dynamics for Small Country

- General Solution:

$$D(t) = \frac{Y}{r}\left(1 - e^{-t(\rho - r)}\right)$$

$$C(t) = \rho \frac{Y}{r} e^{-t(\rho - r)}$$

- Interpretation? Case differentiation needed

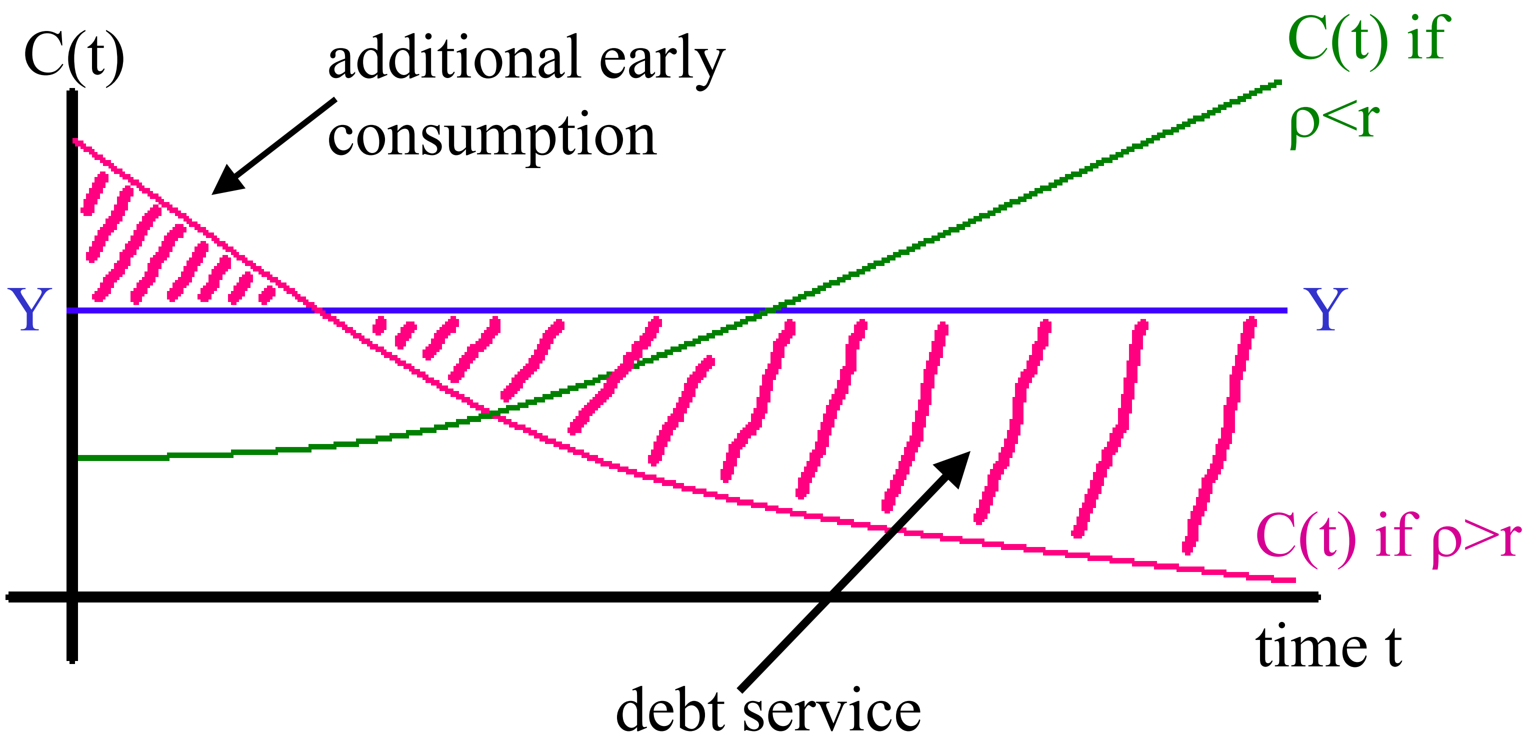
1. $\rho > r$ (i.e. time discount rate bigger than interest rate)

   Early consumption is increased (beyond Y), at the price of an increasing debt burden. When $t \to \infty$, entire national income is spent on debt service.

2. $\rho < r$ (i.e. time discount rate smaller than interest rate)

   Early consumption is decreased, in order to accumulate savings that allow for ever-growing consumption in the future.

# Debt-Dynamics for Small Country



# Discount Rate – Dynamic Analysis

Results of 2-country Ramsey with $\rho_1 < \rho_2$

$$\rho_1 + \frac{\dot{C}_1}{C_1} = F_1' = \rho_2 + \frac{\dot{C}_2}{C_2} = F_2' = r$$ (Keynes-Ramsey Rule)

Implies $\hat{C}_1 - \hat{C}_{'2} = \rho_2 - \rho_1 \quad \Rightarrow \quad \frac{C_1(t)}{C_2(t)} \propto e^{t(\rho_2 - \rho_1)}$

And thus: no steady state with $\dot{C}_1 = \dot{C}_2 = 0$

unless $\rho_1 = \rho_2$

# Discount Rate – Dynamic Analysis

Results of 2-country Ramsey with $\rho_1 < \rho_2$

- Unequal rates of time discounting thus lead to diverging consumption flows:

$$\lim_{t \to \infty} C_2(t) = 0$$

- For the long-run interest rate $r = F_K$ we find:

$$r = \min(\rho_1, \rho_2)$$

# Discount Rate – Dynamic Analysis

Conclusion:

- Significant effects if discount rates are allowed to vary across countries/regions
- Steady state analysis may not be meaningful
- Empirical evidence may even suggests an endogenously changing rate of time preference

# Research Questions

- Terms of Trade effects: how important are they, can they ‚still‘ be neglected in dynamic models? If not, how to model these effects (role of production function in a world of multiple traded goods?)
- Are globalized / newly opened markets anticipated or non-anticipated shocks? How to model these in a dynamic context?
- Role of different discount rates?
- Technological spillovers? How can they be modeled?

P I K