BIG BANG or Slow Motion?

On the Expansion of Renewable Energies

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1. Introduction

- Models on induced techn. change: gradual transition from fossil to renewable energies
- However: historical examples for *rapid expansion* of new products or technologies
- E.g.: cars between 1920 – 1950, or mobile phones between 1980 – 2000

1. Introduction

Driving forces behind "big bang" expansion of a sector:

- R&D not profitable if output small
- Output small if production costly or poor quality
- **Positive feedback effect:**

  - Higher output → more R&D

  - More R&D → higher output (lower patent prices, lower prod. costs, higher product quality)

1. Introduction

Positive feedback effect gives rise to possibilty of **2 stable states** of a sector:

1. Low investments in capacity and little R&D effort (*"low-investment trap"*)

2. High investments in capacity and high R&D effort (low patent fees make high capacity investments viable)

- Discontinuous transition from state 1 to state 2: *"big bang expansion"*

1. Introduction

- Goal: explore possibility of “big bang“ expansion in renewable energy sector
- Simple theoretical model of world energy production with endogenous R&D
- Static partial equilibrium framework
- Model illustrates complex interplay between renewable energy production sector and an R&D sector for renewable energies

Related Literature:

- Gerlagh, Lise (2005) Carbon taxes: A drop in the ocean, or a drop that erodes the stone? The effect of carbon taxes on technological change. *Ecological Economics*
- Edenhofer, Bauer, Kriegler (2005) The impact of technological change on climate protection and welfare: Insights from the model MIND. *Ecological Economics*

Overview:

- 1. Introduction ✔
- 2. The model
- 3. Results

2. The model:

The model contains the following sectors and markets:

1. Renewable energy production sector
2. R&D-sector for renewable energies
3. Fossil energy sector
4. World energy market

2.1 Renewable energy prod. sector

- Firm j's capacity for en. generation: $K_j = \kappa(a_j) I_j$
- a_j : knowledge stock , I_j : investment in capacity
- Capacity is fully used for energy generation
- Firm j's profit: $\pi_j = pK_j - I_j - \theta a_j^{priv} I_j$
- p : energy price , θ : license fee for patented innovations (private knowledge)
- a_j^{priv} : amount of private knowlege used by firm j to build new capacity

Assumptions about knowledge:

- Two types of knowledge: public (freely available), and private (protected by patents)
- Total amount of knowledge: $a = a^{priv} + a^{pub}$
- Amount used by firm j : $a_j = a_j^{priv} + a_j^{pub}$
- Public knowledge for free: $a_j^{pub} = a^{pub} \quad \forall j$
- Furthermore, in equilibrium: $a_j^{priv} = a^{priv} \quad \forall j$

→ Firms use *all* knowledge: $a_j = a^{priv} + a^{pub} = a \quad \forall j$

2.2 R&D-sector for renewable energies

- Firm i owns mass of a_i^{priv} patents
- Amount of innovations linear in R&D effort r_i:

$$a_i^{priv} = \varphi r_i$$

- Patents licensed to *all* firms in renewable energy production sector
- Firm i's profit: $\pi_i = \theta a_i^{priv} I - r_i$
- I : aggregate investment in ren.en.prod. sector

Relation between a^{priv} and a^{pub} :

- Total amount of private knowledge: $a^{priv} = \varphi r$

  (r : aggregate R&D effort)

- Private knowledge yields public knowledge via spillovers: $a^{pub} = a_0 + \chi a^{priv} = a_0 + \chi\varphi r$

  (a_0 : initial amount of public knowledge)

→ Total amount of knowledge:

$$a = a_0 + (1+\chi)\varphi r$$

2.3 Fossil energy sector

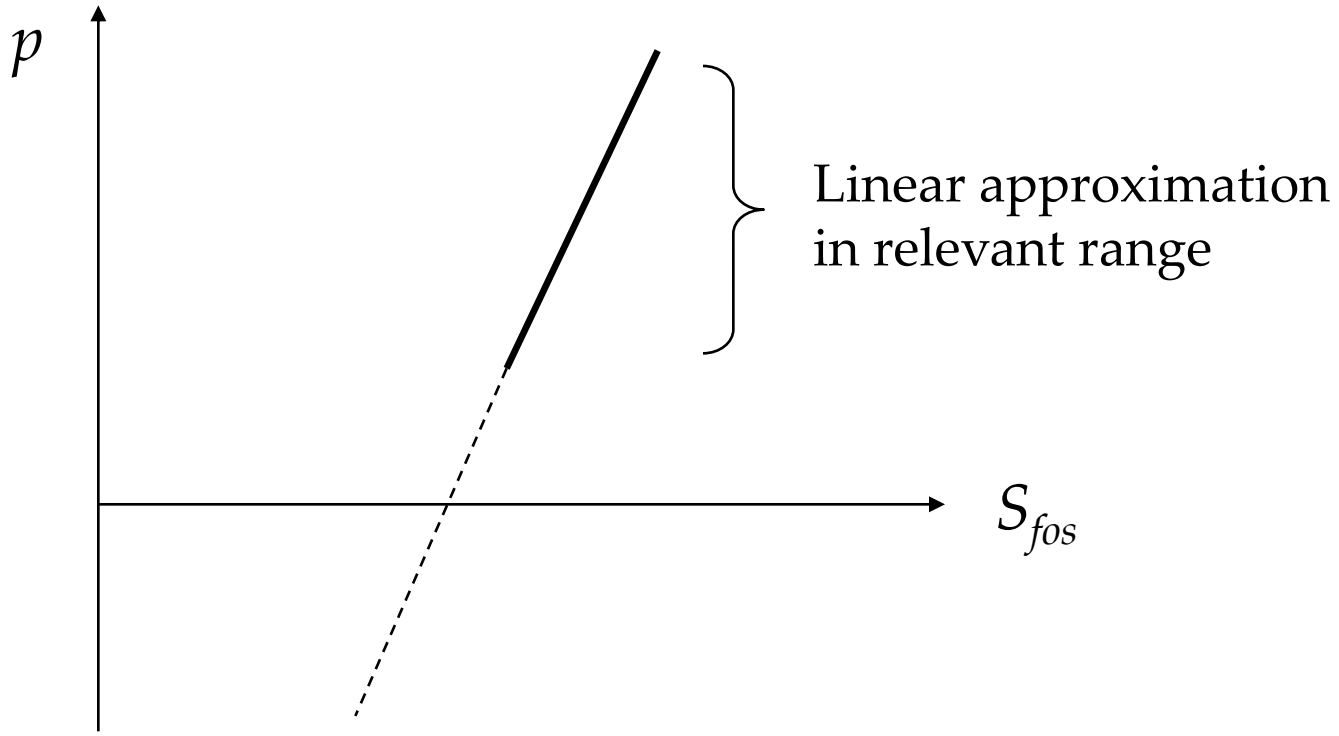
- Assumption: potential for cost-reducing innovations smaller than in ren.en. sector (fossil sector already well established)
- Approximate fossil energy supply by simple linear supply curve:

$$S_{fos}(p) = \alpha\left(p + A - \tau\right)$$

- τ : carbon tax rate

2.3 Fossil energy sector

Inverse supply curve for fossil energy:



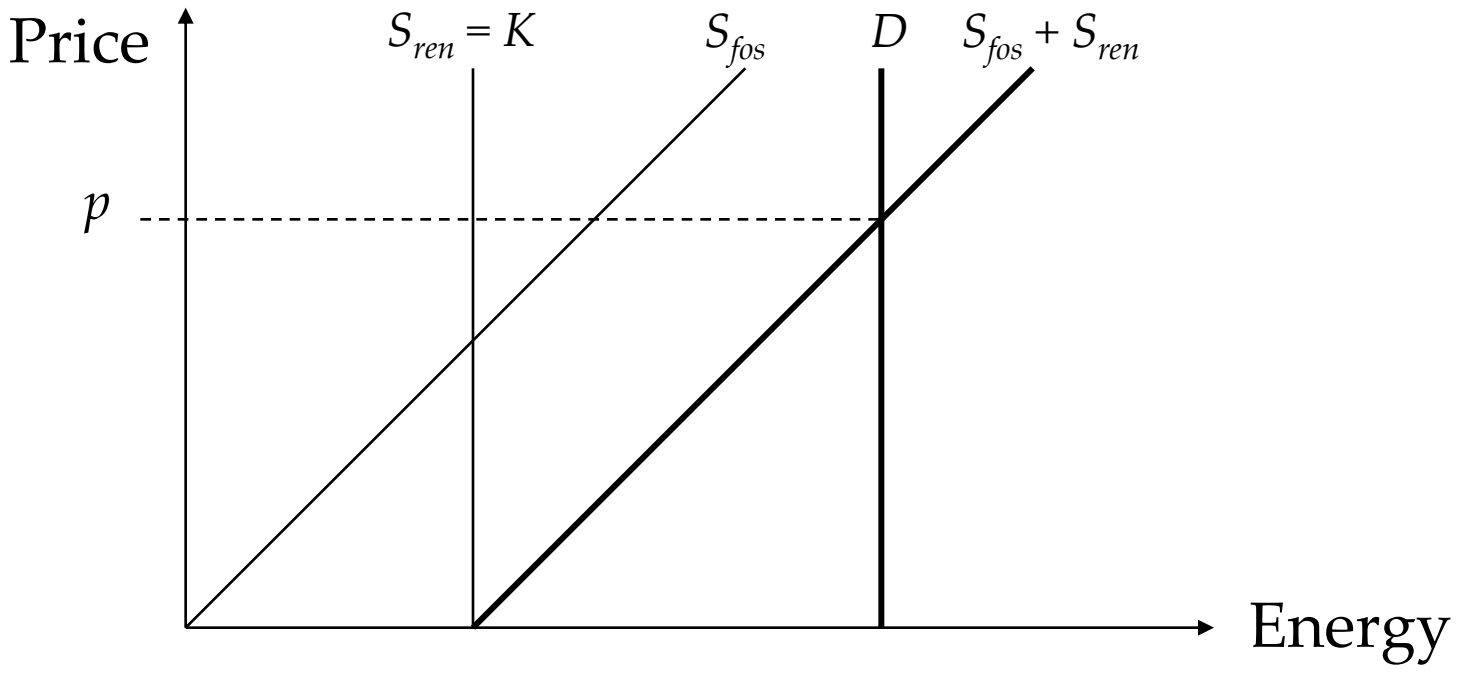
2.4 World energy market

- Linear world energy demand: $dem(p) = B - \beta p$
- Supply of ren. energy: $S_{ren} = K = \kappa(a) I = a^{\eta} I$
- Market clearing cond.: $dem = S_{fos} + S_{ren}$
- Using $D \equiv B - \alpha A$, it can be written as:

$$D = p + \kappa(a) I - \alpha\tau$$

2.4 World energy market

For fixed capacity K in the renewable sector:



Equilibrium concept:

- Assume price-taking behavior in all sectors

- *Competitive equilibrium*:

Set of prices p and θ , investment decisions I_j , and R&D efforts r_i , such that:

(i) Firms in the renewable energy production sector maximize profits,

(ii) Firms in the R&D sector for renewable energies maximize profits, and

(iii) The world energy market clears

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3. Results

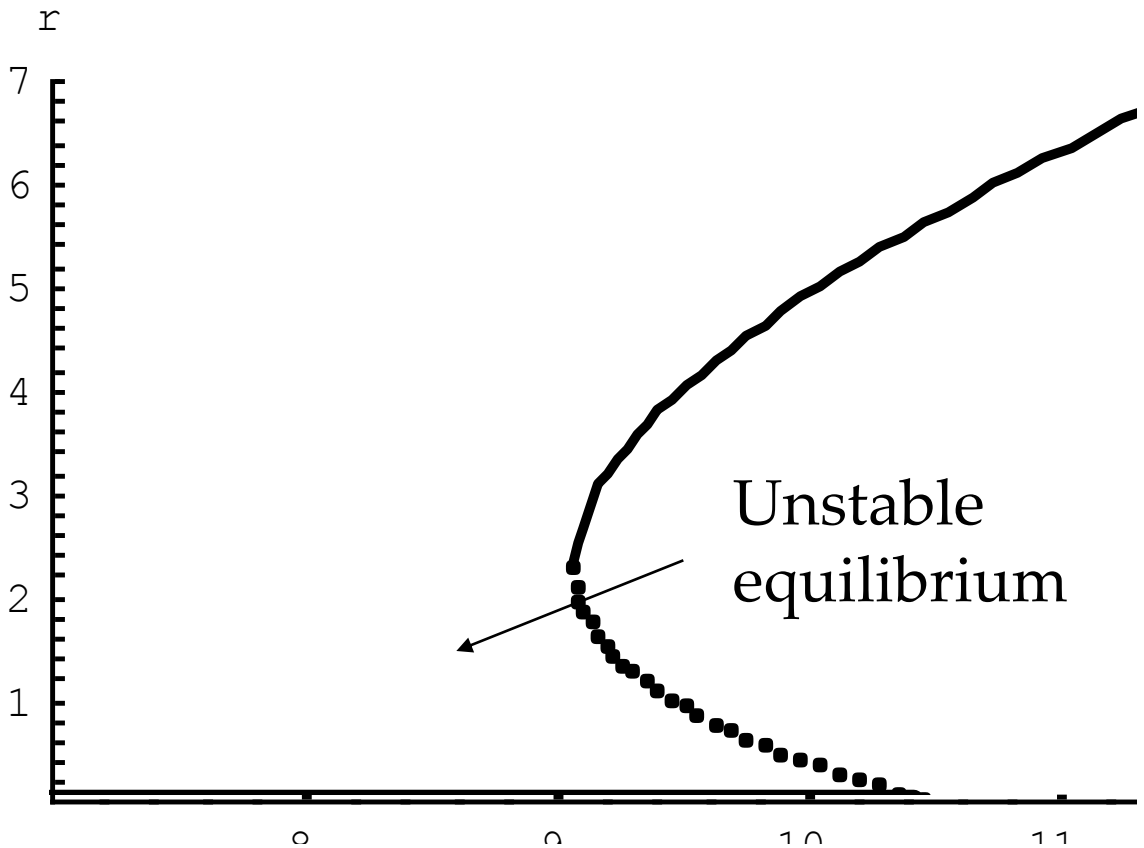
- In the model, a rise in world energy demand D has equivalent effects upon all variables as a rise in the carbon tax rate τ

→ Energy-saving policies and carbon tax are, thus, *not* substitutes (to the contrary!)

- If world energy demand D or the carbon tax rate τ increases, the expansion of the renewable energy sector is *discontinuous*

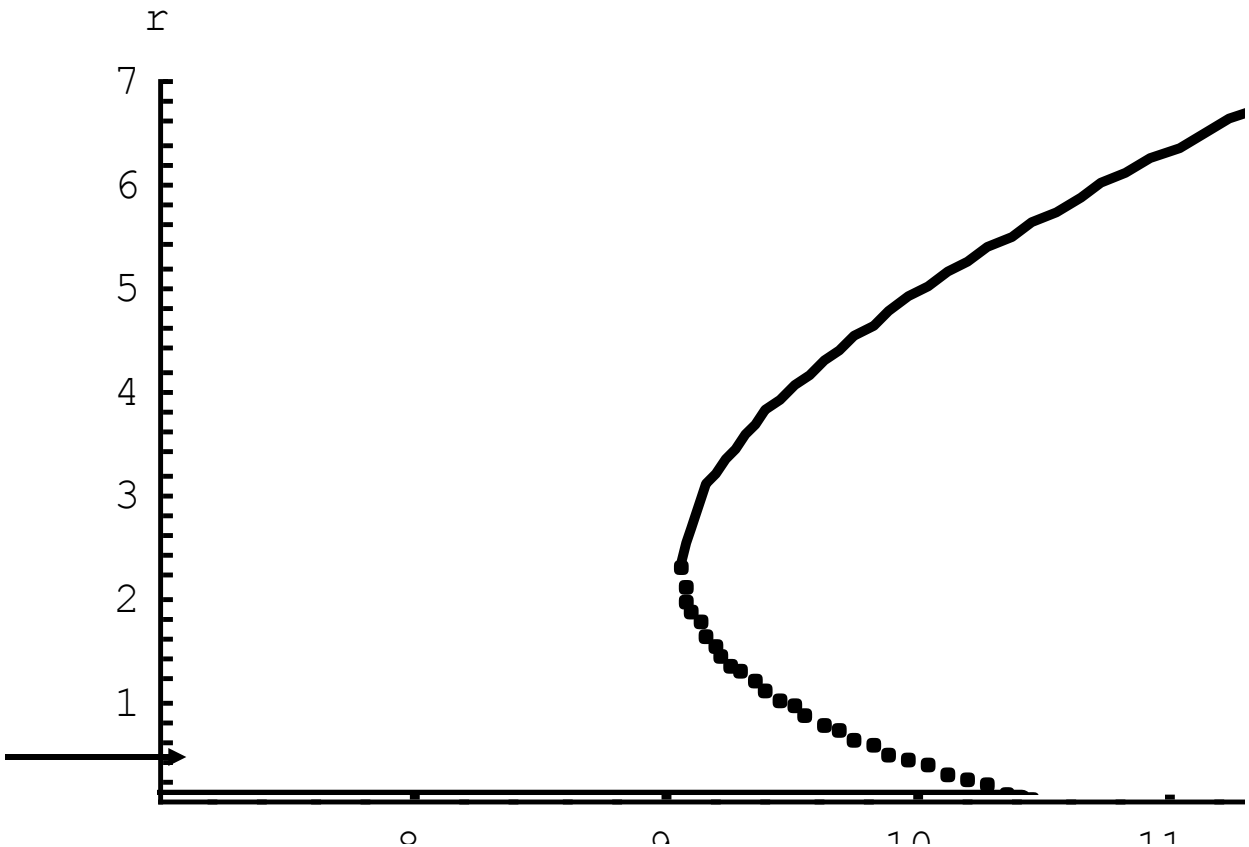
3. Results

Equilibrium R&D effort in ren. energy sector:



3. Results

Transition from lower to upper stable state:



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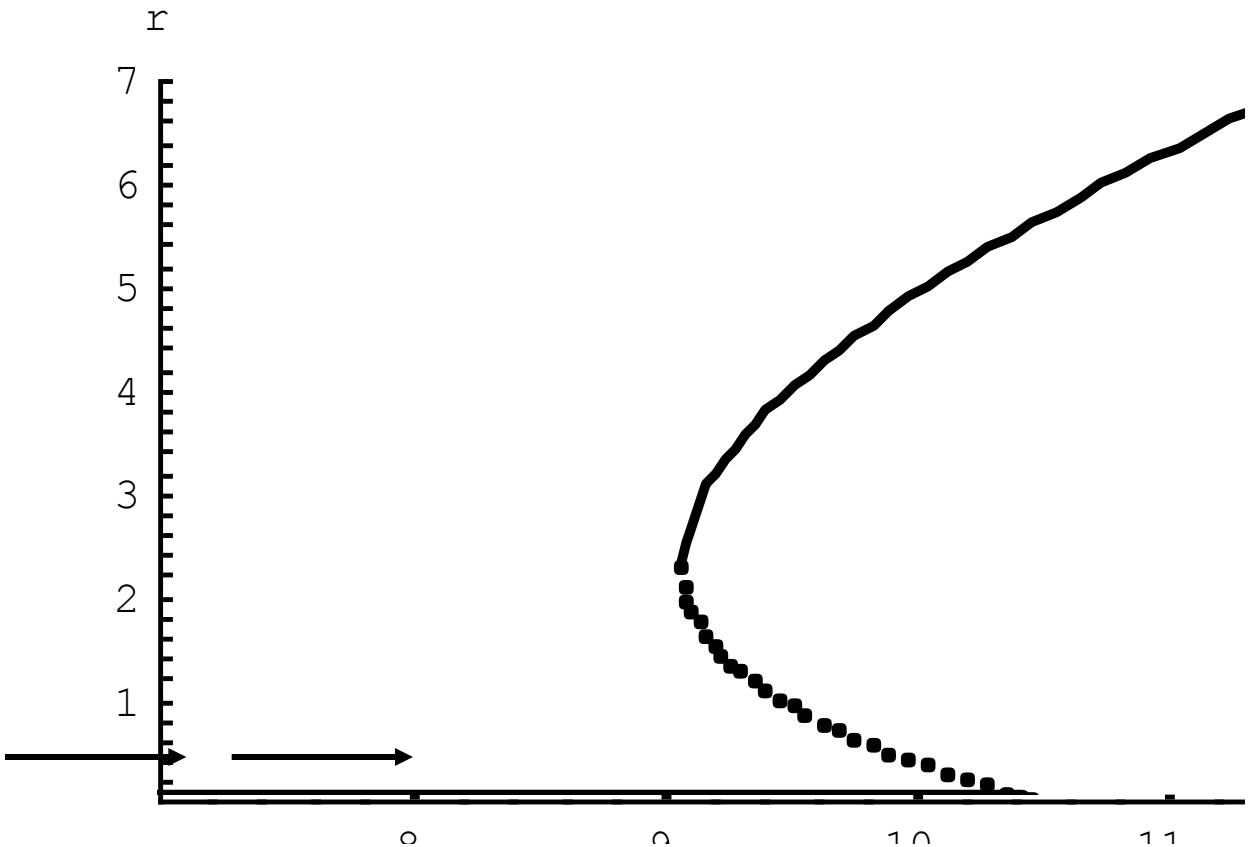

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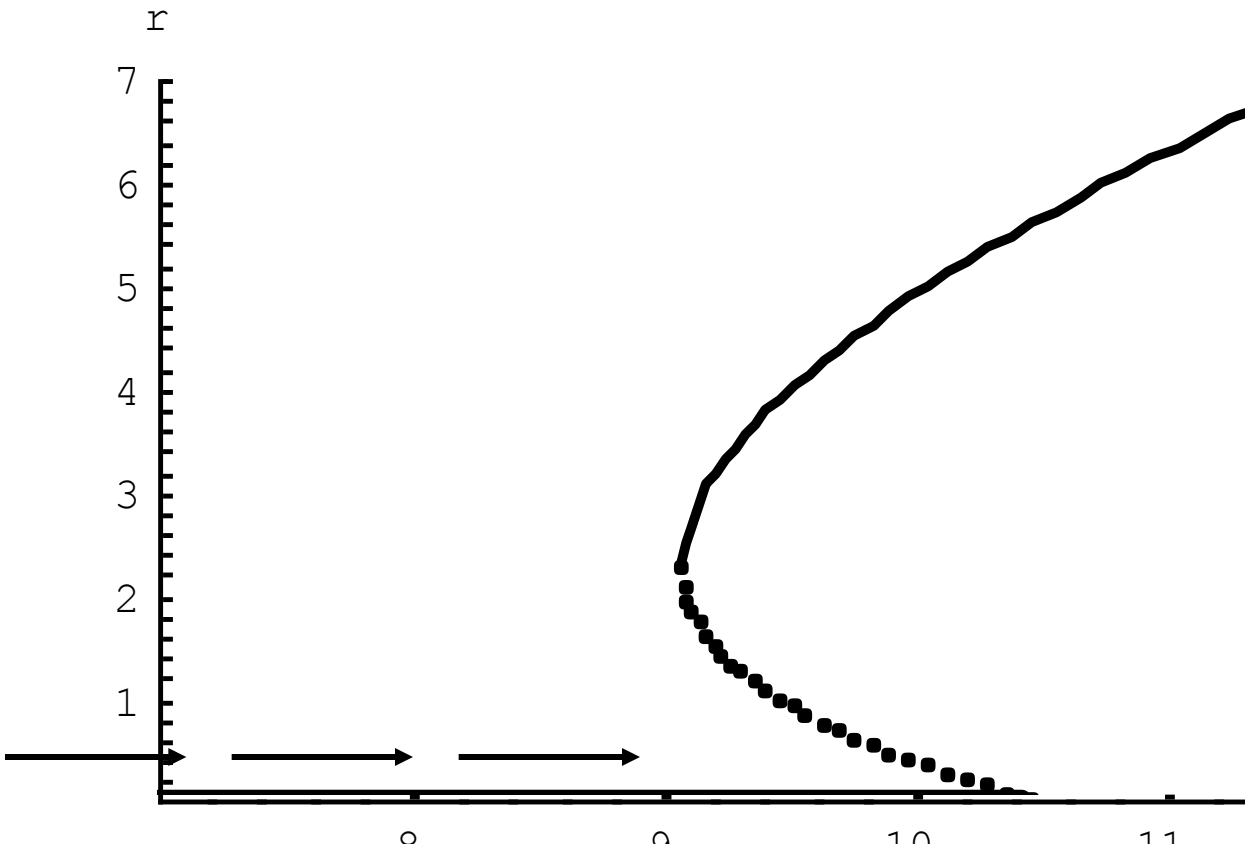
Transition from lower to upper stable state:



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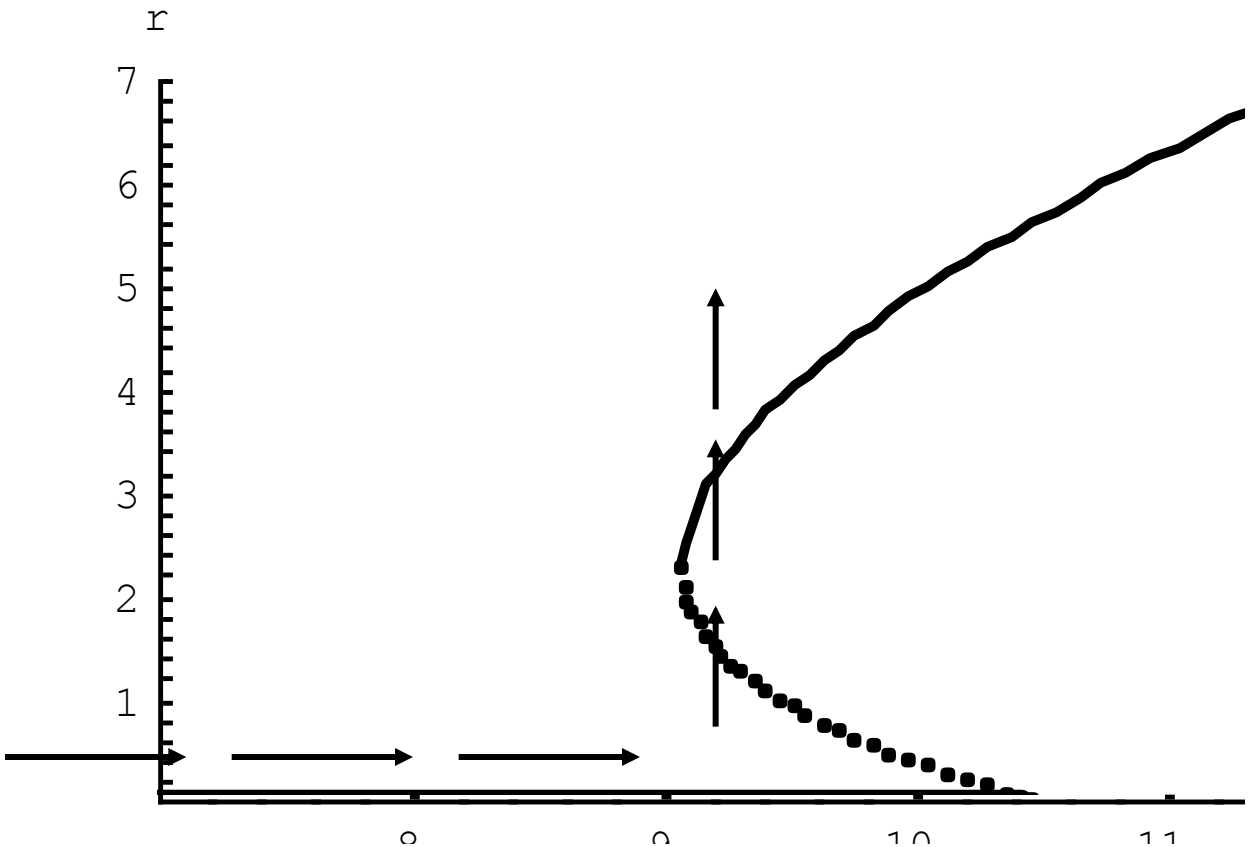
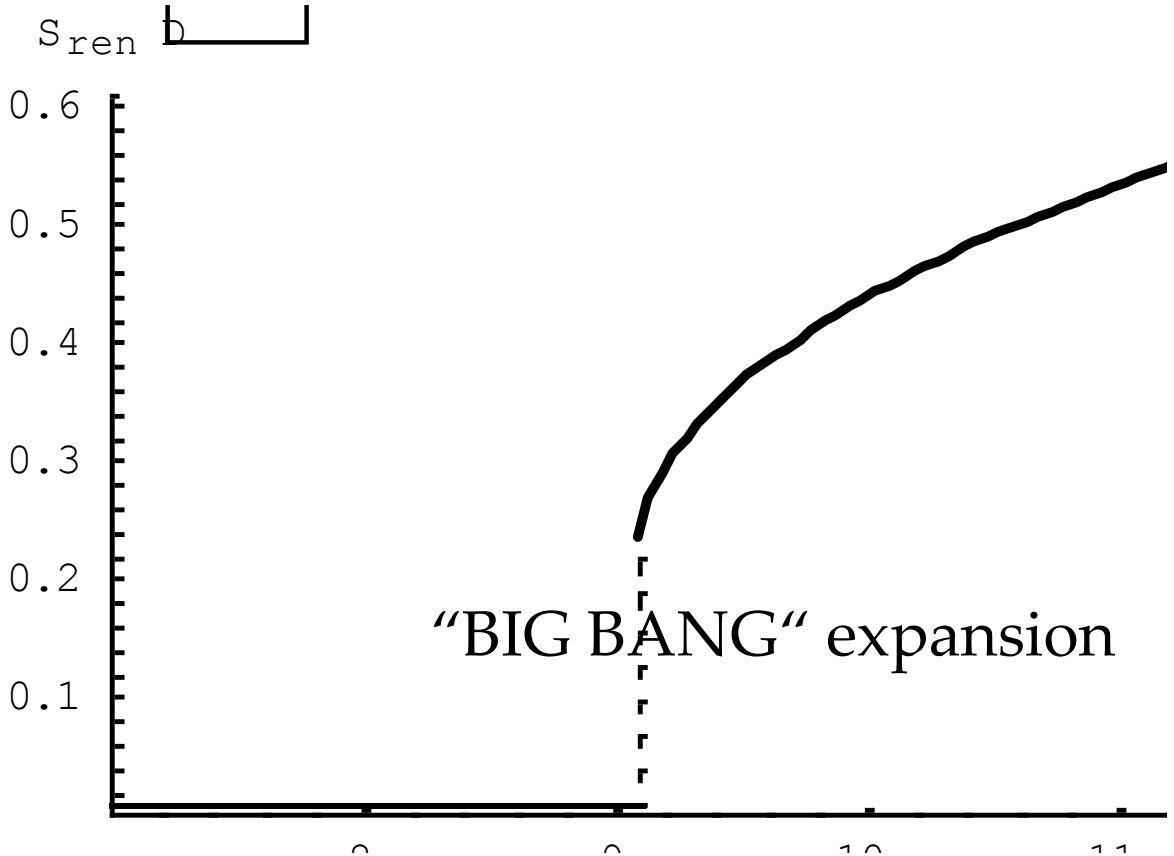
Transition from lower to upper stable state:



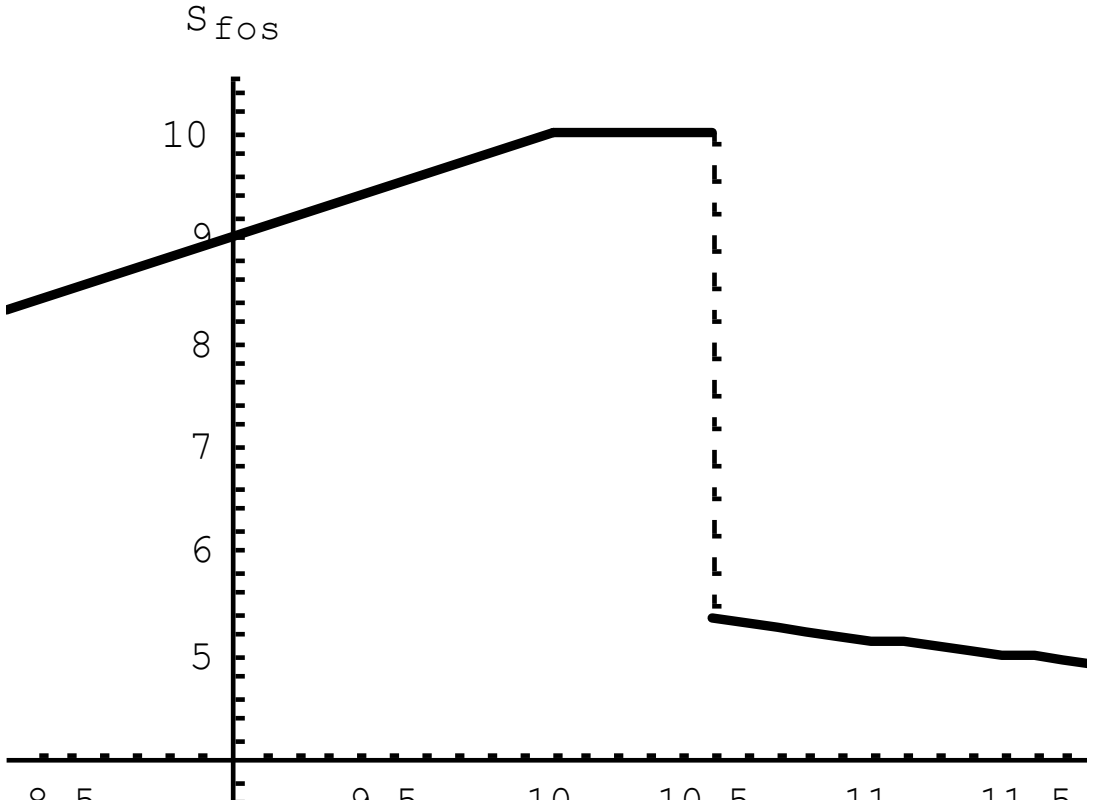
3. Results

Share of renewables in world energy mix:



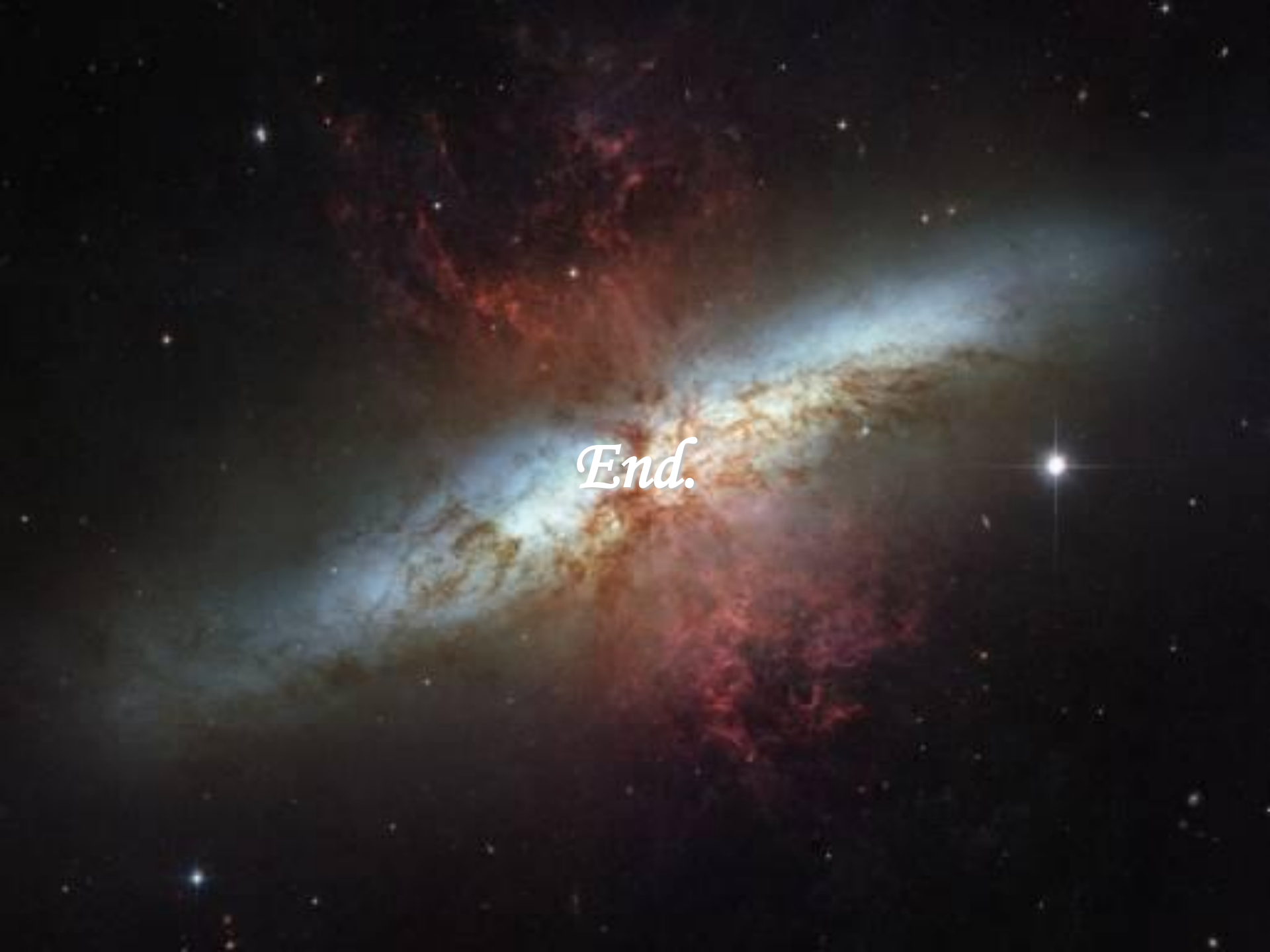
3. Results

Equilibrium supply of fossil energy:



Conclusion:

- Expansion of renewable energy sector not necessarily gradual
- "Low-investment trap": little investments in capacity yield little R&D effort
- Adequate policy measure to escape low-investment trap: *carbon tax*
- IF carbon tax politically not feasible: increase in world energy demand is an alternative policy
- Paradoxically: well-intended energy-saving policies can lead to higher emissions!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