Chapter 3:  
Modelling the electricity sector using FTT:Power  
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- **4CMR: at the crossroads of disciplines**
  Integrating economics, engineering, climatology, geography, social sciences…

- **Study Energy-Economy-Environment interactions**
  Strongly data led (econometrics) and/or focus on systems dynamics,

- **Focus on impact assessments of climate change policy**
  Projections of global greenhouse gas emissions and environmental impacts

  - **Energy systems modelling at the global scale**
    Fuel combustion emissions, technological change, the diffusion of innovations
Global Energy-Economy-Environment system

Planetary Boundaries

Environment
  Climate
  Natural resources
  Water
  Land

Energy systems
  Innovation
  Diffusion
  Investment

Policy Law

Macroeconomy
  Growth
  Distribution
  Investment
  Prices

Human Development
De-nuclearisation or emissions reductions?

East-Asia currently faces difficult choices for energy generation.
1- After the Fukushima accident, questions are raised with nuclear
2- With climate change, questions are raised with fossil fuels

Research questions:
- What is the impact on the energy sector of phasing out nuclear?
- What is the impact on the energy sector of phasing out coal?
  - Do emissions increase or decrease?
  - Do costs increase or decrease?
Problem of modelling technology choice:
Discrete choice theory, innovation-selection-diffusion

Defining a driver for technology substitutions

Separating choice from industrial dynamics:

Probabilistic Choice matrix: $F_{ij}$

Modelling decision-making

Revealed preferences integrates agent diversity

Probabilistic Choice matrix: $F_{ij}$
Modelling technology substitution

Coal → CCGT → Hydro → Wind → PV → BIGCC

\[ F_{ij} \]

\[ t = 1 \]

\[ t = 2 \]

\[ t = 3 \]

Modelling technological change

Substitutions

Coal → Coal
CCGT → CCGT
Hydro → Hydro
Wind → Wind
PV → PV
BIGCC → BIGCC

$t$ → $t + \Delta t$
Counting technology substitutions

Substitutions

Counting technology substitutions

\[ \sum_{i,j} F_{ij} \]

The Lotka-Volterra equation of population dynamics

$$S_i = \sum_j S_i S_j (A_{ij} F_{ij} + A_{ji} F_{ji}) t$$

Constraints of the system

Peak demand and storage capacity

\[ \Delta S_i = \sum_j S_i S_j (A_{ij} F_{ij} G_{ij} - A_{ji} F_{ji} G_{ji}) \frac{1}{\tau} \Delta t. \]  

(1)

\[ S_{\text{flex}} C F_{\text{flex}} + S_{\text{var}} C F_{\text{var}} + S_{\text{base}} C F_{\text{base}} = \overline{C F} \leq \overline{C F}_{\text{rated}}, \]  

(2)

\[ S_{\text{flex}} C F_{\text{flex}} + S_{\text{var}} C F_{\text{var}} \geq \overline{C F} \left( \frac{\Delta D}{D} + \frac{U_{\text{var}} T_D}{D} + \frac{E_s}{D} \right), \]  

(3)

\[ S_{\text{flex}} - S_{\text{var}} \geq \left( \frac{\Delta U_D}{U_{\text{tot}}} - \frac{U_s}{U_{\text{tot}}} \right), \]  

(4)

\[ S_{\text{base}} + S_{\text{var}} \leq \left( \overline{C F} - \frac{1}{2} \frac{\Delta U_D}{U_{\text{tot}}} + \frac{U_s}{U_{\text{tot}}} \right), \]  

(5)

Constrains growth of certain technologies
In situations of scarcity of flexibility
e.g. renewables in China
Constraints of the system

Base load vs peak load demand: splitting of the market
Results: electricity generation and emissions

Assumptions:
- Exogenous nuclear, and oil plant capacity
- All other generator types endogenous
- S1: No new nuclear builds, existing plants remain until retirement
- S2: No new coal builds, existing plants remain until retirement
- All scenarios:
  - FiTs for biomass, biogas, onshore+offshore wind and PV solar
  - No subsidies or carbon taxes
Results: electricity generation and emissions
Results: electricity generation and emissions

Japan:
- Slow demand growth rate
- Nuclear shut down replaced by fossil fuels $\rightarrow$ emissions $\uparrow$
- Baseline: emissions go back to original trajectory when nuclear restarts
- S1: nuclear replaced by coal, emissions higher than Baseline
  - Double 2008 emissions level in 2030
  - Electricity consumption unchanged
- S2: coal replaced by gas + renewables,
  - Emissions in 2030 $\sim$ 2008 level
  - Electricity consumption reduce ($\sim$8%) due to higher price
Results: electricity generation and emissions
Results: electricity generation and emissions

China:
- Fast demand growth, fast rise in emissions mostly from coal

Baseline:
- Large nuclear capacity rise (assumption)
- Hydro resources generally near the limit (FTT cost-supply curve)
- Other renewables quite insignificant

S1: nuclear entirely replaced by coal, \(\rightarrow\) emissions higher than Baseline
  \(\sim 2.5\) times higher in 2030 than in 2008

S2: coal replaced by expensive hydro projects + large scale biomass + gas
  - Consumption reduced (\(~9\%) due to higher price
  - Emissions \textit{below 2008 level} (\(~50\%\))
Results: electricity generation and emissions
Results: electricity generation and emissions

Korea:
- Fast growth rate of demand and emissions, large amounts of coal
- Important share of nuclear
  - Baseline: fast rise of coal, some renewables (due to FiT)
    - Rise in nuclear (assumption)
  - S1: nuclear replaced by coal → emissions higher than baseline
  - S2: coal replaced by gas + renewables + nuclear,
    - Emissions in 2030 ~ 2008 level
    - Electricity consumption reduce (~15%) due to higher price
Results: electricity generation and emissions
Taiwan:
- Fast growth rate of demand and emissions, large amounts of coal
- Important share of nuclear
  - Baseline: fast rise of coal, some renewables (due to FiT)
    - Rise in nuclear (assumption)
  - S1: nuclear replaced by coal $\rightarrow$ emissions higher than baseline
  - S2: coal replaced by gas + renewables + nuclear,
    - Emissions in 2030 $\sim$ 2008 level
    - Electricity consumption reduce ($\sim$15%) due to higher price
Results: electricity generation costs

Baseline

Cost of electricity production (USD/MWh)

- Base Japan
- Base China
- Base Korea
- Base Taiwan

Over the years:
- 2010: Base Japan
- 2015: Base China
- 2020: Base Korea
- 2025: Base Taiwan
- 2030: Base Taiwan
Results: electricity generation costs

Cost of electricity production (USD/MWh)

- Base Japan
- Base China
- Base Korea
- Base Taiwan
- S1 Japan
- S1 China
- S1 Korea
- S1 Taiwan

Years: 2010 to 2030
Results: electricity generation costs
Results: electricity generation costs

S1 & S2
Baseline:
  - Costs are nearly constant throughout the period

S1:
  - Costs are nearly unchanged in all cases,
    - nuclear is replaced by coal

S2
  - Costs increase significantly in all cases:
    - Coal is the least cost option, which we phase out
    - FiT costs are added to total system costs
      - Uptake of renewables expensive
    - Grid balance provided by more hydro + gas turbines
List of model references

- Data exploration on the 4CMR website: http://www.4cmr.group.cam.ac.uk/research/FTT/fttviewer
- Consumption of non-renewable resources: Energy Policy, 63, 469-483 (2013) See also 4CMR working papers: http://ideas.repec.org/p/ccc/wpaper/002.html