Can we Move to a Low Carbon Economy with Little Cost?

-- a view from the perspective of uncertain endogenous technological change

Tieju Ma

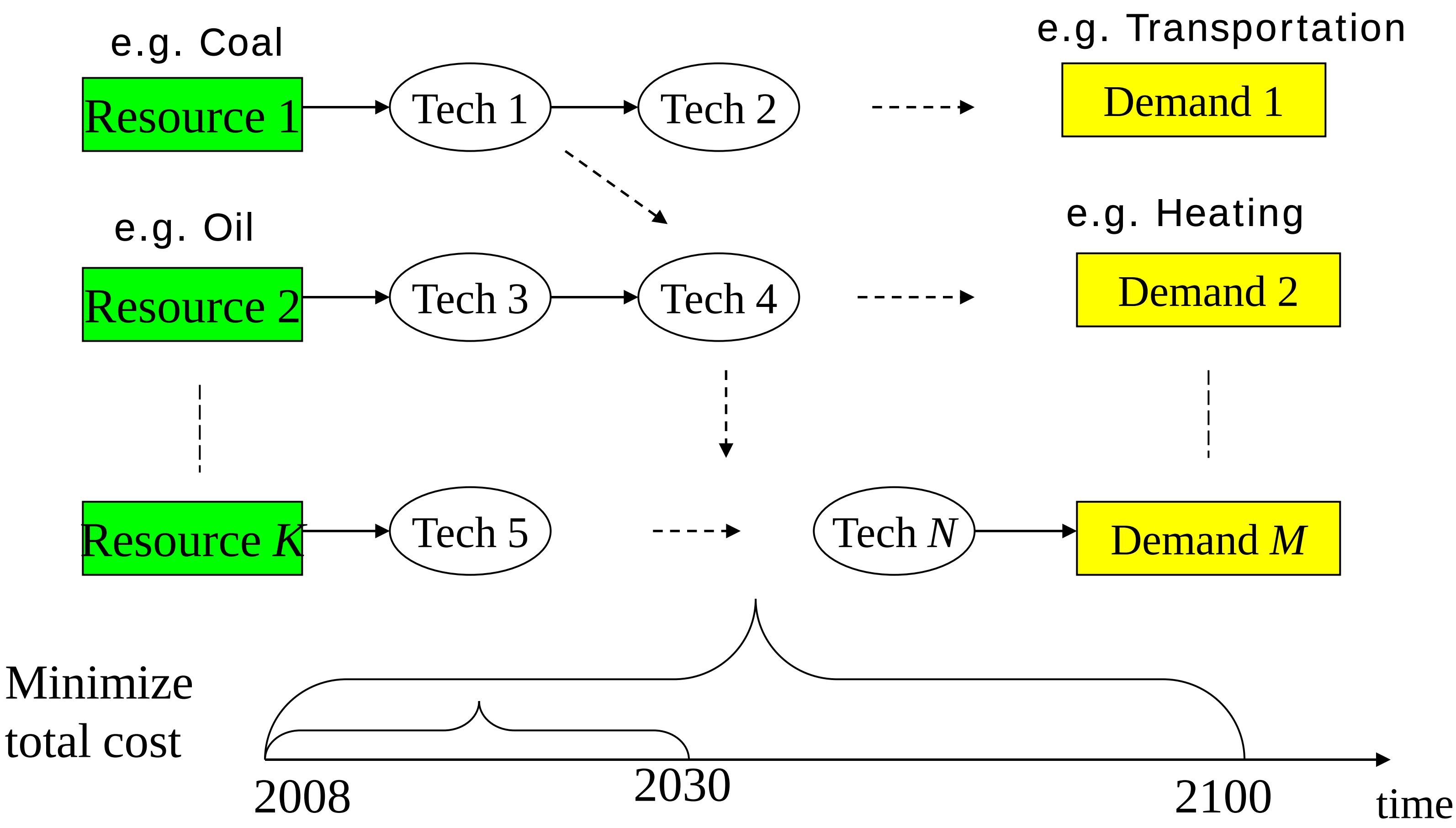
International Institute for Applied Systems Analysis IIASA, Austria

School of Business, East China University of Science and Technology, China

Introduction

- Carbon emissions from human activities have caused global warming. For surviving and sustainable development, we need to move to a low carbon economy.
- Many people are worrying about that moving to a low carbon economy need high investment on new technologies and thus it will restrain the development of the economy. Policy makers hesitate to make decisions to promote the transition.
- Is there any path which can lead the economy to a low carbon one with little cost? In other words, the economy can be developed as well during the transition.
- My study tries to show some light on this issue from the perspective of optimization models of uncertain endogenous technological change by using a simplified energy system model as a heuristic research device.

Techno-economic optimization models



to find technology strategies which can satisfy final human demand with the minimal total cost under certain constraints.

General Form of Techno-Economic Optimization Models

$$\min \sum_{t=1}^{T} C^t \bullet X^t$$

Subject to constraints:

e.g., on

- *Demands*
- *Resources*
- *Emissions*

$$X^t = \begin{pmatrix} x_1^t \\ \vdots \\ x_N^t \end{pmatrix}$$ Technology Strategies at time *t*

$$C^t = \left(c_1^t, \cdots, c_N^t\right)$$ Cost vector

T: Time scale of the problem

E.g., MESSAGE (IIASA), MARKAL (IEA)

Technological change in traditional models

- Technological change was largely treated as exogenous, e.g.,
  - A technology’s efficiency increases 1% every year.
  - Productivity increases 2% every year.
  - A technology’s cost decreases 2% every year.

- Thus technological change was treated as a free good, or “a manna from heaven”.

Modeling Endogenous Technological Change

- From 1990s, IIASA, Stanford, etc.
  - Wide acceptance of “increasing returns” (W. B. Arthur 1988) on technology adoption / technological learning.
  - Increasing computation capability
- $$C^t = f\left(X^0, X^1, \cdots, X^{t-1}, B\right)$$

  B is a vector contains technologies’ learning rates
- Other names: LBD (Learning-by-doing) models, induced technological change models.

Learning rates, progress ratio, and leaning curves

$$c_{Fi}^{t} = c_{Fi}^{0} \times (\overline{C}_i^t)^{-b_i}$$

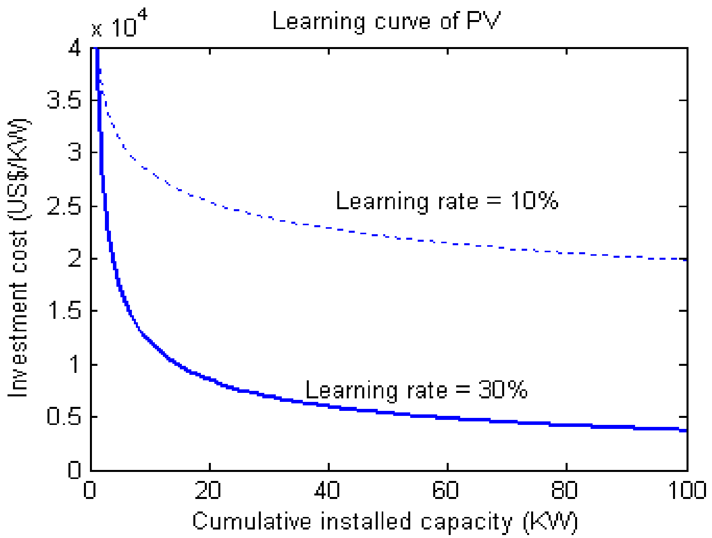
c_{Fi}^{t} : Investment cost of technology *i* at time *t*

c_{Fi}^{0} : Initial Investment cost of technology *i*/ parameter

$\overline{C}_i^t$: Cumulative installed capacity of technology *i* by time *t*

$1-2^{-b_i}$: learning rate of technology *i* -- **the percentage reduction in future investment cost for every doubling of cumulative capacity**

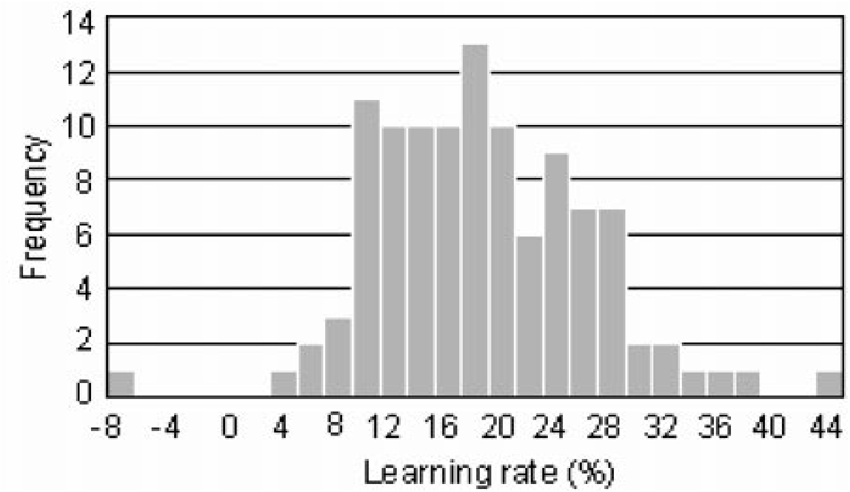
An example:
Suppose PV's (initial) investment cost for the first unit is 40000US$/KW, and its learning rate is 30%



Uncertainty in learning rates

Historical observations show that

- Technological learning is uncertain
- Learning rates commonly follow log-normal distributions



McDonald and Schrattenholzer 2001

Overestimating learning rate –> financial risk

Need to copy with uncertainties in learning rates

Modeling uncertain technological learning with stochastic optimization

Deterministic learning	$\min \sum_{t=1}^{T} f\left(\bar{X}^{t-1}, B\right) \bullet X^t$
The risk-factor method	$\min \sum_{t=1}^{T} f\left(\bar{X}^{t-1}, B\right) \bullet X^t + \rho R\left(X\right)$
The first risk-constrained method	$\min \sum_{t=1}^{T} f\left(\bar{X}^{t-1}, B\right) \bullet X^t$ $R\left(X\right) < \nu$
The second risk-constrained method	$\min \sum_{t=1}^{T} f\left(\bar{X}^{t-1}, B\right) \bullet X^t + R\left(X\right)$ $R\left(X\right) < \nu$

$$\bar{X}^{t-1} = \left(X^0, X^1, \cdots X^{t-1}\right)$$

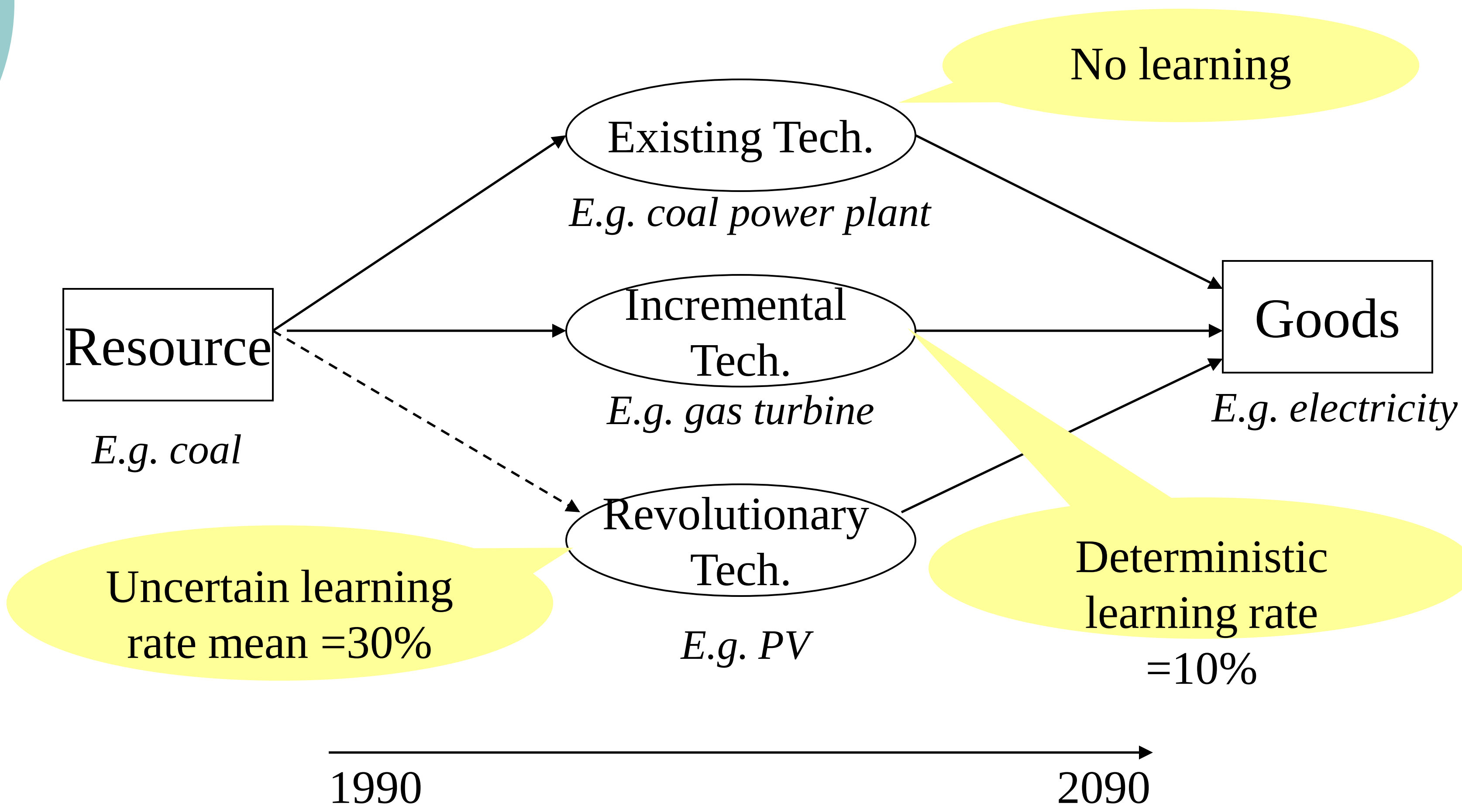
$$X = \left(X^1, \cdots, X^T\right)$$

ρ -- a risk factor denoting a decision maker's attitude to risk.

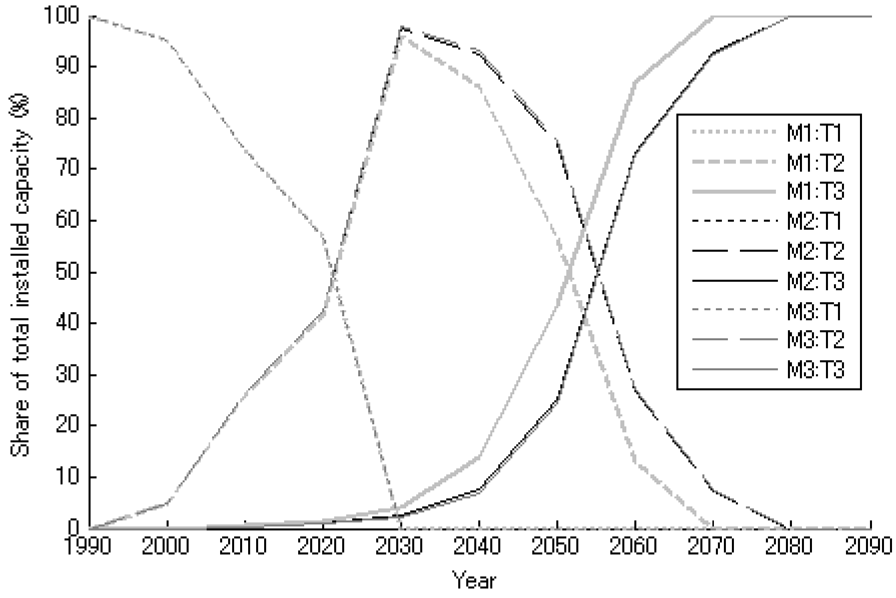
$R\left(X\right)$ -- expected risk cost resulted from overestimating learning rates

ν -- an upper-limit on expected risk cost.

A highly stylized model-- Inspired by energy and climate change policy models



Results with base line cases

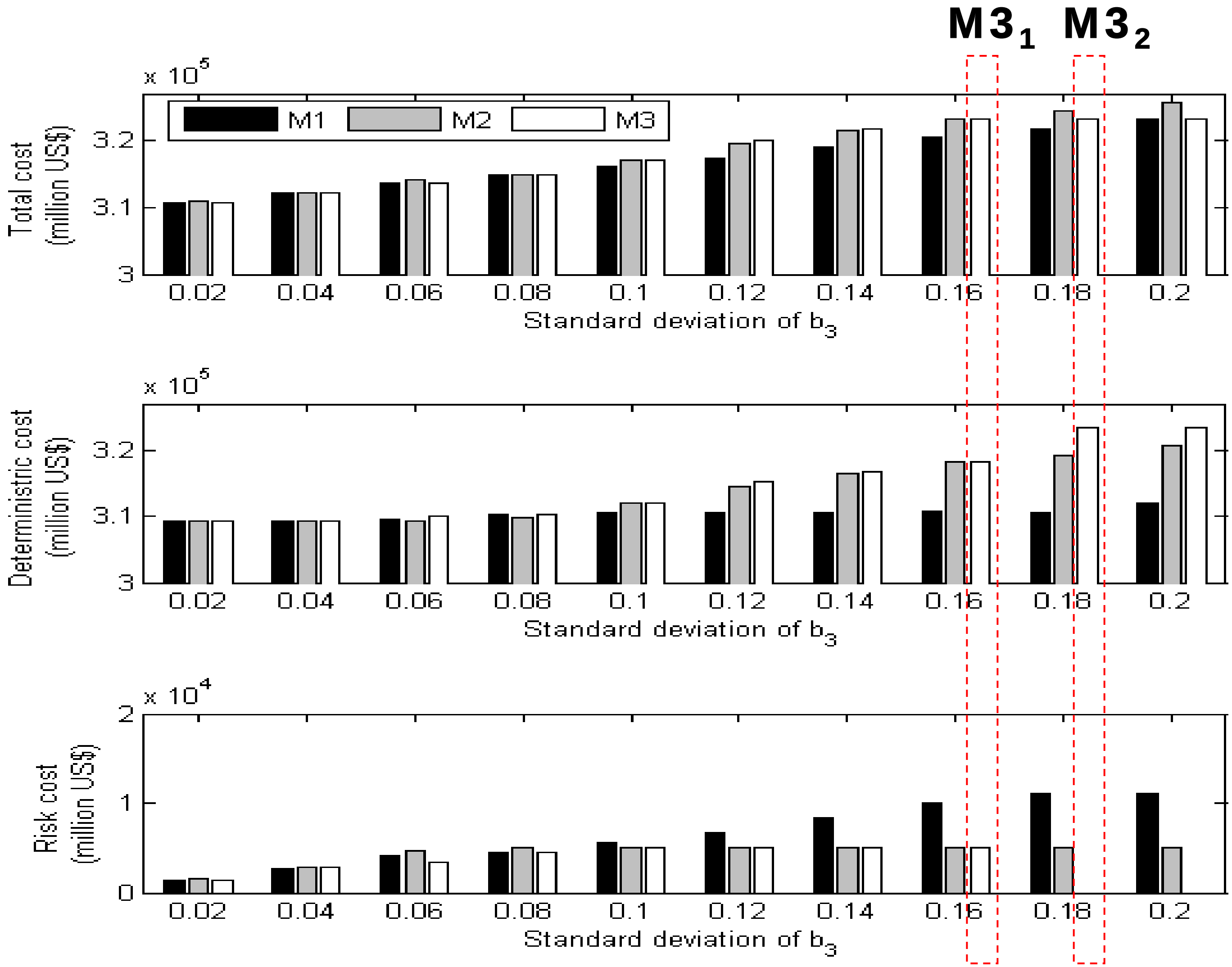


$\rho = 1 \quad \nu = 5$ billion US$

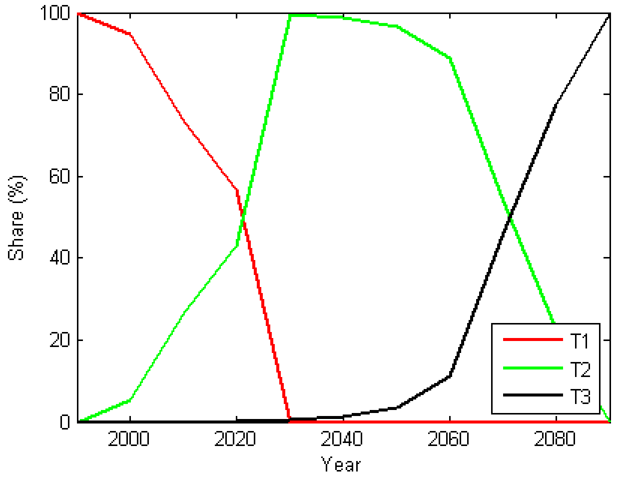
M1: the risk-factor method
M2: the first risk-constrained method
M3: the second risk-constrained method

T1: the existing technology
T2: the incremental technology
T3: the revolutionary technology

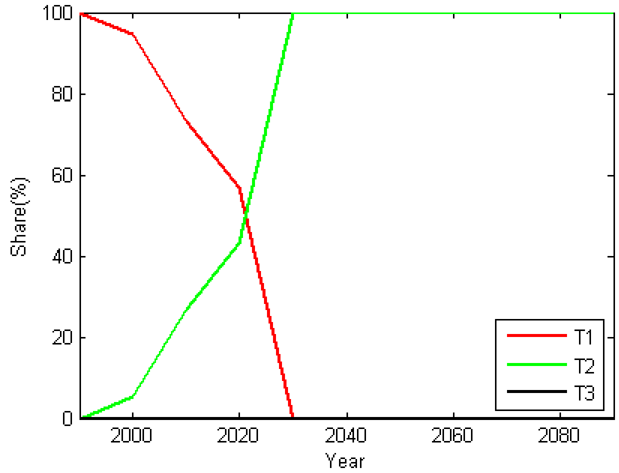
Cost of the system



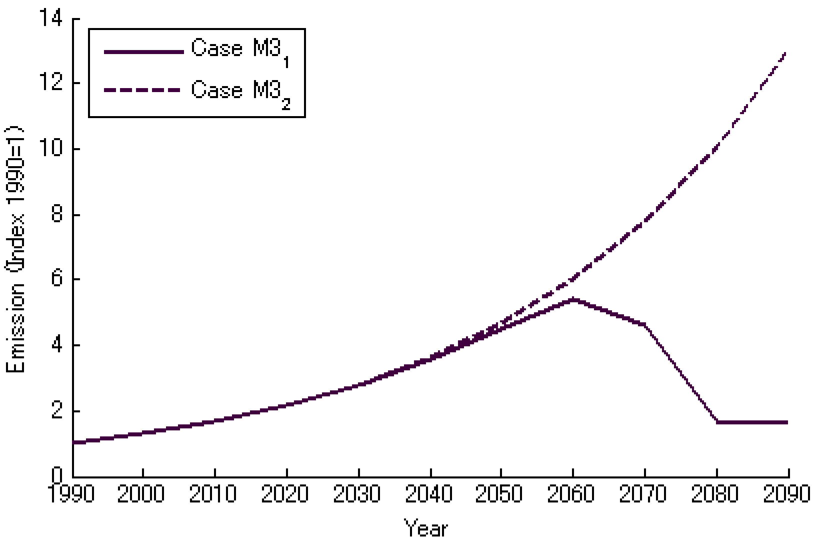
Technology dynamics of Case $M3_1$



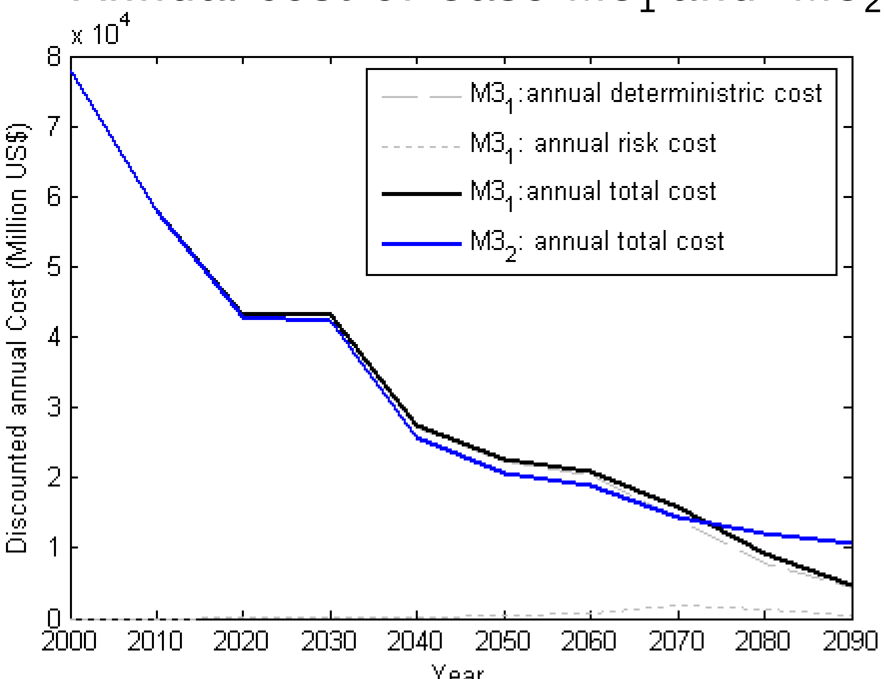
Technology dynamics of Case $M3_2$



Emission index of Case $M3_1$ and $M3_2$



Annual cost of Case $M3_1$ and $M3_2$



Concluding remark

My study shows that with technological learning, two different development paths may have very similar total costs. And these two technology development paths may result in totally different emission paths, which means, with early policy interventions, there is opportunity that an economy can be led to a low carbon one without much additional cost.

My study tells the possibility, but not tell how.