

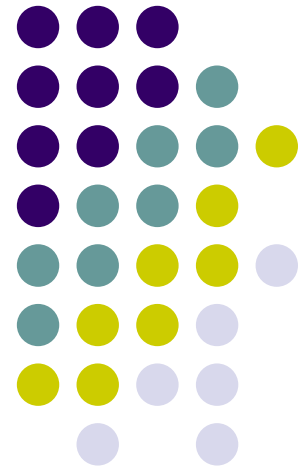
Modeling Technological Change in Energy Systems

-- from optimization to agent-
based simulation

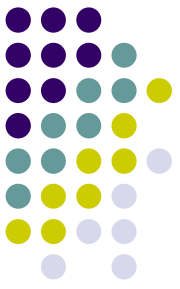
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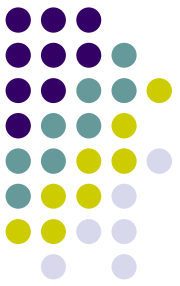


Modeling energy systems



- Operational optimization models are one of the main streams in modeling energy systems
- Agent-based modeling and simulations seems to be another rising stream
- Technological change is an important factor.
- Various agent-based models could be developed with different understandings of agents and their behaviors, e.g.,
 - An agent-based model of new electricity trading arrangements (Bunn and Oliveira, 2001)
 - An agent-based hydrogen vehicle/infrastructure model (Stephan and Sullivan, 2004)
 - An agent-based model for organic building-out of energy systems (Ma, Arthur, Grubler, and Nakicenovic 2006)
 - An agent-based network model of diffusion of new eco-technology (Cantono and Silverberg 2007).

Objective

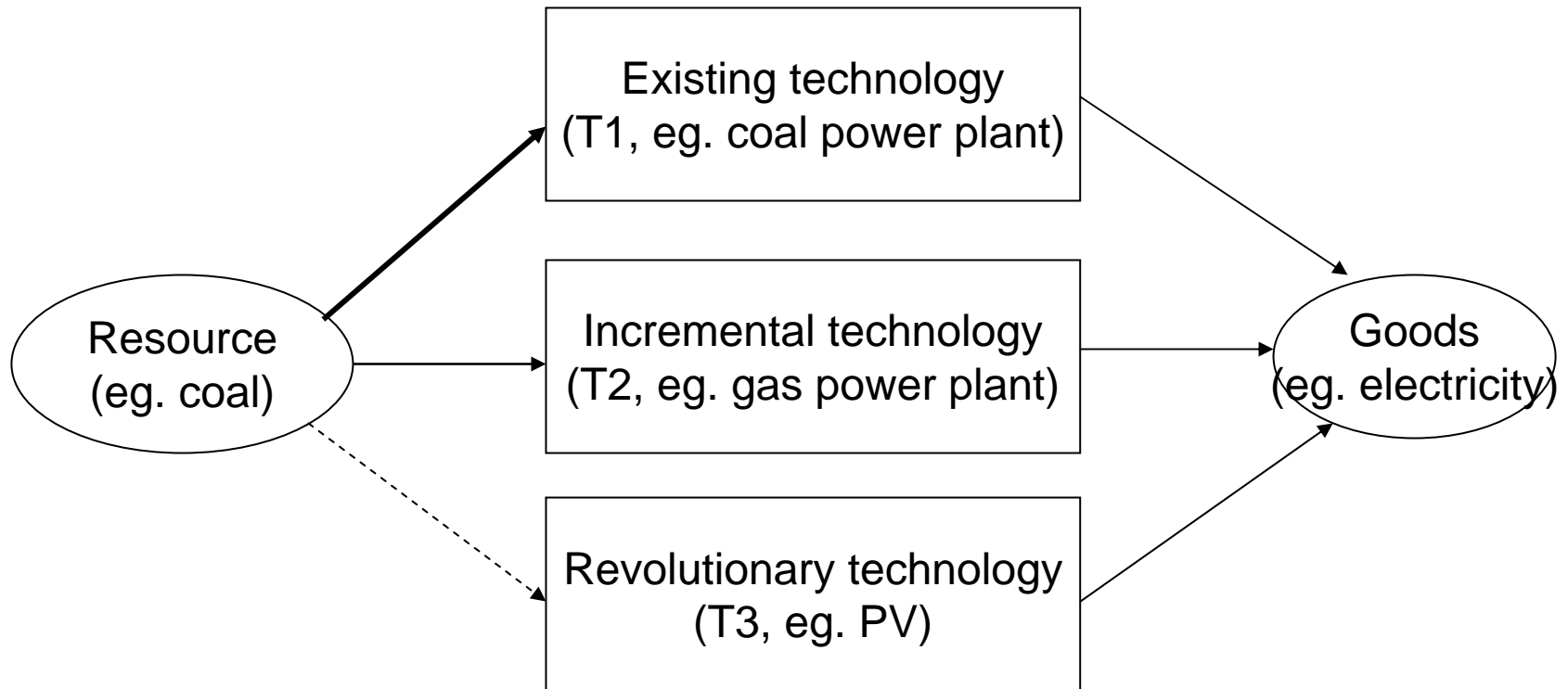
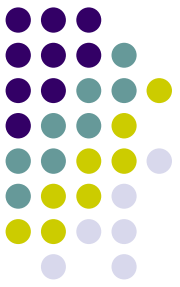


- What are the essentials of ABM for energy systems?
- And why and how it is different from traditional models, especially the way technological change is dealt with?

Three stylized models based on a deliberately simplified energy system for providing some insights into the above issues,

- A traditional optimization model
- An endogenous technological change model
- An agent-based model

The Deliberately Simplified Energy System

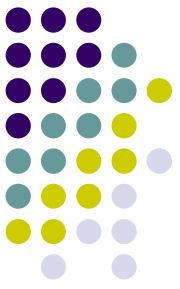


Time dimension: 100 years

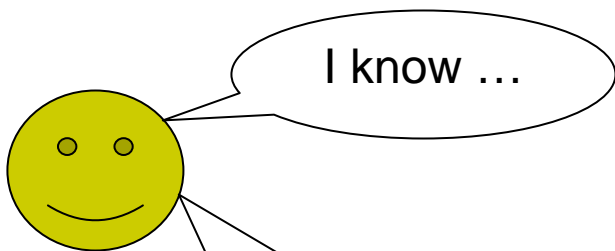
1990

2090

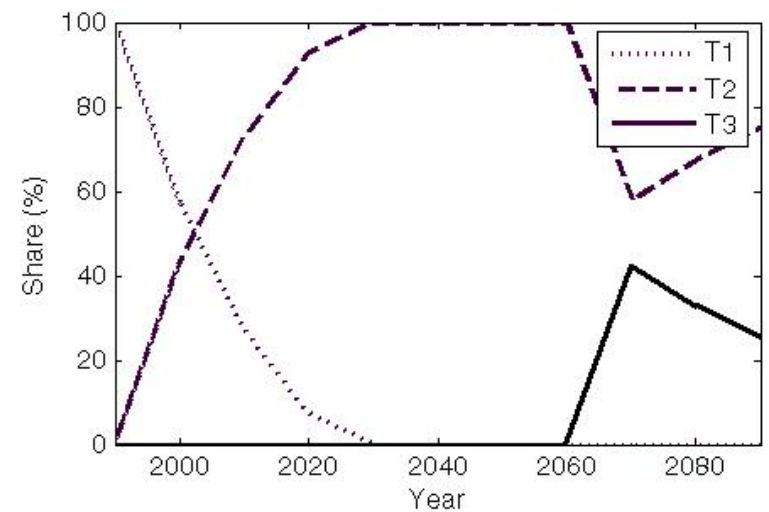
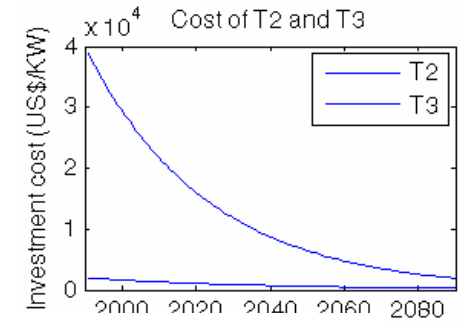
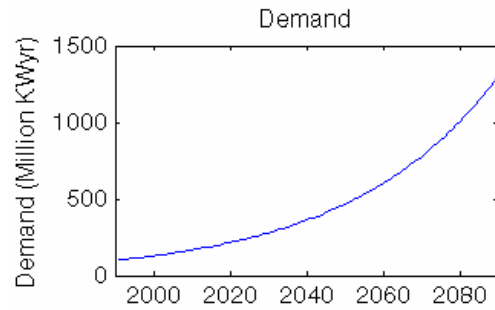
The Traditional Optimization Model



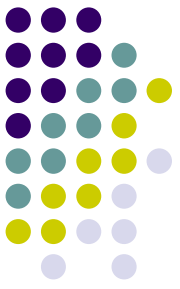
A global social planner who makes a long-term strategic plan for the energy system thus the discounted total cost is minimized for satisfying the given demand;



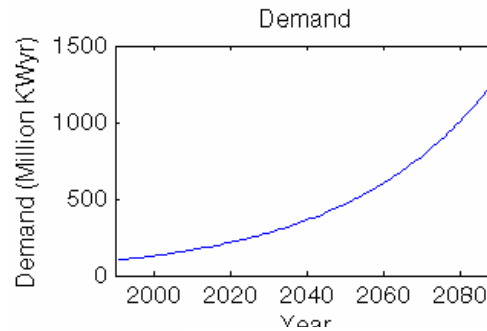
So, for the following 100 years, for minimizing the discounted total cost for satisfying the demand, we should ...



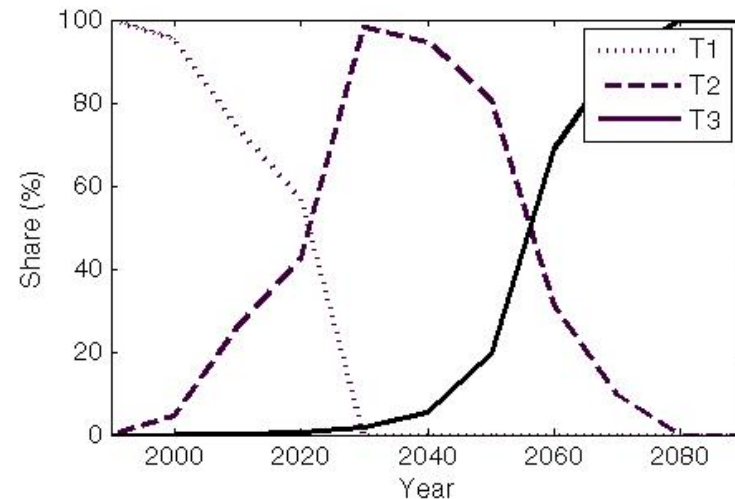
The Endogenous Technological Change Model



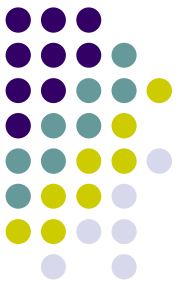
The same story as that of the traditional optimization model except that: the investment costs T2 and T3 are now a function of the cumulative experience in using them – technological learning



If we use T2 and T3, their costs will decrease; the more we use them, the more their costs decrease



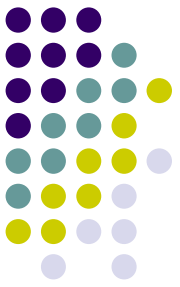
About Agent-Based Modeling



- Agents: autonomous decision-making entities (Bonabeau, 2002).
- ABM: modeling (complex adaptive) systems with multiple elements/entities adapting or reacting to the pattern these elements create together (Arthur, 1999).
- Agent-based simulation:

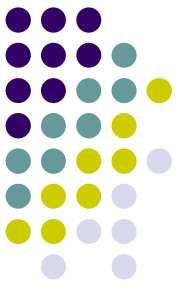
Simulation is a third way of doing science. Like deduction, it starts with a set of explicit assumptions. But unlike deduction, it does not prove theorems. Instead a simulation generates data that can be analyzed inductively. Unlike typical induction, however, the simulated data comes from a rigorously specified set of rules rather than direct measurement of the real world. While induction can be used to find patterns in data, and deduction can be used to find consequences of assumptions, simulation modeling can be used to aid intuition (Axelrod, 1997).

The Agent-Based Model

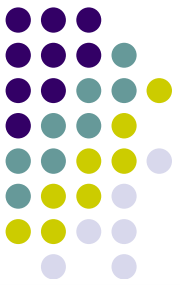


- The planner → Myopic but adaptive agent
- The story of the model is that the planner is not so smart to minimize the total cost of a long-term period, or we can say he is myopic, and his decisions are made for a short term, e.g., one-year; the agent is not clear about the future demand thus it could not be completely rational, i.e., it is possible that the agent would build more or less capacity than really needed; although the agent is myopic and not full-rational, it is adaptive, it will adjust its decision according to resource depletion, demand dynamics, technology costs, all of which are the results of his early decisions;

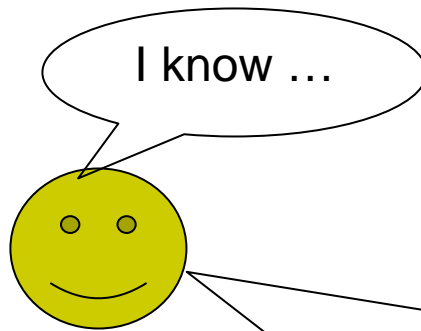
Rules/Assumptions in the Agent-Based Model



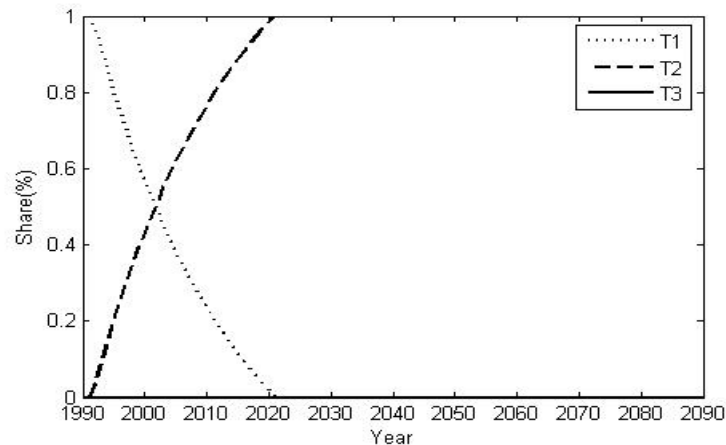
- The agent does not know the future demand, future extraction cost, and future technology costs,
- At each year, the agent calculates the average annual growth rate of extraction cost for the last three years, and then uses this growth rate to forecast the extraction cost for the next year.
- The agent uses each technology's current cost to evaluate which technology is cheapest for the next year.
- The agent's expectation on demand is also based on the last three years' data, it calculates the average annual growth rate of demand for the last three years, and then uses this growth rate to forecast the demand for the next year. If the agent's expected demand for the following year is higher than available capacity, it will build new capacity of the cheapest technology to fill the gap; otherwise it will not build any new capacity.
- At each step, the exogenous increasing demand is influenced by price for satisfying it which is decided by weighted average cost of technologies. The weight of a technology is its share in the energy system.



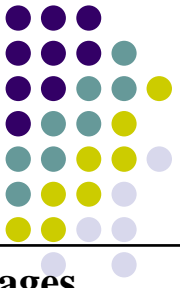
The Agent-Based Model



I make decision for each year based on my expectations about future which is formed based on my knowledge about the past,



Concluding Remarks



Models	Philosophy	Advantages	Disadvantages
Traditional	A decision maker makes a long-term strategic plan under perfect foresight without considering the cost of technological change	Easy to get optimal solution with comparatively small computing complexity	Technological change is treated as outside the “economy box”
Endogenous	A decision maker makes a long-term strategic plan under perfect foresight considering the cost of technological change	Technological learning as a mechanism for the adoption of new technologies.	Nonlinear, non-convex optimization problems, thus high computing complexity and difficult to get optimal (especially global) solutions.
ABM	A decision maker makes adaptive decisions based on the situation created by he/she (or with other decision makers), and technological change is the result of decision makers’ adaptive behaviors.	It is very natural to model adaptive behaviors and interactions among decision agents, and technological learning and uncertainties can easily be introduced in the model.	Results are not optimal solutions but scenarios under various assumptions.