Towards
Next Generation Climate Models

ECF Expert Workshop: Towards the next generation of climate policy models
Berlin
November, 2008
Tom Fiddaman
With thanks to John Sterman

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Agenda

- Risks
- The situation on the ground
- The dominant model paradigm
- Some essential features of alternatives
- Four model examples
- Moving forward

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The Situation on the Ground

- **Technical:**
  - Models and data do not exist for some contemplated policies
  - Modeling is too slow to keep up with the policy process
  - Models divide related problems into analytical stovepipes
  - Equilibrium and optimization dominate
- **Social:**
  - Legislation precedes analysis
  - The origin of disagreements (uncertainty about the world vs. conflicting stakeholder values) is not explicit or understood
  - The impacts of policies may differ from what voters have “signed up for”
  - Negotiations are often dominated by non-climate interests

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Some Prominent IAMs

- IGSM – dynamic general equilibrium
- MERGE – intertemporal optimization
- MiniCAM – partial equilibrium, intertemporal optimization
- MESSAGE – energy system optimization
- ASF – hybrid
- AIM – hybrid top-down/bottom-up
- WorldScan – general equilibrium
- DEMETER – top-down optimization
- ENTICE – intertemporal optimization
- MIND – hybrid energy/endogenous growth
- RICE – intertemporal optimization

Source: AR4 WG3 Technical Summary

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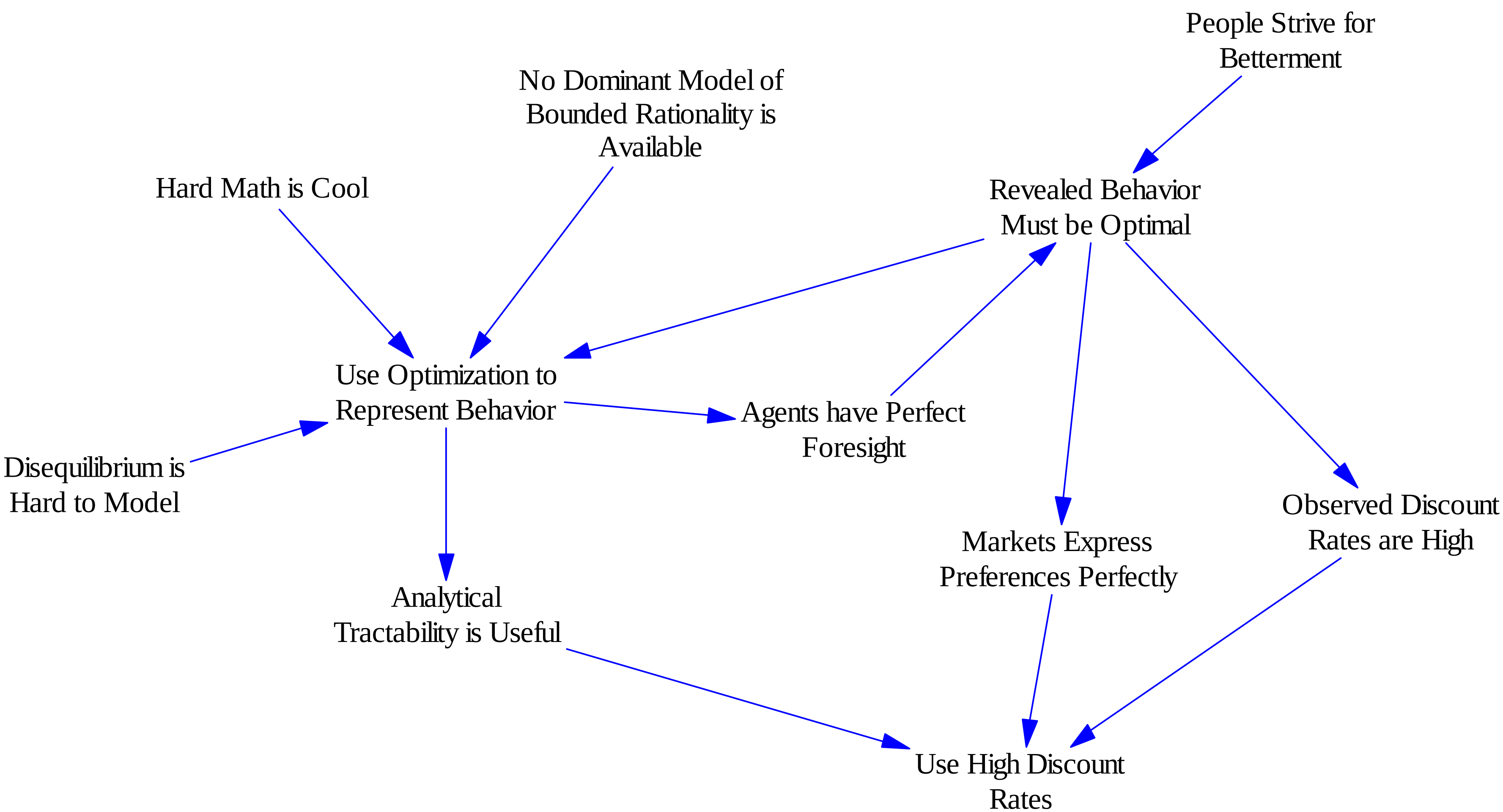
The Equilibrium Rationale



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Why are conventional models successful?

- Behavior is reduced to a numerical algorithm, freeing resources for the specification of detail
- Structural elements and input data are generalizable and reusable
- Material and money are conserved
- Answers satisfy decision maker appetite for detailed planning rather than general strategy development
- Model consumers are unsophisticated, and have insufficient appetites for robustness

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Risks of the Current Dominant Paradigm

- **Many models reinforce unsustainable decisions**
  - Climate risks are underestimated
  - Mitigation costs are overestimated
  - Coordinated risks in other domains are ignored
- **Mental models favoring "wait and see" approaches that lead to poor outcomes go unchallenged**
- **Novel policies are at risk of failure due to untested fundamental design flaws**

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AR4 WG3 Knowledge Gaps

- **Emission data sets and projections**
- **Links between climate change and other policies**
  - Sustainable development, equity, energy security, ...
- **Studies of costs and potentials**
  - Coverage, top-down/bottom-up gap, effects of rates of adoption
- **Innovation, diffusion**
- **Behavior, preferences**
- **Trade, finance**

Source: AR4 WG3 Technical Summary

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Some Essential Elements of an Alternative Approach

- **Behavior**
  - Delays, foresight, biases, extrapolation
  - Multi-agent heterogeneity
  - Networks
  - Evolution
  - Institutional structures
- **Nonlinearities and positive feedbacks**
  - Endogenous technology
  - Biogeophysical processes, especially ecosystems
- **Broad boundary**
  - Non-climate goals and problems: population, poverty, ...
- **Goals, values**

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100

Happiness Index

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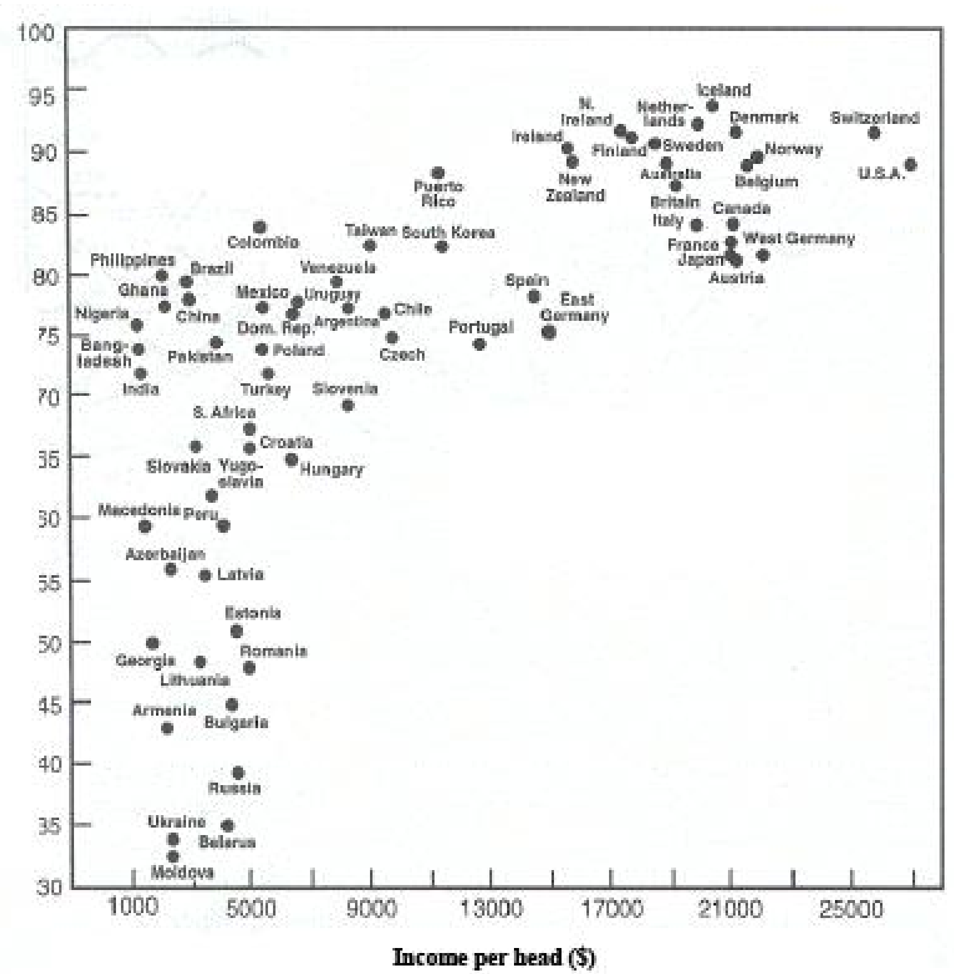
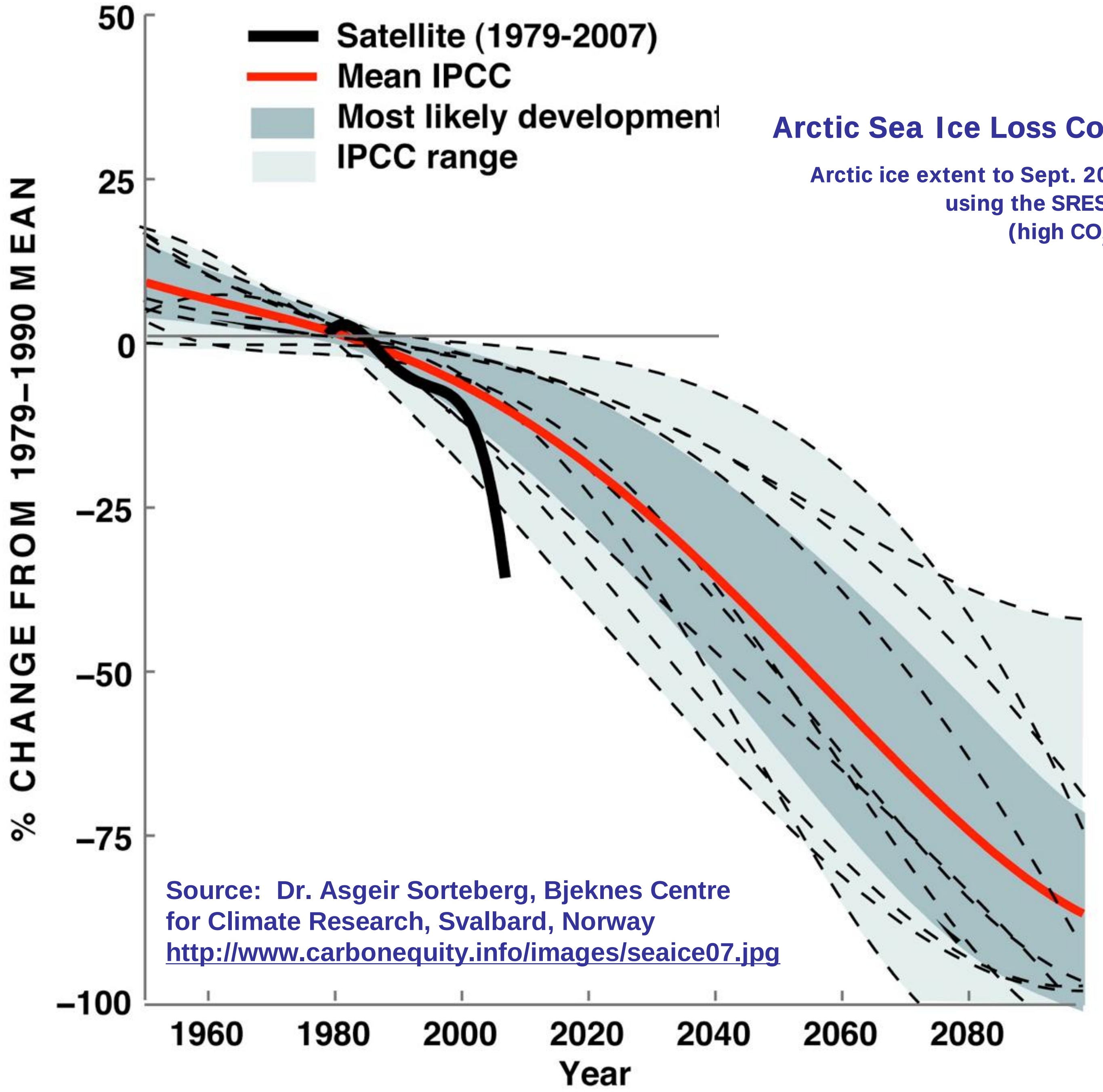


Source: Inglehart and Klingemann (2000), Figure 7.2 and Table 7.1. Latest year (all in 1990s).

Income/Capita

Slide courtesy of John Sterman, MIT



Arctic Sea Ice Loss Compared to IPCC Models

Arctic ice extent to Sept. 2007 compared to IPCC models using the SRES A2 CO_2 scenario (high CO_2 scenario).

Slide courtesy of John Sterman, MIT

Behavior in Integrated Assessment Models

System Dynamics	Dominant IAMs
Decisions use information actually available	Perfect foresight and global knowledge of structure
Decision rules conform to managerial practice	Decision rules conform to theoretical ideals
Desired and actual conditions are distinguished	Actual = desired
Rules are robust under extreme conditions	Disastrous and deviant scenarios are not explored
Equilibrium is emergent	Equilibrium is assumed

Adapted from Sterman (2000)

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Representing Behavior

(FREE)
Hill Climbing
Adaptive-
Extrapolative
Expectations

Hill Climbing
Adaptive
Expectations

Population
Learning
(ABM)

Stochastic
Optimal

Intertemporal
Optimal
(DICE)

Myopic
Optimal
(CGE)

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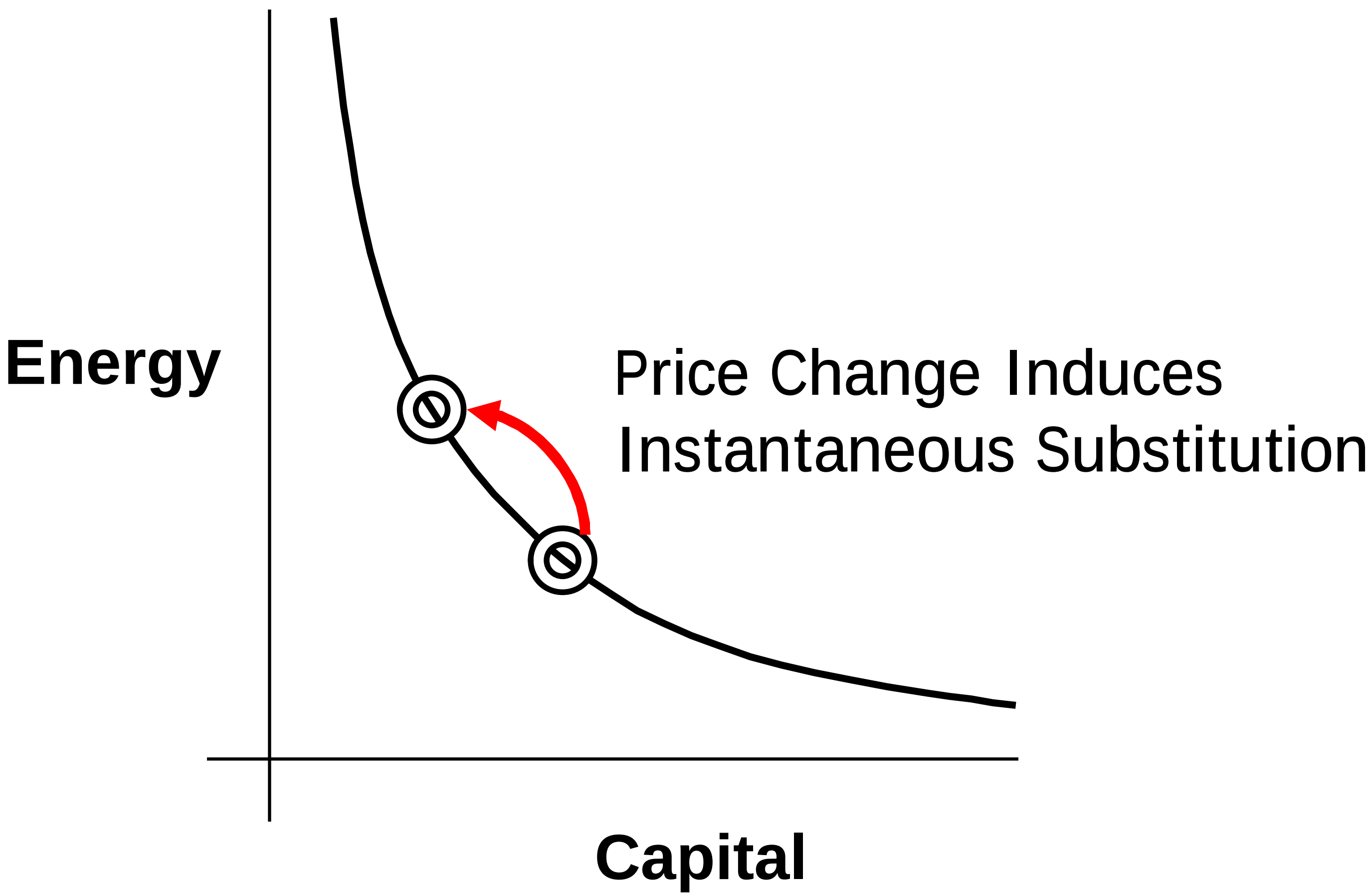
Production Technology



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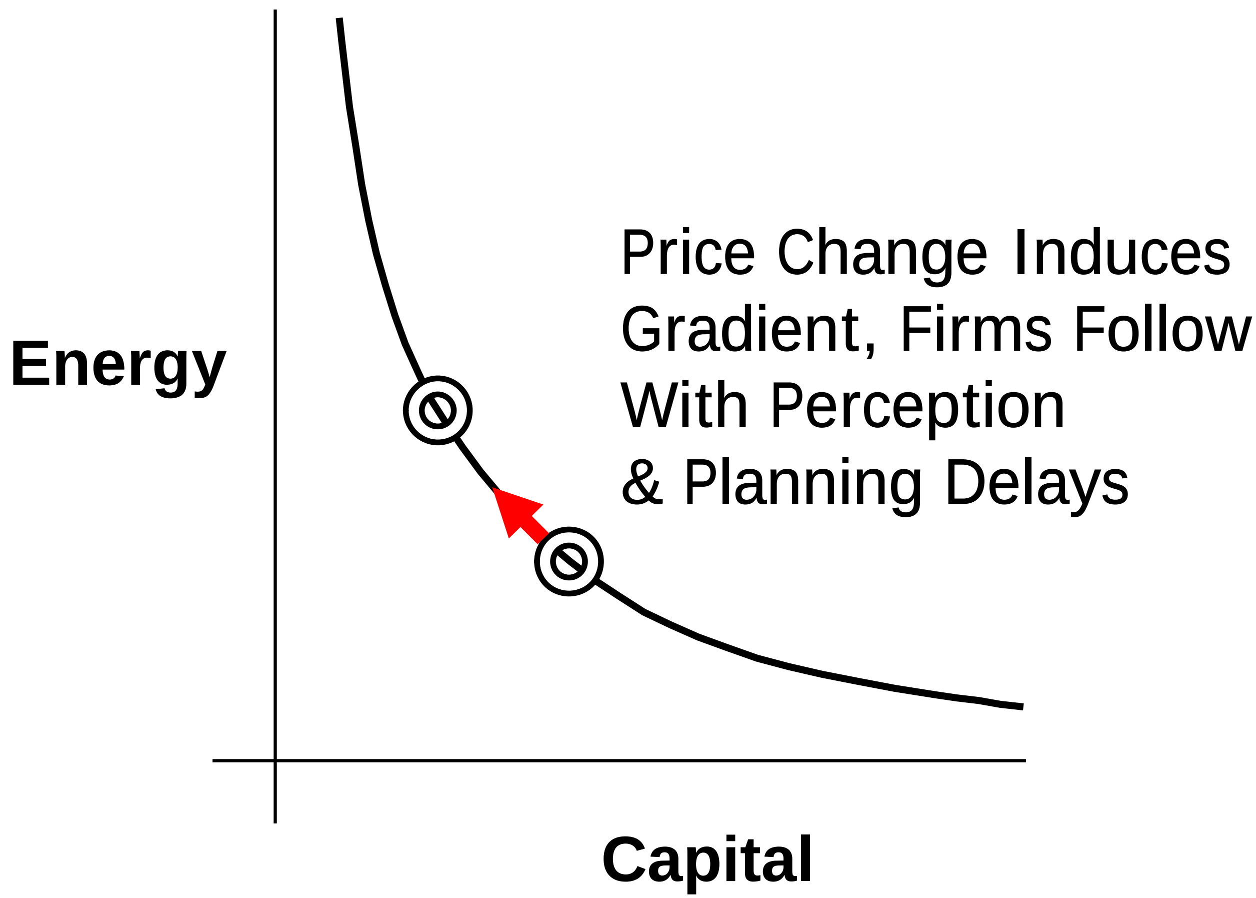

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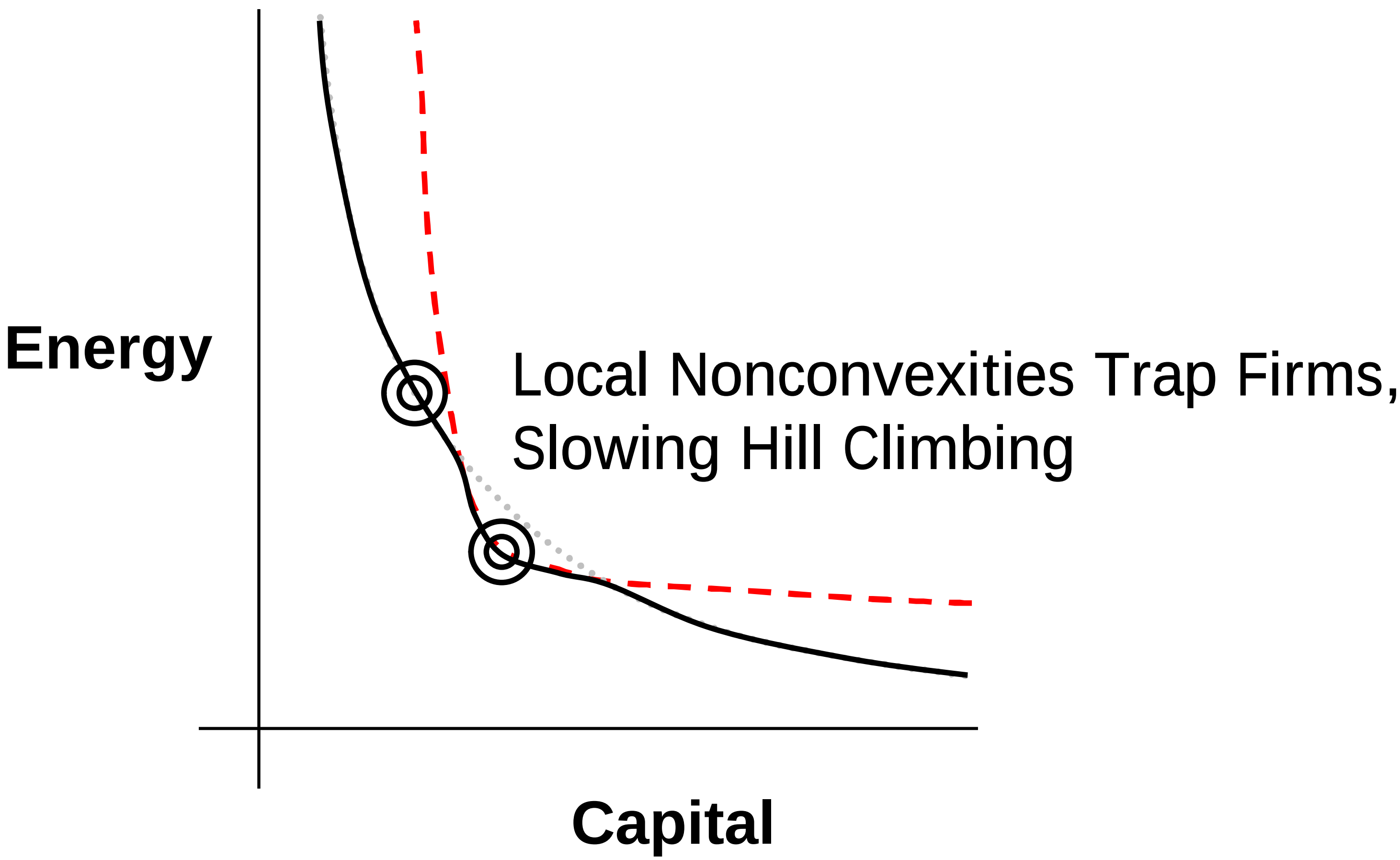

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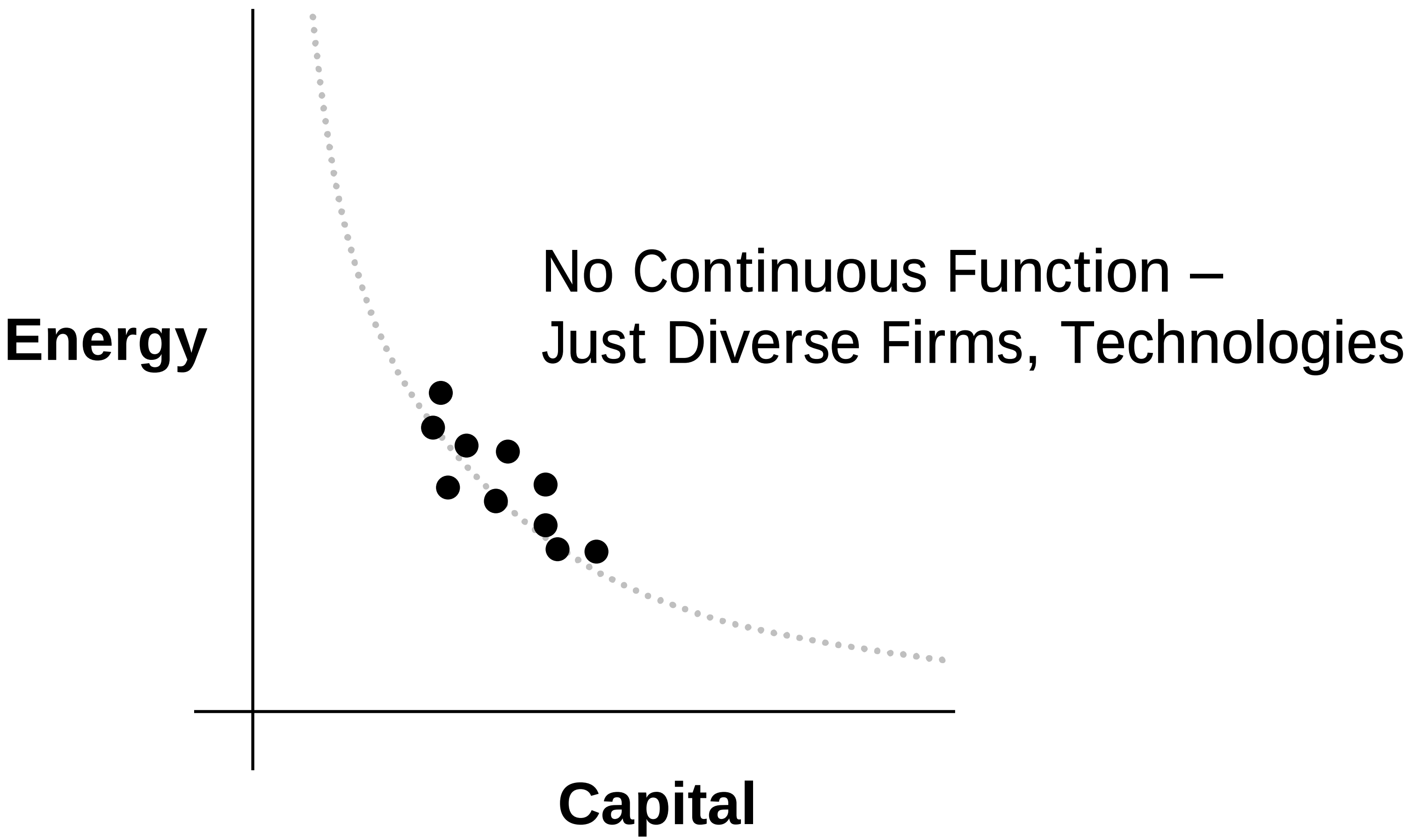

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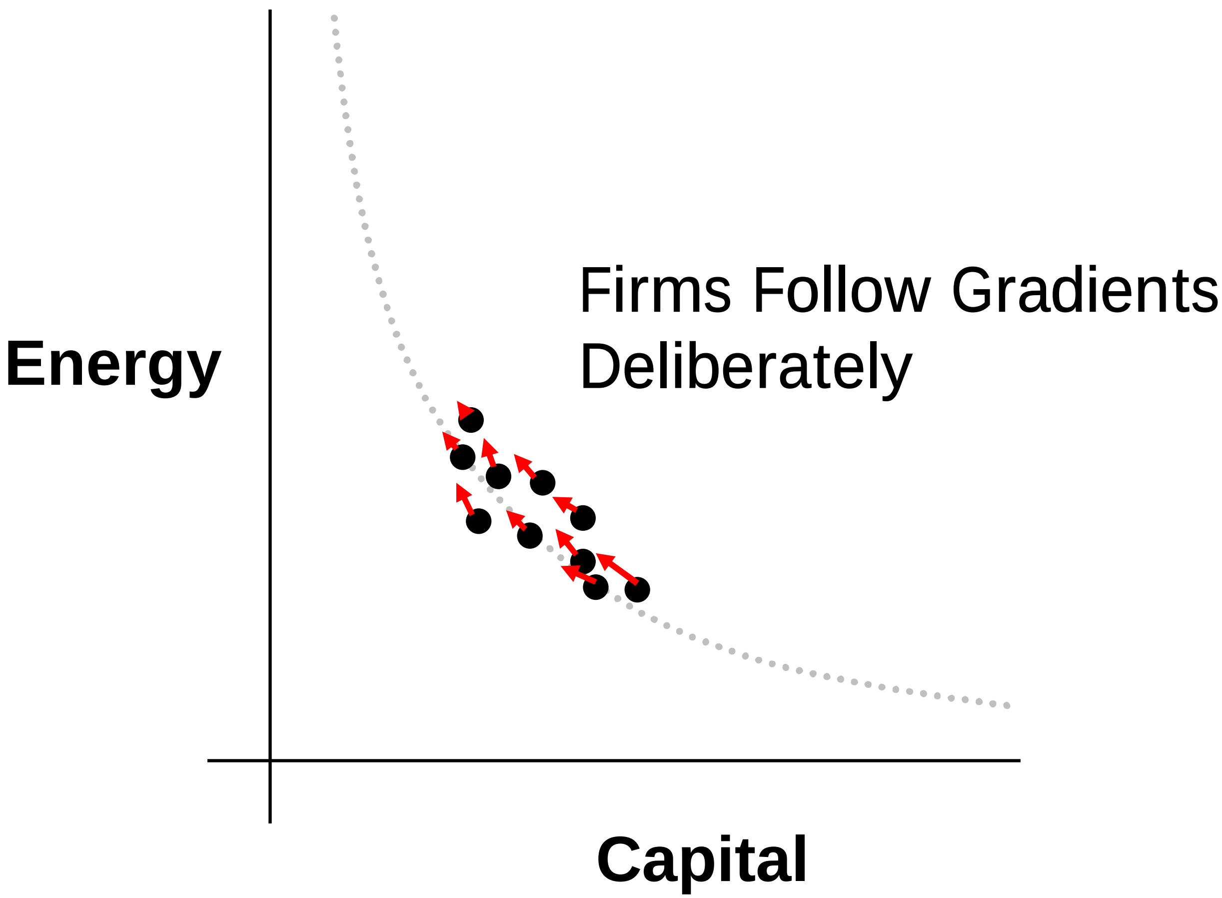

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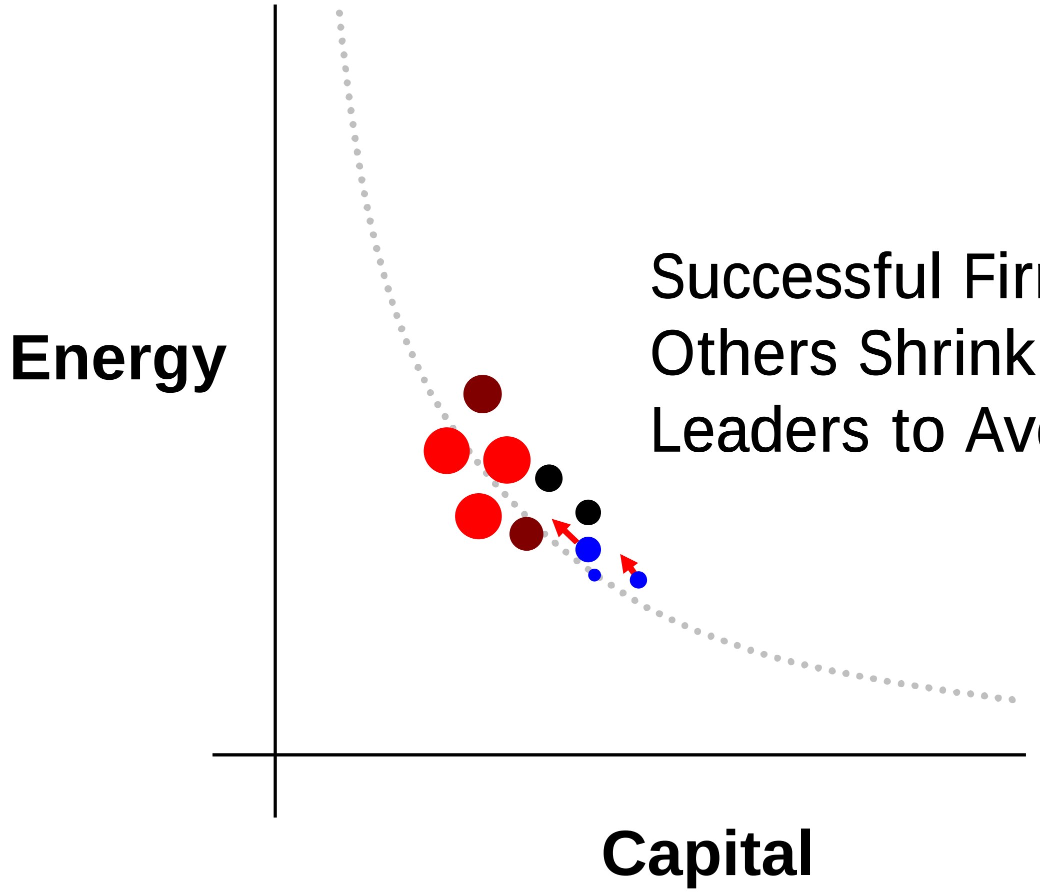

Successful Firms Grow; Others Shrink, and Imitate Leaders to Avoid Failure

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Static vs. Dynamic Tasks

- **Factor allocation is dynamically fairly simple (obvious gradient, quick feedback on performance)**
- **Other problem domains are dynamically complex**
  - Intertemporal allocations
  - Large project management
  - Networks
  - Preferences
  - R&D
- **In dynamically complex environments, the system is likely to evolve faster than equilibrium can emerge**

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Consequences of Misrepresenting Behavior

- **Mismeasurement**
  - If part of the observed inflexibility of the energy-economy system is behavioral, policy effects are understated, costs are overstated, and policy levers are missed
- **Inequity**
  - Postulating goals that justify the observed world order is unfair to future generations and today's poor
- **Fragility**
  - Idealized policy instruments won't deliver in the real world

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Four Models

1. The Energy Transition and the Economy

(John Sterman, 1981)

- **Full behavioral dynamic model with multi-sector economy**
- **Explicit inventories, labor migration, financial flows**
- **Decisions informed by available information, subject to perception delays**
- **Atypical findings about the transition to backstop energy sources:**
  - Energy prices and expenditures overshoot their long-term equilibrium
  - Limited labor and capital mobility and net energy feedbacks amplify direct effects
  - Energy price increases can trigger monetary responses that create inflationary pressure

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2. FREE

(Fiddaman, 1997)

- **Hybrid Neoclassical-behavioral model**
- **Relaxes common suspect assumptions, targeting DICE:**
  - Perfect foresight
  - Exogenous technology
  - Infinite sinks for carbon
  - Instantaneous emissions reductions
  - Optimal (or no) fossil depletion
  - Perfect energy markets
  - Current generation is more important
  - Economic growth stops
  - Welfare = consumption

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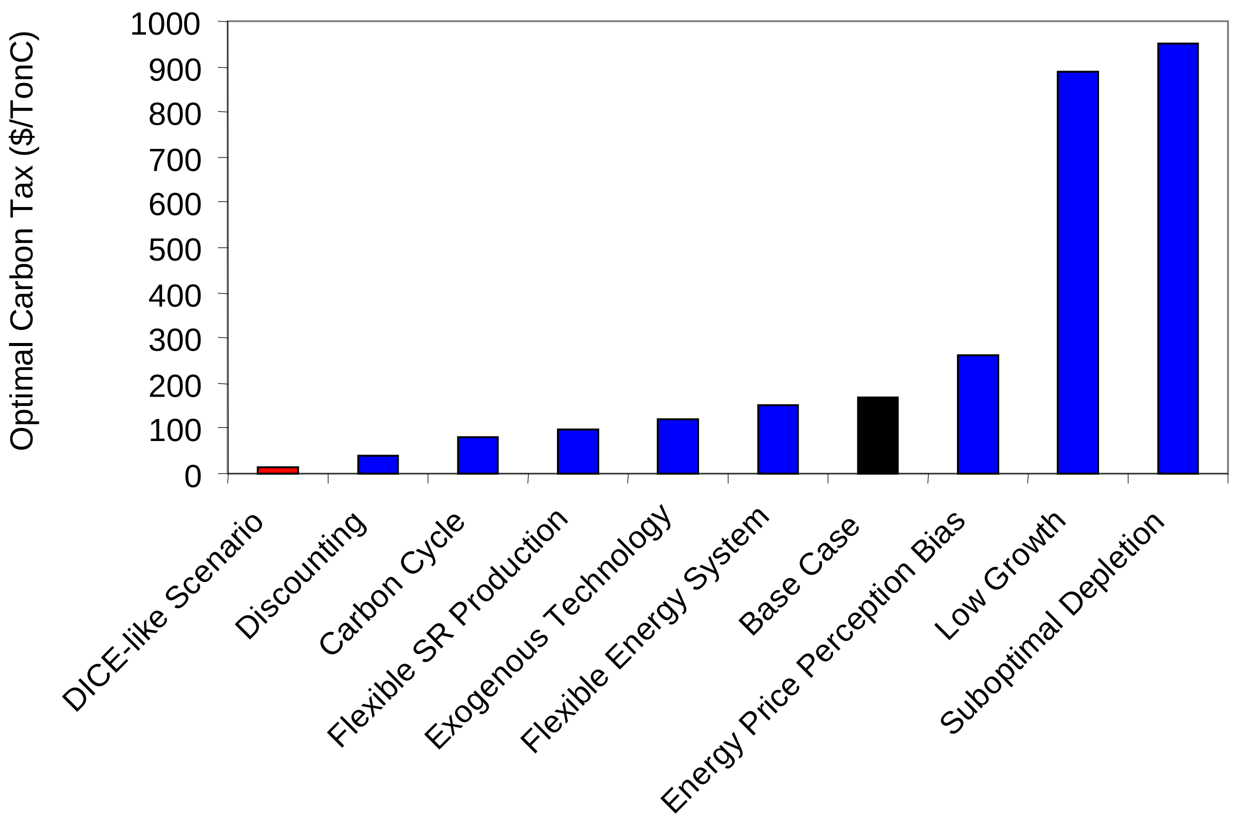
Relaxing suspect assumptions suggests higher abatement effort



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Why tradeable permits?

- Provides “environmental certainty”
- Consistent with Kyoto-style targets
- Better than non-tradeable quotas or mandates
- Permits worked for CFCs, POPs, SOx, lead
- Revenue neutral
- Can be used to promote equity goals
- Equivalent to taxes under special conditions
- Grandfathered allocation buys polluter participation
- Politicians don’t have to mention taxes

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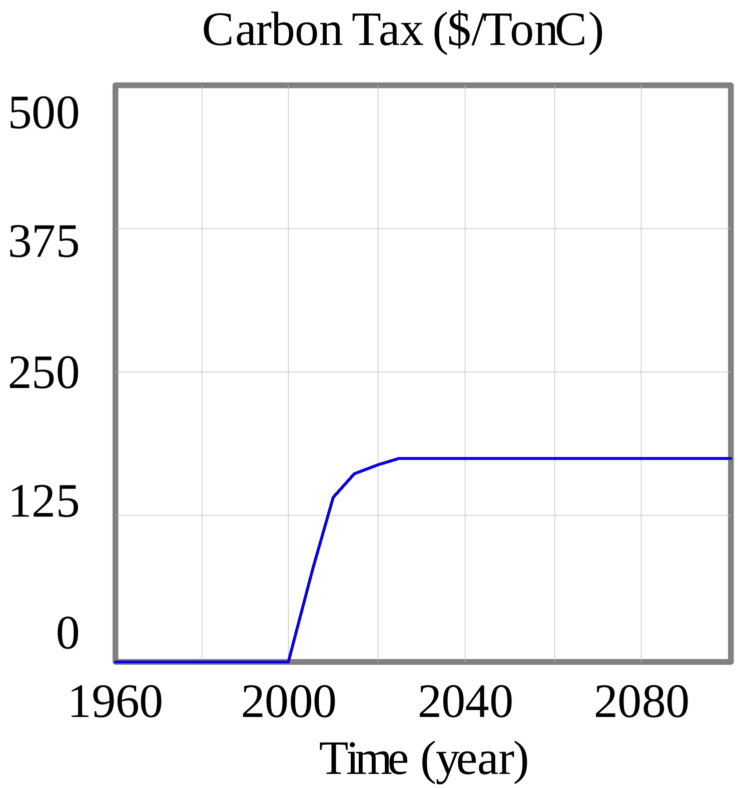
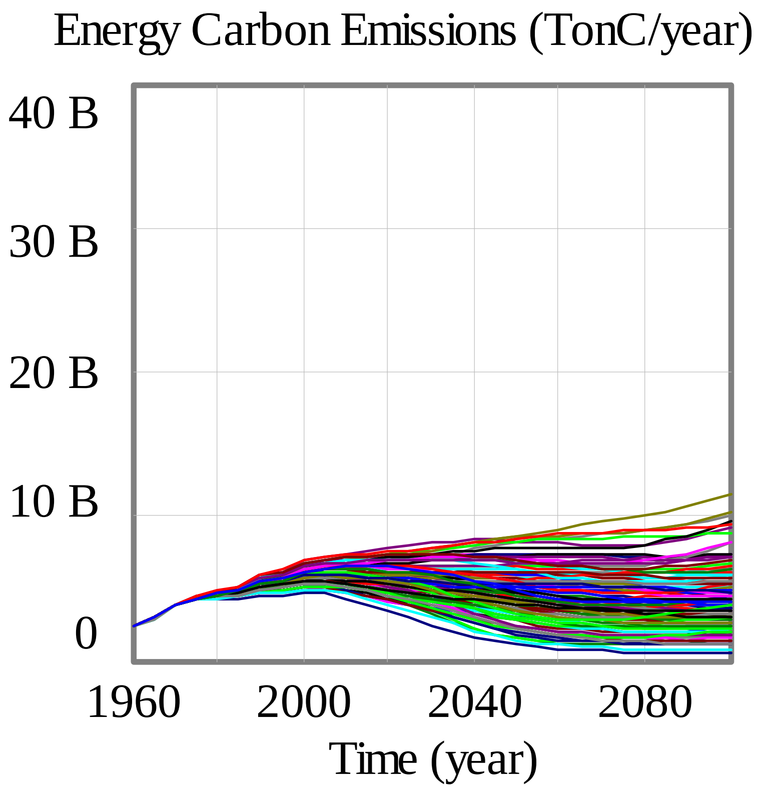
Constant Tax





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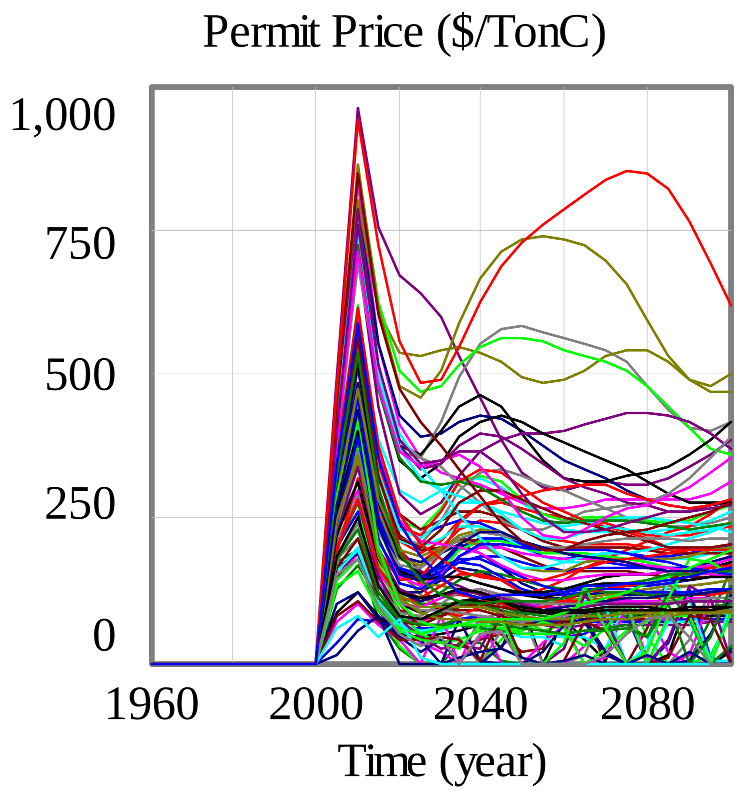
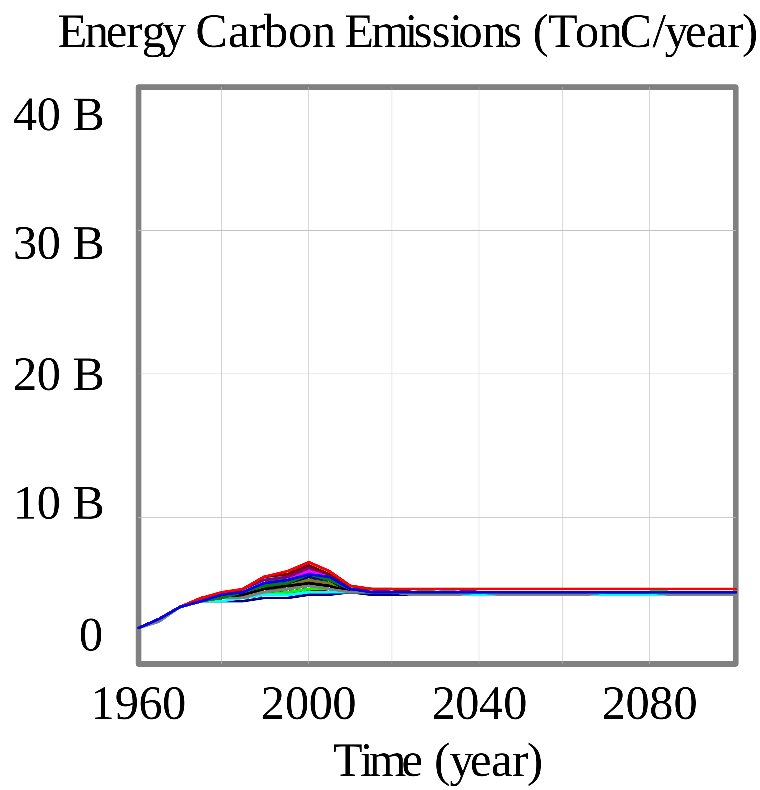
Permits





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Problems with Permits

- **Inflexibility under uncertainty**
- **Dynamic inflexibility**
- **Artificial stock management problems**
- **High transaction costs**
- **Overcompensation, consumer pays more**
- **Overly rigid requirements for stable quantity**
- **Sensitivity to noise, forecasts & measurements**
- **Limited coverage of sectors**
- **Illiquid markets**
- **Encourages basis gaming**
- **Barriers to innovation**
  - Incumbent hoarding
  - Transaction cost scale economies
  - Wealth effects for carbon intensive firms
- **No double dividend from revenue recycling**
- **Brinksmanship and rush-for-the-door**

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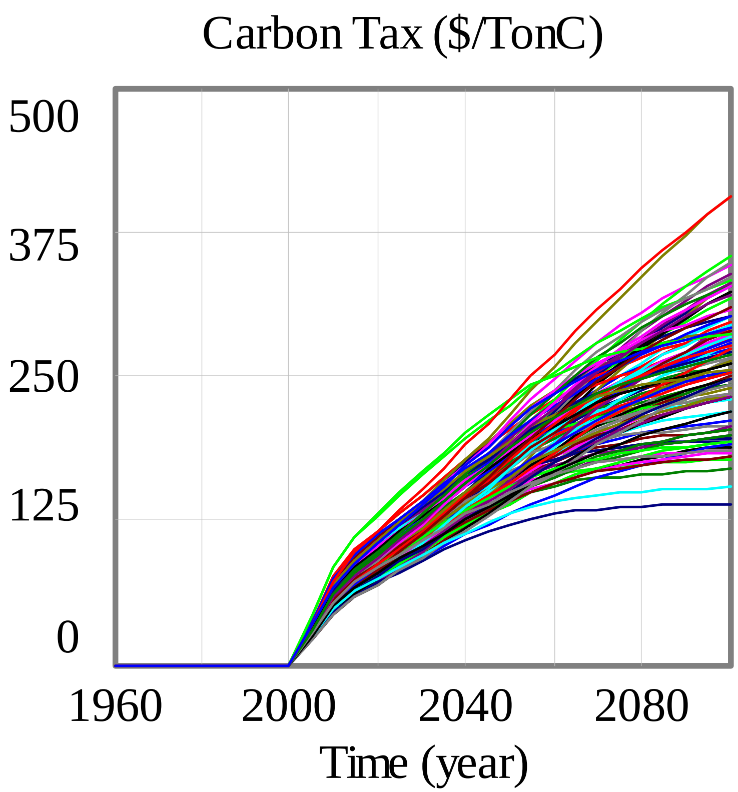
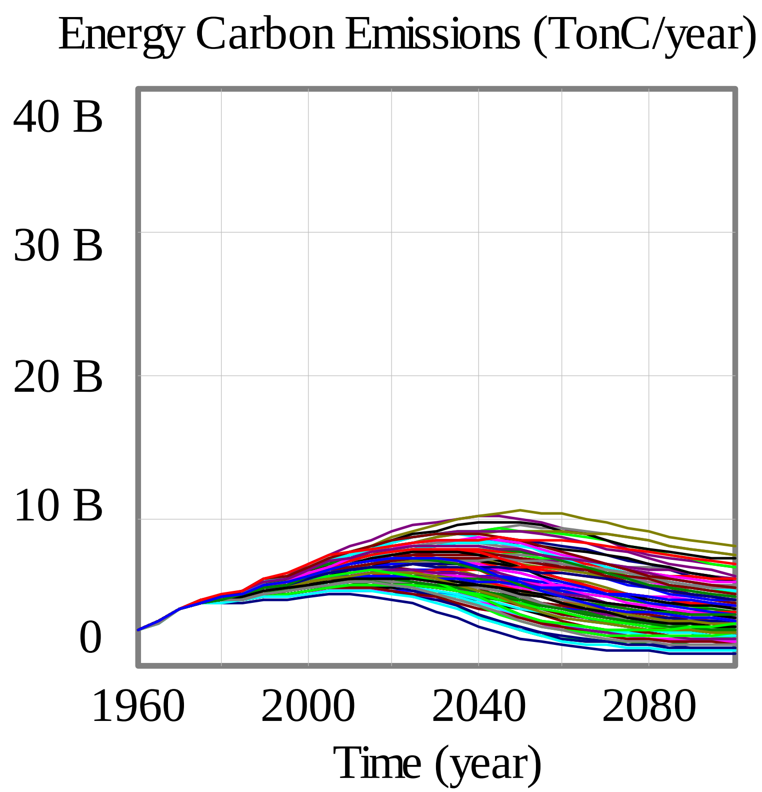
Adaptive Tax





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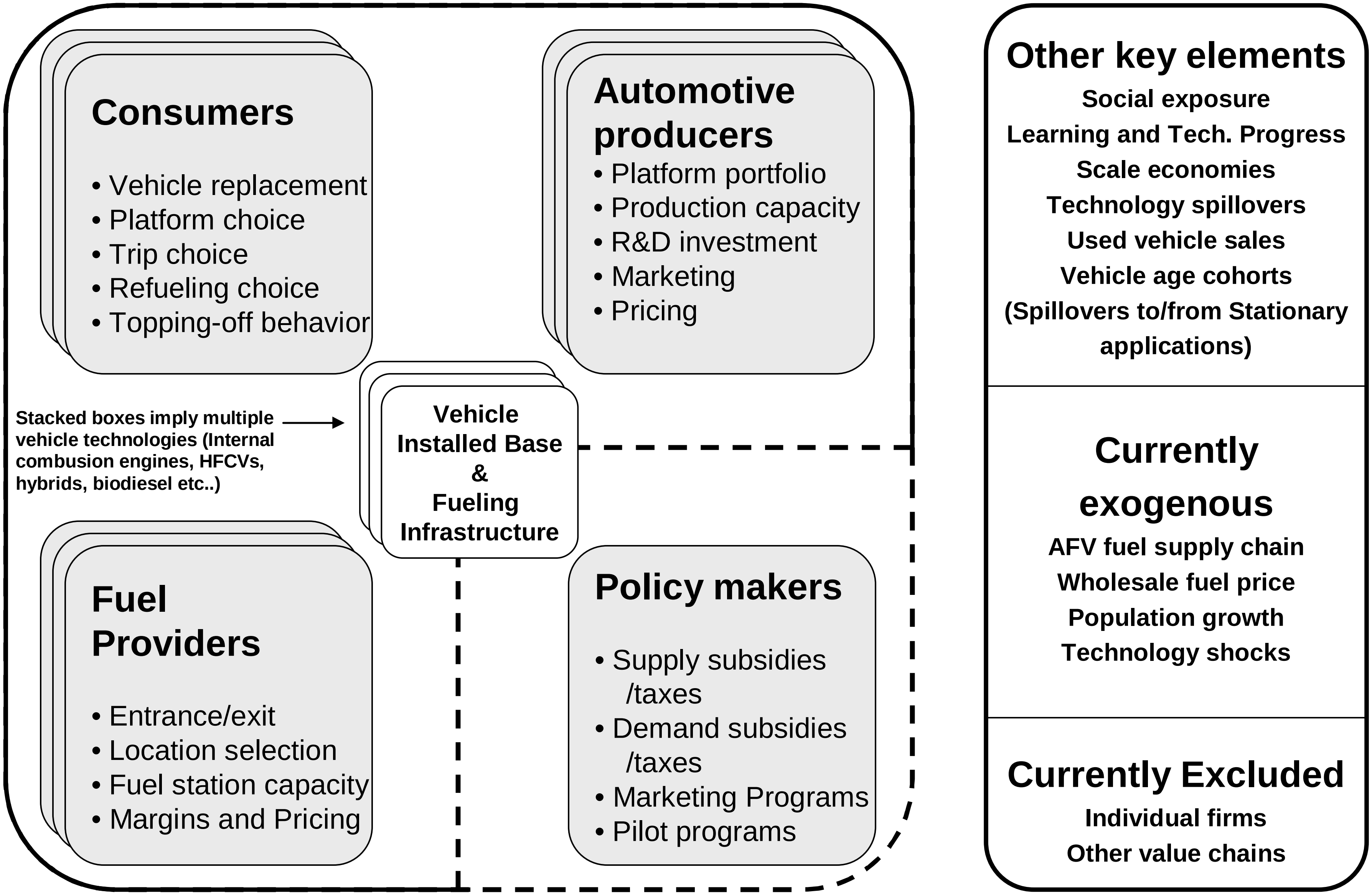
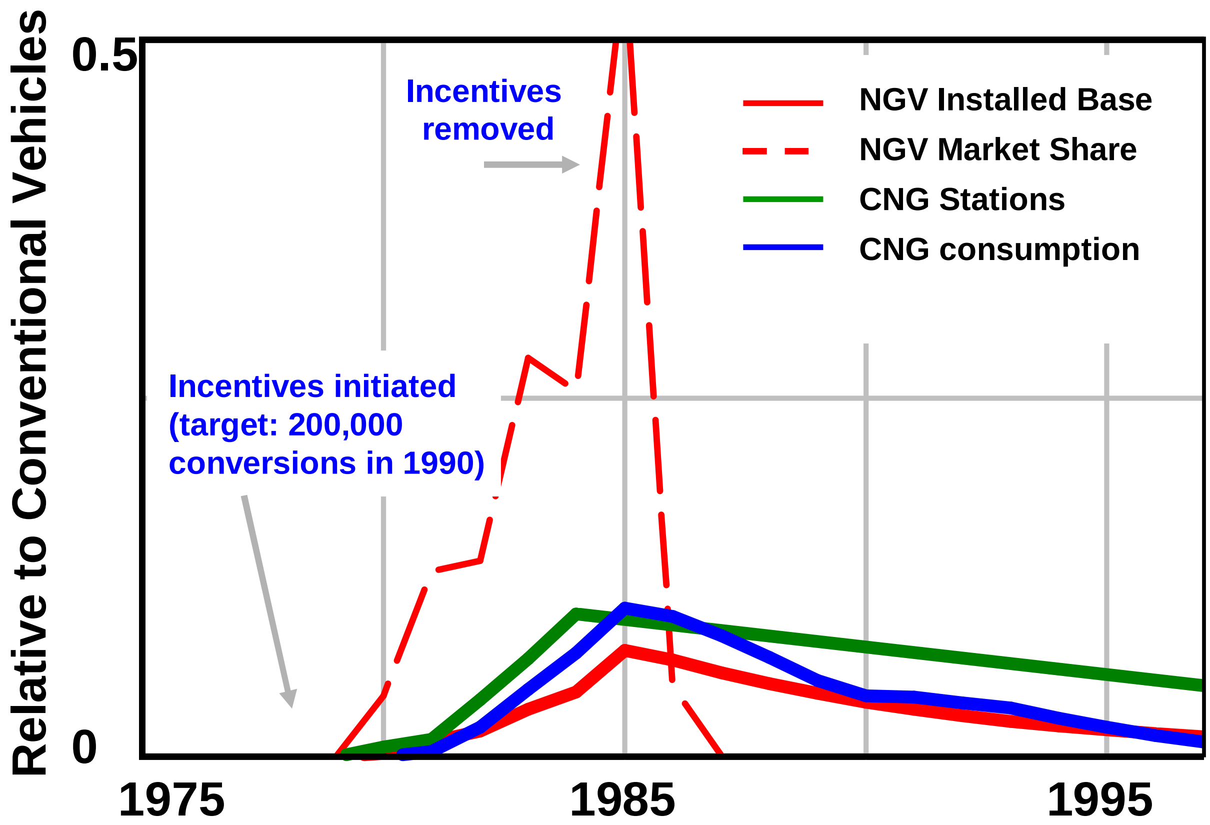
3. Alternative Fuel Vehicle Transition Dynamics



Agents make decisions based on perceived attractiveness of their available choices at each point in time

Slide courtesy of John Sterman, MIT

Compressed natural gas vehicles in New Zealand: a failed introduction



Nearly 10 years of collective commitment did not result in a self-sustaining alternative fuel vehicle market

Slide courtesy of John Sterman, MIT

Strategies for success

- **Dethroning gasoline is difficult: A century of learning, cost reduction, lock-in to existing infrastructure**
- **Multiple interacting reinforcing feedbacks cause strong "tipping" behavior – but also a high threshold.**
- **Creating an economically sustainable AFV market requires aggressive, long-lived policies to drive consumer awareness and adoption, vehicle costs and performance, and fuel infrastructure over the tipping point.**
- **Strong Worse-Before-Better dynamic: short run costs, long run gains – environmental and economic.**
- **Strong reinforcing feedbacks create win-win-win-win for the public, government, auto OEMs and fuel providers, but only if all participate. No one actor can do it alone; pain and gain sharing necessary.**

Slide courtesy of John Sterman, MIT

Many Counterintuitive Dynamics

- Early fuel station rollout where largest and soonest profit leads to urban focus, market failure.
- More costly exurb/rural focus builds sustainable, profitable AFV and alt fuel market, with greater urban market share, larger NPV for all, including fuel providers.
- A more efficient AFV can slow or prevents adoption due to negative impact of lower fuel demand on alt fuel profitability and infrastructure investment.
- Success rapidly reduces gov't fuel excise tax revenues; fuel tax must rise over time to maintain revenues (and compensate for drop in world oil price induced by lower consumption).
- Faster AFV sales leads to surplus used conv. vehicles. Low used car prices limit AFV diffusion. Early decommissioning of conventional cars a high-leverage policy.
- Others…

Slide courtesy of John Sterman, MIT

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4. A Role for Simple Climate Models

- **People operate on a pattern-matching heuristic, suggesting that if emissions stabilize tomorrow, atmospheric GHGs and temperature will also stabilize (see Sterman's *Cloudy Skies*). Unfortunately this is not so.**
- **It is difficult to translate multilateral emissions commitments, expressed as a mix of absolute, intensity, and effort targets, into an emissions trajectory.**
- **Negotiations are dominated by non-climate considerations.**
- **Decision makers won't wait for model runs.**

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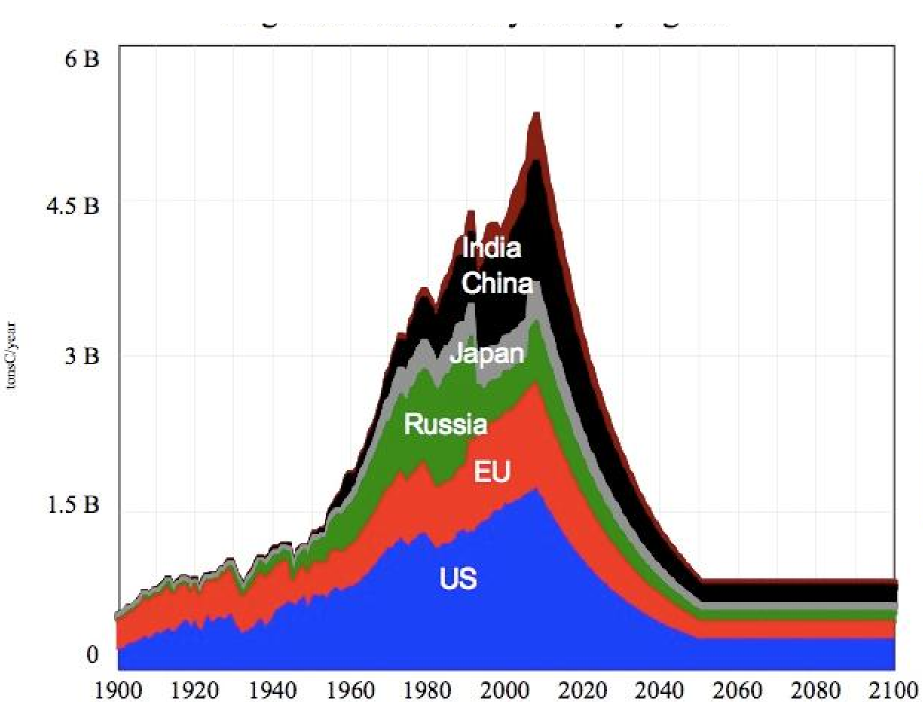
Pangaea and the Copenhagen Climate Exercise

Participants work in teams representing the parties to the UNFCCC process to negotiate a global agreement to reduce GHG emissions This simulation has been used with groups ranging from students at MIT to senior policymakers.

For examples of such model-supported "climate war games" see Climate Interactive http://www.climateinteractive.org/

Professor John Sterman checks in with students negotiating greenhouse-gas emissions.
Credit: Marc Bernsau



"Future News for a Future World"

Climate Game Times

Washington
Today, humid, 95 degrees, severe thunderstorms in late afternoon, low 75.

VOL CLVII... NO. 154,289 — MONDAY, OCTOBER 5, 2015

Climate Change Group to Try Framework Agreement

Representatives from China, the European Union, India and the United States convene today in Washington, D.C., to attempt to reach a Framework Agreement on Managing Long-Term Climate Change

NEWS ANALYSIS

creation of a new international disaster relief agency.

Finally, the Secretary General will urge delegates to set a strategy for deep near-term reductions in greenhouse gas emissions and for speeding up the pace of innovation and commercialization of new energy technologies.

The meeting takes place against a backdrop of growing global alarm and tension over global climate change. The last seven years have seen an increase in heatwaves, droughts, floods, wildfires, high food prices, and intense tropical storms, including Cyclone Bhola II, which killed nearly 200,000 people in Bangladesh in 2013, and the Category 5 hurricane that hit the Caribbean and Miami in July of this year, causing an estimated $75 billion in damage.

LEADERS DISCUSS ENVIRONMENT, NATIONAL SECURITY & WAR GAMES

A Summary of Remarks by Hon. Carol Browner, Gen. Chuck Wald (Ret.) & Peter Schwartz

By CHRISTINE PARTHEMORE

Last night, a crowd of more than 100 luminaries heard from three experts about the intersection of climate change and national security and how to plan for an uncertain future. The speeches were part of the opening ceremonies of the four-day meeting on long-term climate change effects.

The evening started with what was billed as a "conversation" between Carol M. Browner, former Administrator of the U.S. Environmental Protection Agency, and Chuck Wald, a retired four-star U.S. Air Force General.

Browner described a world that is now witnessing many of the effects of climate change projected by scientists fifteen years ago, when she was head of the EPA.

The biggest difference with how this challenge is interpreted today, she explained, was that it is now clear that climate change is "an economic issue, not solely an environmental one." Today, the business community is con-

Slide courtesy of John Sterman, MIT

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Modeling for a Sustainable World

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Goals

Conventional statement:

- **Identify optimal tradeoff between abatement and impacts across regions, sectors, fuels, gases…**

Better statement:

- **Discover actions that**
  - control in our favor where possible,
  - anticipate what is inevitable, and
  - hedge against what's uncertain
- **Implement**

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Technical Challenges

- **Bottom-up foundations for top-down models: how to develop aggregate model structures consistent with dynamics of populations of realistic agents?**
- **How to maintain transparency and usability when doing things right implies more structure?**
- **Productivity:**
  - Faster model building
  - Efficient federation of models
  - Reuse of data and structure
  - Automation of robustness checks
  - Exploration and visualization

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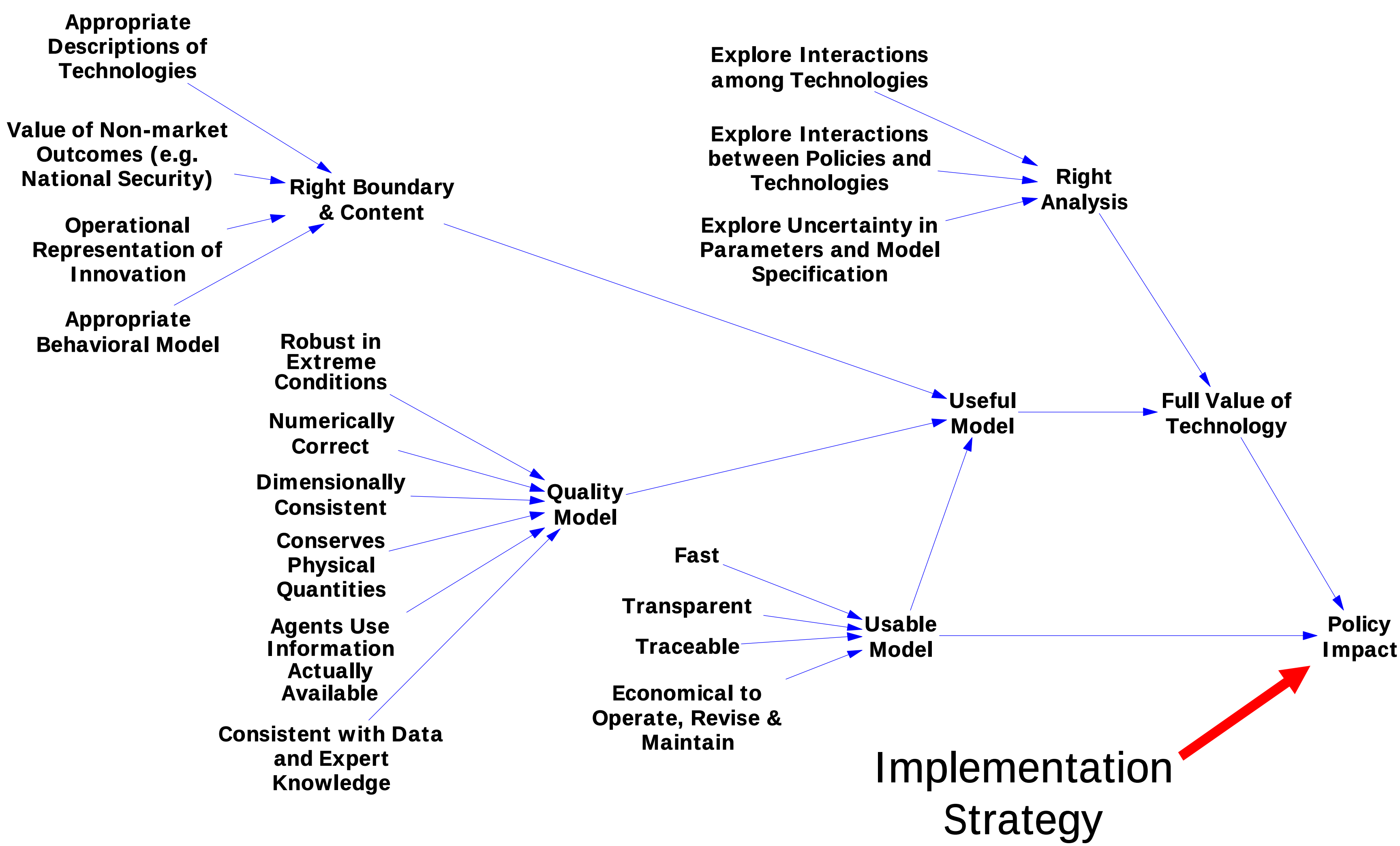
Balanced Mix of Critical Elements



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Model Typologies

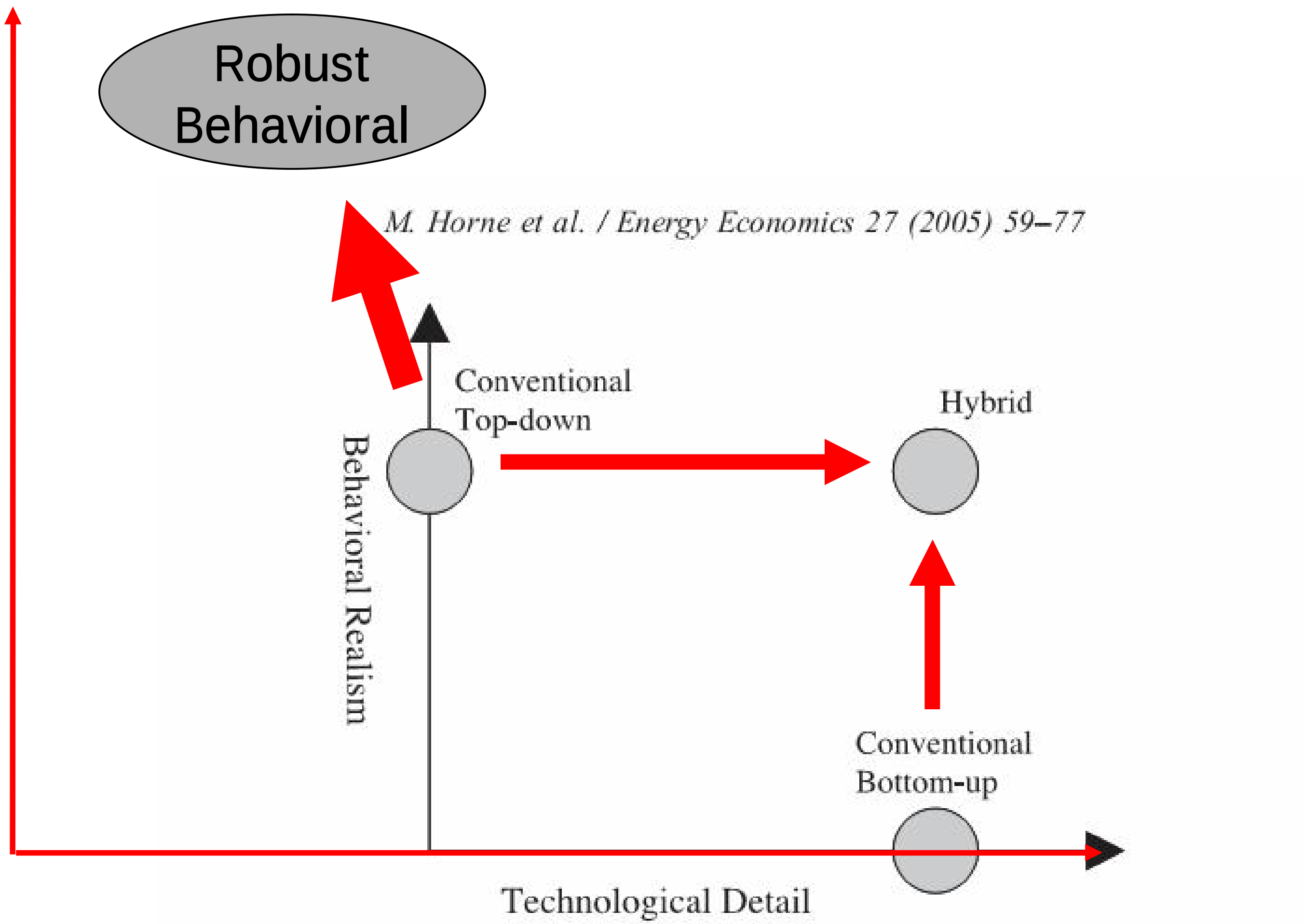

Fig. 1. Energy-economy model typologies (adopted from Jaccard et al., 2003).

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Competing with Established Models

- **Obstacles:**
  - Big IAMs are far down the learning curve: they are a good expression of a flawed paradigm
  - Funding follows results (success to the successful), especially when the results are palatable

- **Solutions?**
  - Leverage the established models
    - Reuse data and structure
    - Help to make the good insights accessible
  - Work as a community
  - Be more responsive to decision maker needs
  - Serve untapped audiences (media, education, ...)
  - Exploit inherent advantages (speed, transparency)
  - Market well

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One Approach: Collaborative Modeling

- **Transfer insight from domain experts to decision makers**
- **Get questions from decision makers to analysts Integrate data across agencies and NGOs**
- **Integrate models**
- **Compare models**
  - For refinement and learning
  - For diverse opinions
- **Coordinate policy rollout over time (decision points, signposts, milestones)**
- **Identify important uncertainties in order to focus attention and further inquiry**
- **Identify areas of agreement among stakeholders**
- **Brainstorm new policies**

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Missing Models

- Dynamics of social change – where is the leverage?
- Firm emissions and permit inventory management, aggregated to market behavior
- Political process for tax, permit, and other policy setting
- Coevolution of land use patterns & transport energy intensity
- Multiproject R&D resource allocation with adaptive project funding
- Renewable and low-carbon portfolio standards with multi-stakeholder interactions
- Oil and gas depletion with realistic government and firm agents allocating resource access
- Saving and investment behavior with explicit intertemporal choice
- Evolution of preferences for carbon-intensive vs. carbon-free activities

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