# Evolutionary Modeling and Environmental Economics

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## My interpretation of evolution

- Evolution best approach to understand and managing dynamic complexity
- Evolution rising star in many fields: (biology), psychology, computer science (evolutionary computation), sociology, economics and philosophy
- Evolution not an easy theory
- Evolution both historical cause of human behaviour (evol. psychology) and general approach for (policy) analysis of complex systems (evol. algorith/computation)

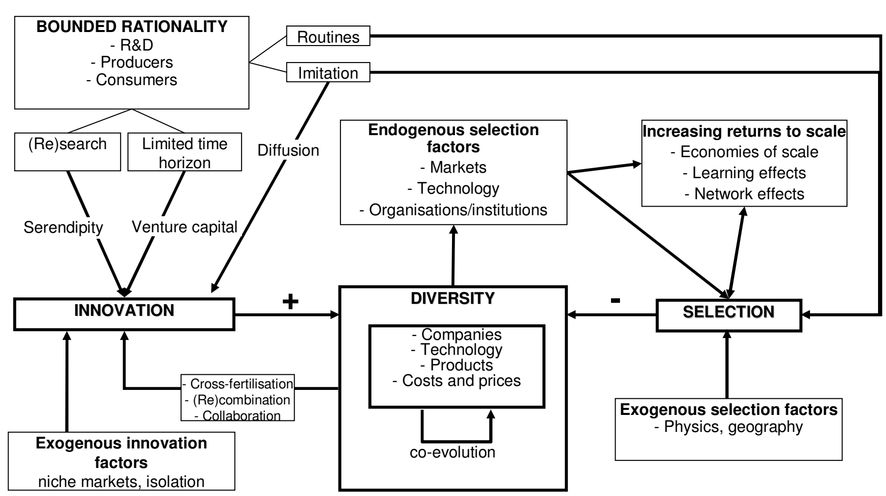
## Evolutionary concepts

- *Population and diversity*
- *Bounded rationality*
- *Innovation*
- *Inheritance*
- *Selection environment*

- Evolution core: Selection reduces and innovation increases diversity, through inheritance in a cumulative way

- Repeated selection: *path dependence* and *lock-in* (extreme, irreversible reduction of diversity)
- Mutual selection of subsystems: *coevolution*
- Differential growth of diverse groups: *group selection*
- Emergence of new levels: *upward-downward causation*

## A simplified picture of the evolutionary economy



## Evolution relevant for environmental studies?

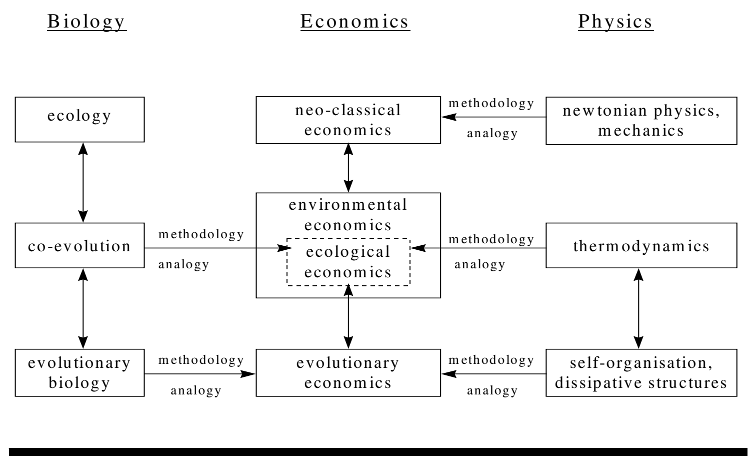
- *Environmental technology:* progress, lock-in, optimal diversity, recombinatory innovation
- *Humans exert selection pressure:* genetics of biological populations; biodiversity-resilience connection
- *Economic-environmental history:* major inventions/macromutations and coevolution (humans maladapted?)
- *Transition to sustainable systems:* lock-in, demand-supply coevolution, interest groups
- *Policy and management:* flexibility/options, learning, flexibility, bounded rationality (limits to behavioral change, biophilia hypothesis)

[ Penn DJ (2003). The evolutionary roots of our environmental problems: towards a Darwinian ecology. *Quarterly Review of Biology* 78(3):275–301 ]

## Population / economic growth & environment

- During $20^{th}$ century:
  - world population quadrupled,
  - global economy expanded 14-fold,
  - energy use increased 16 times,
  - ‘control’ of 40% of world biomass.
  - climate change, biodiversity loss …
- Evolutionary perspective:
  - Extreme & rapid change of environment => humans a *maladapted species*

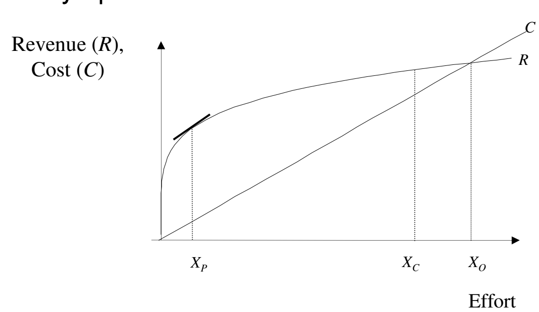
# Interactions between disciplines




*Source:* Mulder & van den Bergh (2000)

# CASE 1: Common Pool Resource (CPR) problem

- E.g., fishing, irrigation
- Outcome (effort $X_C$) suboptimal because of stock externality (resource is a shared production factor)
- Productivity per unit of effort decreases beyond optimum effort $X_P$ (here sector profit=$R$-$C$ maximal) => overuse (overfishing)
- If free entry even erosion of profits (open access equil. $X_O$)
- Socially optimal: restrained level of individual resource exploitation



# Policy insights from field studies (E. Ostrom)

- ➔ Sustainable resource use possible due to evolution of norms: *self-regulation, 'quasi-voluntary'*
- ➔ Alternatives:
  - *Centralized, coerced governance:* no moral support, often monitoring problems
  - *Strictly voluntary regime:* no evolution, thus less cooperation (one-shot game)
  - *Privatisation:* but public goods, unfair distribution, market power

# Aggregate evolutionary game model

(Sethi & Somathan, AER, 1996)

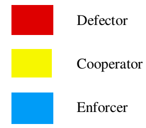
- ➔ 3 strategies: defectors, cooperators, enforcers
- ➔ replicator dynamics (´survival of the fitter´):

$$dx_i/dt = x_i\,(f_i - f)$$

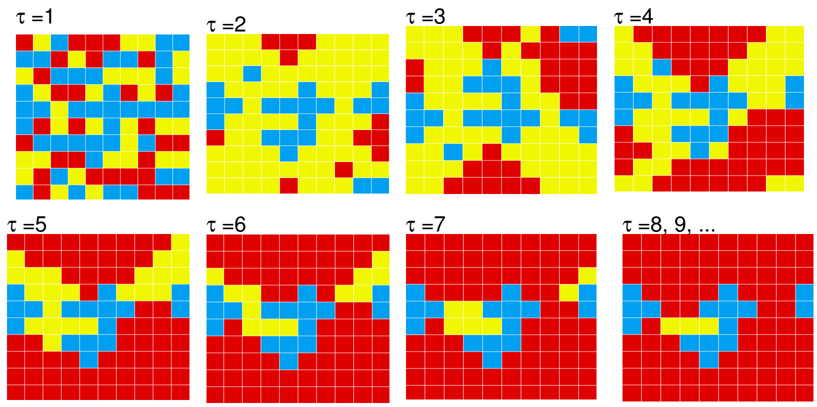
  - with $x_i$ relative proportion of subset in population, $f_i$ associated fitness, average fitness $f = \Sigma_i\, x_i\, f_i$
  - Fitness depends on population distribution of characteristics: $f_i = r_i^T As$ - $A$ payoff matrix, $r_i$ = pure (0,1)/(1,0) or mixed ($x,1$-$x$) strategy, $s$ = fractions ($p,1$-$p$) of strategies in population
- ➔ Results: 2 equilibria:
  - only defectors
  - mix cooperators/enforcers

## Spatial evolution

(Noailly et al., 2007)




$z_0$=(30%;40%,30%)




Now also equilibria with all three strategies: protected clusters/zones

## CASE 2: Creating resistance as an externality

(A. Munro, ERE, 1997)

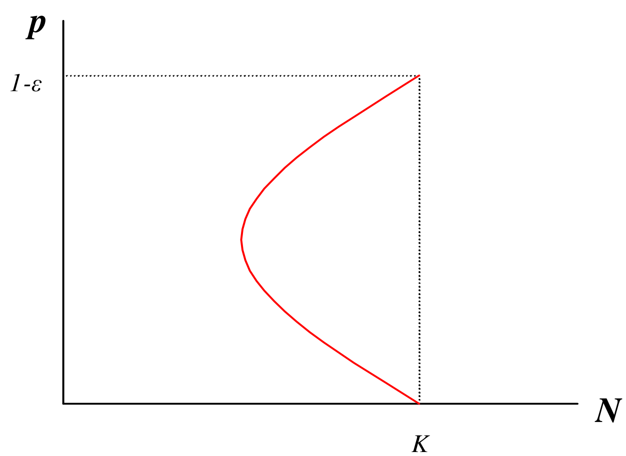
$$\max_{x(t)\geq 0} \int_0^{\infty} [\mathrm{f}(N)-\mathrm{c}(x)]e^{-\delta t}\mathrm{d}t \qquad (1)$$

$$\mathrm{d}N/\mathrm{d}t = [r-xp(2-p)-rN/K]N \qquad (2)$$

$$\mathrm{d}p/\mathrm{d}t = p\{(W-x)/[W^{*}-xp(2-p)] - 1\} \qquad (3)$$

*N* = pest population size
*p* = proportion of 'susceptible alleles' *'A'* in pest population
*(1-p* is proportion of 'resistant alleles' *'a')*
*W* = absolute fitness
x = control variable (pesticide use)

# A fixed dosage W-$x$ < Wa (W>Wa)




# Optimization

- ➔ … of (1) s.t. (2): reflects *myopic* decision making, assuming genetic composition (*p)* fixed; moving target.
- ➔ ... of (1) s.t. (2)&(3): fully optimal plan, under foresight about impact insecticide use.

Comparison: optimal end values for $x$ and $N$ lower, for $p$ higher; NPV also higher.

=> under myopia pesticide use too high.

# CASE 3: Sugarscape multi-agent evolution

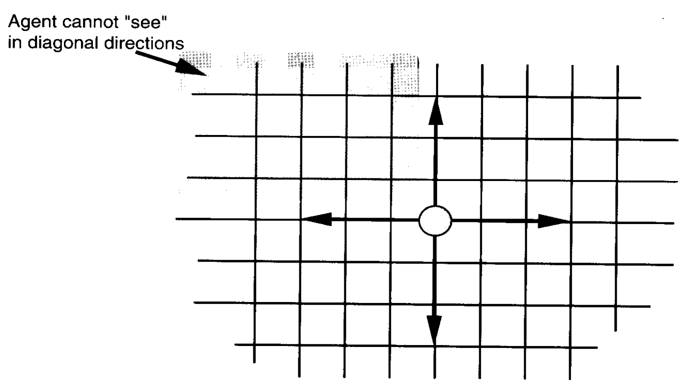
*Artificial life* - multilevel evolution:

– *Selection (society 'learns'):* changes population distribution of fixed characteristics (vision, metabolism)
– *Individuals learn:* behavioural rules are adapted - experience or imitation
– Even *transmission (and selection) of genetic traits* via sex ' cultural and genetic evolution may reinforce (parents´ genes and bringing-up)
– *Relevant for environmental studies:* sugar hills, pollution, congestion

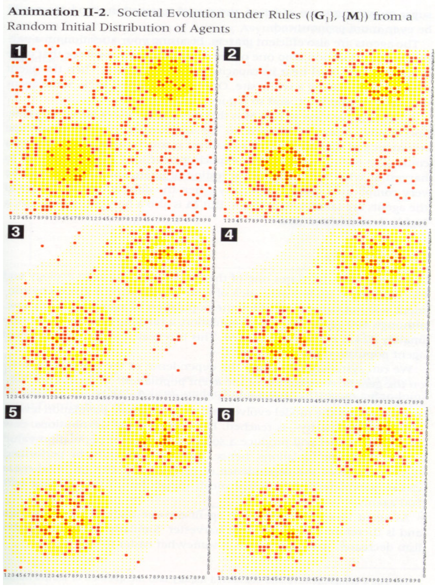
[ Epstein C, Axtell R (1996) *Growing Artificial Societies: Social Science from the bottom up*. MIT, Boston, MA ]

# Agent vision: bounded rationality

**Figure II-3.** Agent Vision

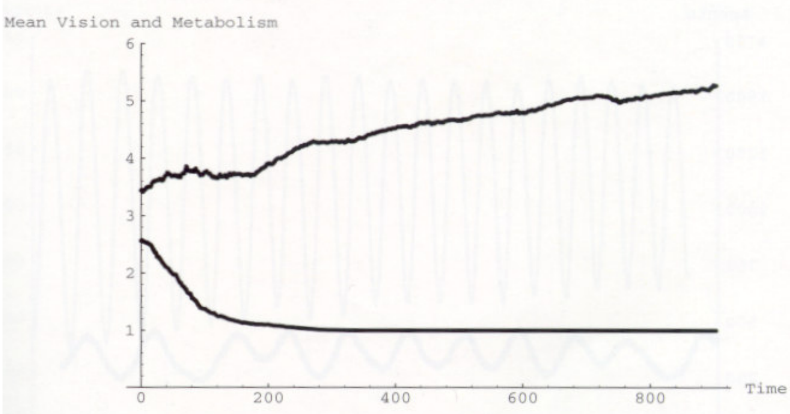


## Spatial dynamics on sugar hills illustrated




## Evolution of mean vision & metabolism

**Figure III-2.** Evolution of Mean Agent Vision and Metabolism under Rules ({$G_1$}, {M, S})



## Some findings

- ➔ Distribution of income/wealth: uneven without policy ('laisser faire')
- ➔ Patterns of global population dynamics: stable, instable or oscillating
- ➔ Spatial development: environmental (resource, pollution, congestion) factors influential

- ➔ Extensions: cultural tags, groups, conflicts/war, networks, diseases, trade (2 resources-goods)

## CPR spatial and Sugarscape models: *Are local interactions relevant?*

- ➔ *Environmental:* water, air, fauna, vegetation (biodiversity) - *landscape ecology*
- ➔ *Economics:* communication, cooperation, punishing, monitoring, learning, imitation - *spatial and network economics*
- ➔ But *economic processes* involve very often *non-local interactions*: phone, fax, (e)mail, internet, international trade, large distance transport
- ➔ … *environmental processes also nonlocal:* global environmental problems, uniformly mixing pollutants – GHGs.

## CASE 4: Evolutionary policy and sustainability transitions

- ➔ Society-wide system innovation with a focus on basic economic activities: energy, mobility, agriculture

- ➔ Transition policy/management:
  - System failures (lock-in), new forms of governance and systemic instruments, power, groups/coalitions, dealing with uncertainty
  - Combination of *environmental regulation*, *innovation policy* and *'escaping lock-in'*

## *Note:* transitions prominent in evolutionary biology

- ➔ Chemical cycles, protocells, cells, multicellular organisms, sex, animal groups, human societies
- ➔ Sequence suggests trends: more complex specialisation, labour division, cooperation & emergence
- ➔ Result of self-organisation – not regulation: similar to how humans organize themselves in firms & groups
- ➔ *Economics may learn from evolutionary biology – conceptualisation, methods, insights.*

[ Maynard Smith, J., and E. Szathmáry (1995). *The Major Transitions in Evolution.* Oxford University Press, Oxford ]

## Three important evolutionary-economic issues in transitions research

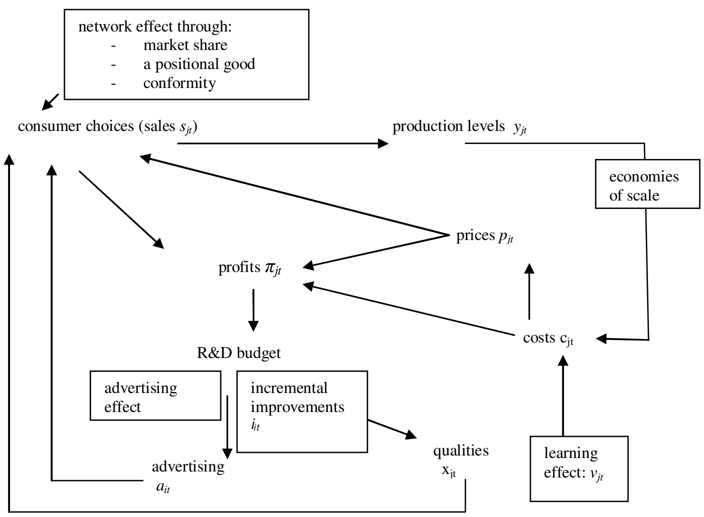
- Coevolution of demand and supply, lock-in of technology:
  - increasing returns to scale, bounded rationality (interaction/imitation consumers, advertisement, status-seeking) and unlocking policies
  - Finding: status effect can contribute to unlocking through emergence of distinct niches
- Power, conflict, coalitions, vested interests
  - Applying cultural group selection theory (?)
- Optimal diversity
  - avoiding short term efficiency (renewables vs energy conservation), trade-off between likelihood of recombinant innovation and increasing returns to scale, dimensions of diversity (variety, balance, disparity)

## Coevolution of demand and supply

- Evolution of consumer preferences interacts with innovation of firms: demand pull + technology push combined (several models - Windrum/Birchenhall)
- Consumers get satisfaction not only from the intrinsic value of a good but also from its social embeddedness
- Combination and synergy of most important increasing returns on demand and supply side: Scale economies, learning-by-doing, demand network externalities
- Positional good, status effect: 2 consumer classes (different preferences wrt price vs quality, different influence networks)

K. Safarzynska and J.C.J.M. van den Bergh (2008). Demand-supply coevolution with multiple increasing returns: Policy for system transitions. *Technological Forecasting and Social Change*, forthcoming.

# Overview of evolutionary system



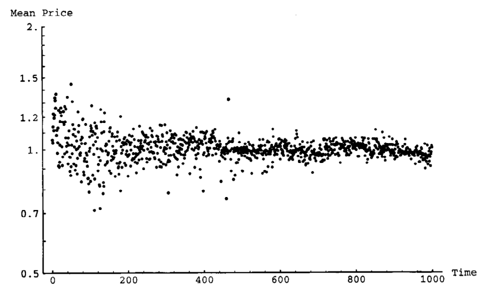

# Some findings

- ➔ Monte Carlo simulation method, parameters chosen from uniform distributions in plausible ranges
- ➔ Increasing returns on the demand side more important (statistically significant) than those on supply side
- ➔ The network effect leads to clustering of choices
- ➔ Status effect (purchase of status commodities) causes a struggle between desire for distinction and conformity
  - initially cyclical consumption patterns
  - whereas conformity contributes to lock-in, status effect can contribute to unlocking through emergence of distinct niches

# Neoclassical vs evolutionary policy

- Neocl. economics assumes rationality + perfect information, esp. via prices: no surprise that price regulation works well then

- If bounded rationality + imperfect information (e.g., local interaction), price regulation performs worse
  - *Information diffusion*, *awarding prizes*, *advertisement* & *stimulating networks* relevant policy approaches
  - Increase likelihood that desirable behavior/innovation is imitated




➔Local prices (from *Sugarscape*, Epstein & Axtel)

V. Nannen and J. van den Bergh (2008), Evolutionary analysis of climate policy and renewable energy: Heterogeneous agents, relative welfare and social network.

# Closing remarks

- Evolutionary framework is not accepted by all environmental (social) scientists:
  - “Social Darwinism” and “genetic determinism” fears
  - Social scientists often judge evolution without knowing much about it
  - In economics evolutionary game theory now widely used/accepted, but this is not a complete representation of evolution

- Evolution has a triple role in environmental science:
  - Social-economic-technological evolution (culture, imitation, technical innovation and diffusion)
  - Biological evolution (biodiversity, resource management, agriculture),
  - Combination / interaction (coevolution)