Economic drivers of biological complexity

Trust, reputation and market-mechanism in-vivo

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The paper

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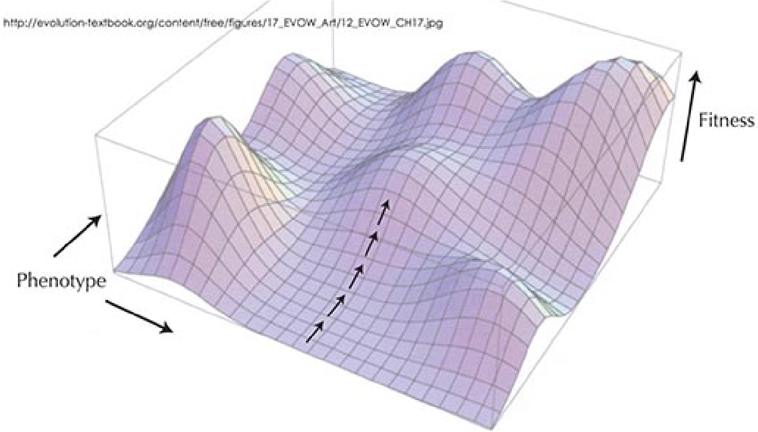
Overview

1. Complexity in Nature
2. The Major Transitions of Evolution
3. Cooperation in Nature
4. The Second Problem of Cooperation: generating benefit
5. Biological Markets

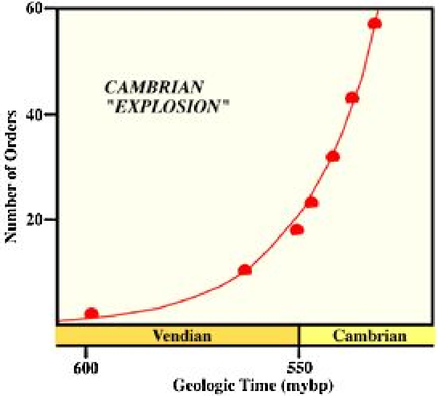
Darwin's Tangled Bank

Fitness

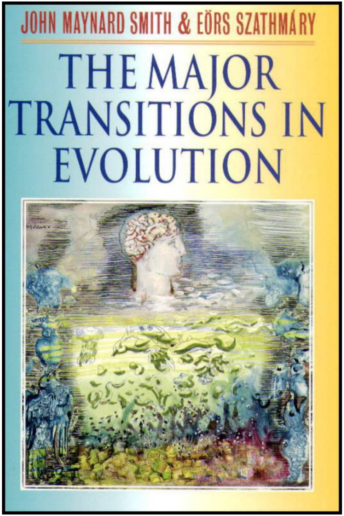

http://evolution-textbook.org/content/free/figures/17_EVOW_Art/12_EVOW_CH17.jpg
Fitness
Phenotype

Pre-Cambrian Organisms

The Cambrian Explosion



Maynard Smith and Szathmary



The Major Transitions

Higher-Level	Lower-Level
genes	regulatory networks
individual cells	genes
multi-cellular organisms	individual cells
societies	multi-cellular organisms

Cooperation

	C	D
C	5, 5	1, 10
D	10, 1	2, 2

Cooperation

	C	D
C	5, 5	1, 10
D	10, 1	2, 2

	C	D
C	R, R	S, T
D	T, S	P, P

Prisoner's Dilemma: $T > R > P > S$

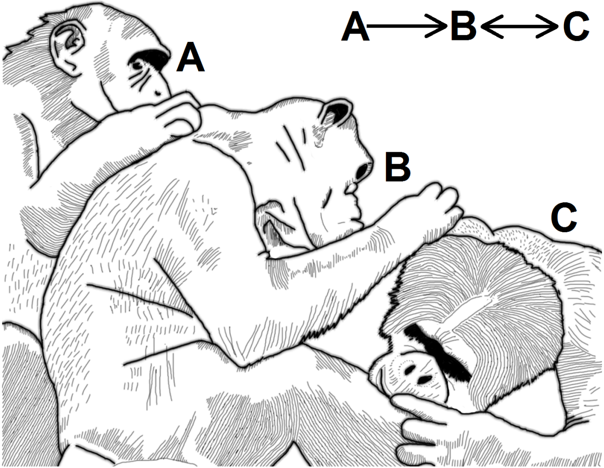
The Donation Game

- Consider a population of n agents.
- Each player has the same fungible and transferable endowment which is replenished on each iteration.
- Play is repeated over $E[N]$ iterations.
- Randomly pair players on each round.
- The first player can choose a fraction of their endowment $\gamma \in \{0, c\}$ to invest.
- The second player is passive.

Donation Game Payoffs

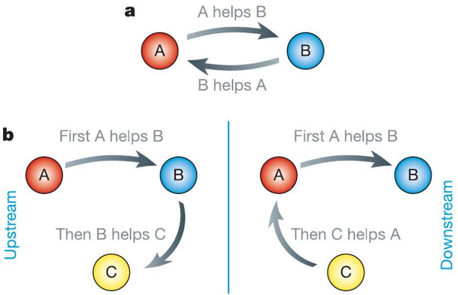
- Payoffs:
  - First player: $-\gamma$
  - Second player: $m \times \gamma$
- The cost/benefit ratio is $m = b/c$
- Provided that $m > 1$ then a social surplus can be generated through reciprocation.

Allo-grooming



[Russell and Phelps, 2013]

Reciprocity



a). *Direct* Reciprocity, e.g. tit-for-tat.
b). *Indirect* Reciprocity based on reputation, e.g. gossip.
[Nowak and Sigmund, 2005] [Phelps, 2013]

Five rules for the evolution of cooperation

		Payoff matrix: C	Payoff matrix: D	Cooperation is... ESS	Cooperation is... RD	Cooperation is... AD	
Kin selection	C	$(b-c)(1+r)$	$br-c$	$\frac{b}{c} > \frac{1}{r}$	$\frac{b}{c} > \frac{1}{r}$	$\frac{b}{c} > \frac{1}{r}$	r...genetic relatedness
	D	$b-rc$	0				
Direct reciprocity	C	$(b-c)/(1-w)$	$-c$	$\frac{b}{c} > \frac{1}{w}$	$\frac{b}{c} > \frac{2-w}{w}$	$\frac{b}{c} > \frac{3-2w}{w}$	w...probability of next round
	D	b	0				
Indirect reciprocity	C	$b-c$	$-c(1-q)$	$\frac{b}{c} > \frac{1}{q}$	$\frac{b}{c} > \frac{2-q}{q}$	$\frac{b}{c} > \frac{3-2q}{q}$	q...social acquaintanceship
	D	$b(1-q)$	0				
Network reciprocity	C	$b-c$	$H-c$	$\frac{b}{c} > k$	$\frac{b}{c} > k$	$\frac{b}{c} > k$	k...number of neighbors
	D	$b-H$	0				
Group selection	C	$(b-c)(m+n)$	$(b-c)m-cn$	$\frac{b}{c} > 1+\frac{n}{m}$	$\frac{b}{c} > 1+\frac{n}{m}$	$\frac{b}{c} > 1+\frac{n}{m}$	n...group size m...number of groups
	D	bn	0				

[Nowak, 2006]

The Second Problem of Cooperation

The other cooperation problem: Generating benefit [Calcott, 2008].
In welfare economics this is sometimes called *efficiency*.

Biological markets

First problem of cooperation:

- Trust
- Reputation

Second problem of cooperation:

- Auctions
- Markets

In nature *Biological Markets Theory*:

- [Noë and Hammerstein, 1995]
- [Noë et al., 2001]
- [Hammerstein, 2003]

Utility and fitness

Economics	Biology
Maximise expected utility	Maximise expected fitness
Increase utility by acquiring wealth	Increase fitness by acquiring energy

- Markets can arise spontaneously whenever individuals:
  - are able to engage in *voluntary* exchange and when
  - they differ in their preferences and holdings.
- Money is a store of value and a medium of exchange.
- Are there analogs in nature?

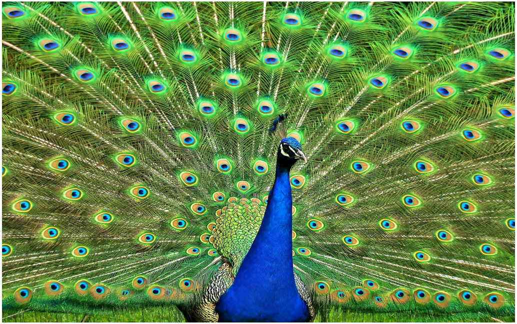
Obligate pollination mutualisms

- Fruit can be considered as payment for service [Bronstein, 2001]:
  - flora donate energy (fructose) to fauna
  - fauna disperse seed
- This gives rise to testable predictions [Hoeksema and Schwartz, 2001, p. 182].

Payments in Nature

[Friedman and Hammerstein, 1991] analyze the mating behavior of a species of fish: hypoplectrus nigricans or “black hamlet”. These fish are hermaphrodites; individual Hamlets produce both eggs and sperm. They mate in pairs and take alternative turns to fertilize a small number of eggs provided by their partner. Friedman and Hammerstein conjecture that this is a form of *trading*; the ratio of sperm to eggs in the general population is so large that it is profitable in terms of reproductive success to “buy” unfertilized eggs in return for left-over sperm. The slow incremental nature of the exchange serves two economic purposes: i) as a hedge against counter-party risk; and ii) as a means of reducing the “market-impact” from flooding the market with an excess supply of perishable goods which would reduce the “price”. The latter strategy is similar to volume-participation algorithms for executing large trades of financial assets [Bialkowski et al., 2008].

Honest signalling



[Zahavi and Zavahi, 1997]

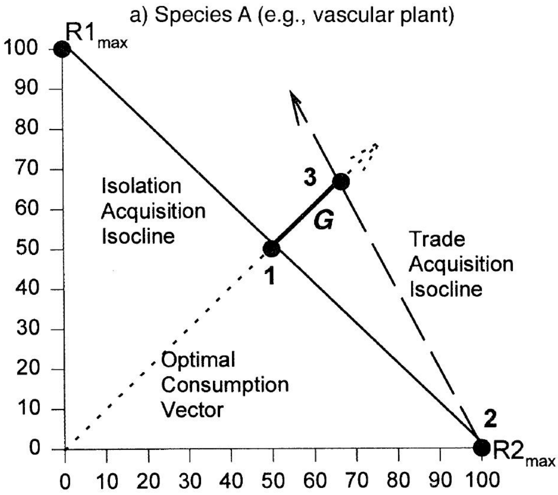
Aggregated signalling

"females have a preference for male aggregations because these facilitate mate choice" [Davies et al., 2012, p. 271]
[Patricelli et al., 2011]

Diversification

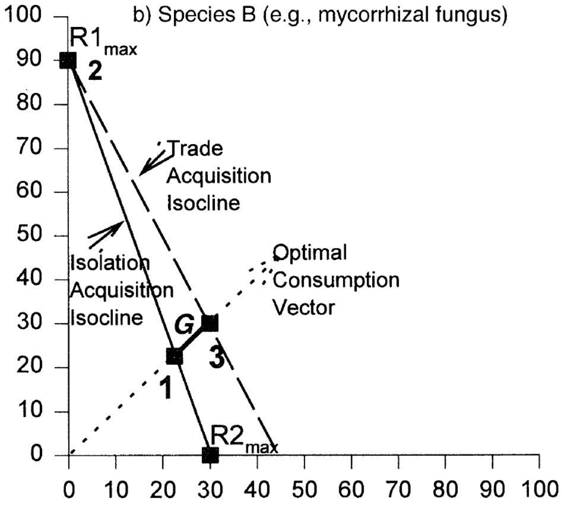
- System-level:
  - Division of labour and specialization
- Individual-level
  - Hedging risk through diversification of investments

Trading Carbon for Phosphorous - Plant



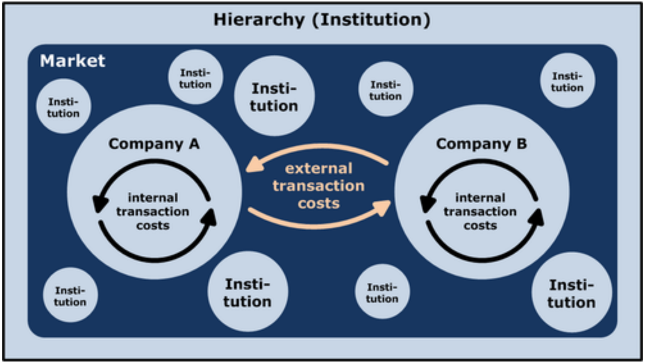
[Schwartz and Hoeksema, 1998]

Trading Carbon for Phosphorous - Fungus



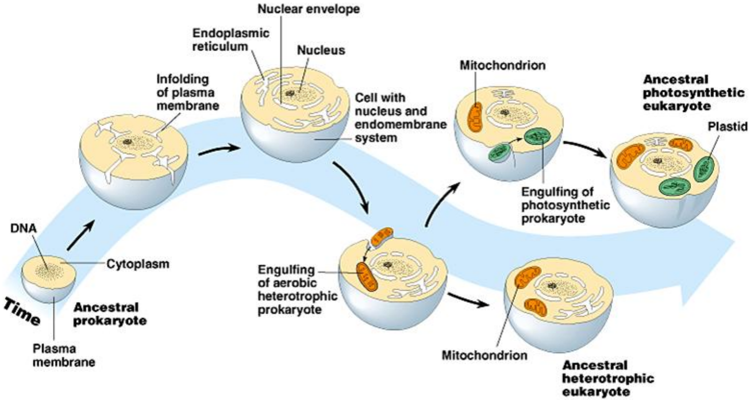
[Schwartz and Hoeksema, 1998]

The Theory of the Firm



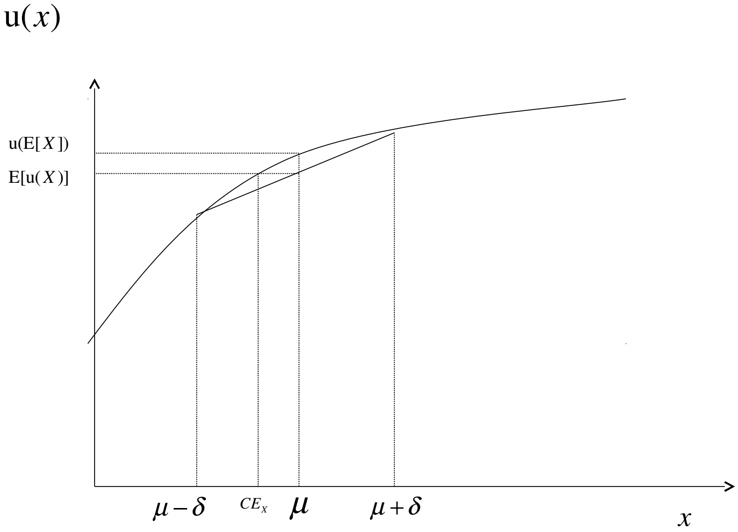
[Coase, 1937]

Endosymbiosis

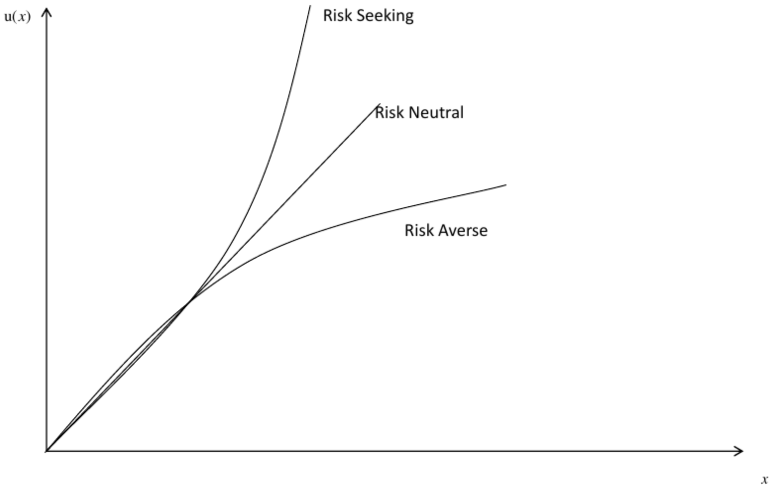


[Sagan, 1967, Margulis, 1981]

Risk aversion



Risk sensitivity



Diversification

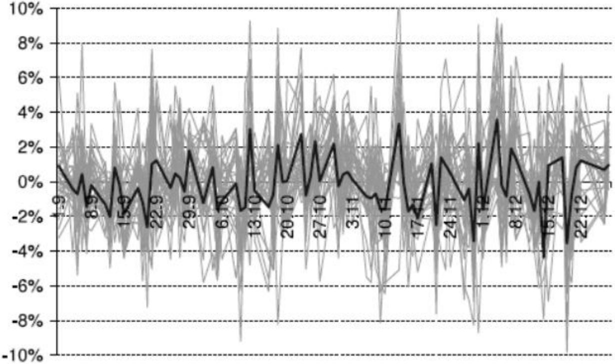


Fig. 1.1: Daily returns of the DAX (black line) and the stocks contained in it (gray lines) for the 4^th^ quarter of the year 2000

Diversification in nature

Ecology, vol. 68, no. 4, pp. 1104-1108, 1987.

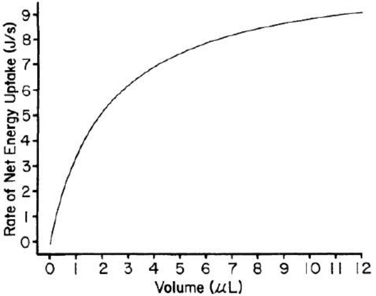


FIG. 1. Expected rate of net energy uptake as a function of nectar volume for an average *B. pennsylvanicus* worker feeding on flowers 3 mm deep, containing 30% sucrose solution, and distributed randomly, as described in Real et al. (1982). Based on Eqs. 1 and 2 and empirical descriptions of flight time (Harder 1985) and ingestion rate (Harder 1986).

[Harder and Real, 1987]

Conclusion

- Markets can arise spontaneously whenever individuals are able to engage in voluntary exchange and when they differ in their preferences and holdings.
- When the individuals are people, it's economics.
- When they're not it's biology.

Bialkowski, J., Darolles, S., and Lefol, G. (2008).
Improving VWAP strategies: A dynamic volume approach.
Journal of Banking & Finance, 32(9):1709–1722.

Bronstein, J. L. (2001).
The costs of mutualism.
American Zoologist, 41(4):825–839.

Calcott, B. (2008).
The other cooperation problem: Generating benefit.
Biology and Philosophy, 23(2):179–203.

Coase, R. (1937).
The Nature of the Firm.
Economica, 4(16):386–405.

Davies, N. B., Krebs, J. R., and West, S. A. (2012).
An Introduction to Behavioural Ecology.
Wiley-Blackwell, fourth edition.

Friedman, J. and Hammerstein, P. (1991).
To trade, or not to trade; that is the question.
In *Game Equilibrium Models I: Evolution and Game Dynamics*, pages 257–275. Springer-Verlag.

Hammerstein, P., editor (2003).
Genetic and Cultural Evolution of Cooperation (Dahlem Workshop Reports).
MIT Press.

Harder, L. D. and Real, L. A. (1987).
Why are Bumble Bees Risk Averse?
Ecology, 68(4):1104–1108.

Hoeksema, J. D. and Schwartz, M. W. (2001).
Interspecific mutualisms as biological markets.
In *Economics in Nature: Social Dilemmas, Mate Choice and Biological Markets*, chapter 8, pages 173–184.

Margulis, L. (1981).
Symbiosis in Cell Evolution.
W. H. Freeman and Company, San Francisco.

Noë, R. and Hammerstein, P. (1995).
Biological markets.
Trends in Ecology and Evolution, 10(8):336–339.

Noë, R., Hooff, and Hammerstein, P., editors (2001).
Economics in Nature: Social Dilemmas, Mate Choice and Biological Markets.
Cambridge University Press.

Nowak, A. and Sigmund, K. (2005).
Evolution of indirect reciprocity.
Nature, 437:1291–1298.

Nowak, M. (2006).
Five rules for the evolution of cooperation.
Science, 314(5805):1560–3.

Patricelli, G. L., Krakauer, A. H., and Mcelreath, R. (2011).
Assets and tactics in a mating market: Economic models of negotiation offer insights into animal courtship dynamics on the lek.
Current Zoology, 57(2):225–236.

Phelps, S. (2013).
Emergence of social networks via direct and indirect reciprocity.
Journal of Autonomous Agents and Multiagent Systems, 27(3):355–374.

Russell, Y. I. and Phelps, S. (2013).
How do you measure pleasure? A discussion about intrinsic costs and benefits in primate allogrooming.
Biology and Philosophy, 28(6):1005–1020.

Sagan, L. (1967).
On the origin of mitosing cells.

Journal of theoretical biology, 14:255–274.

Schwartz, M. W. and Hoeksema, J. D. (1998).
Specialization and resource trade: biological markets as a model of mutualisms.
Ecology, 79(3):1029–1038.

Zahavi, A. and Zavahi, A. (1997).
The Handicap Principle: A Missing Piece of Darwin's Puzzle.
Oxford University Press.