Public Goods:
From Biofilms to Societies

Claudo Carere
StarFLAG EU FP6 project

Simon Levin

DySoc/Exeter, 2021

With thanks to

C3.ai

NSF

Google

GRAND ENERGY DEVELOPMENT HEALTH CHALLENGES

CICS Cooperative Institute for Climate Science

The Simons Foundation

Bridging The Gap DARPA Powered by Ideas

National Institutes of Health

U.S. Department of Homeland Security

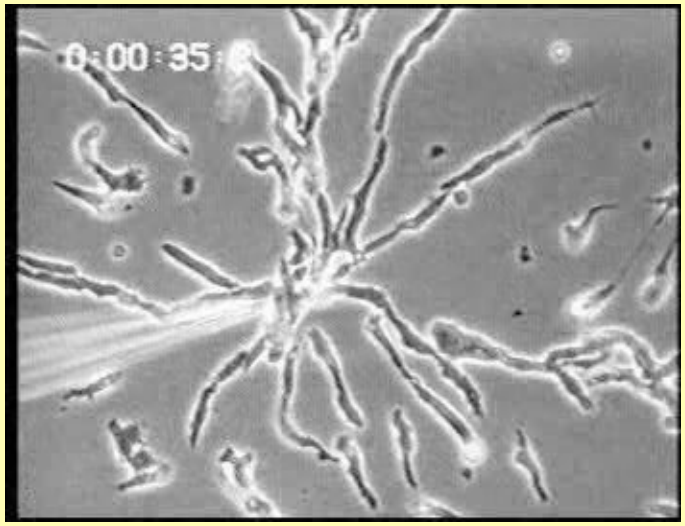
The Andrew W. Mellon Foundation

John Templeton Foundation

norden NordForsk

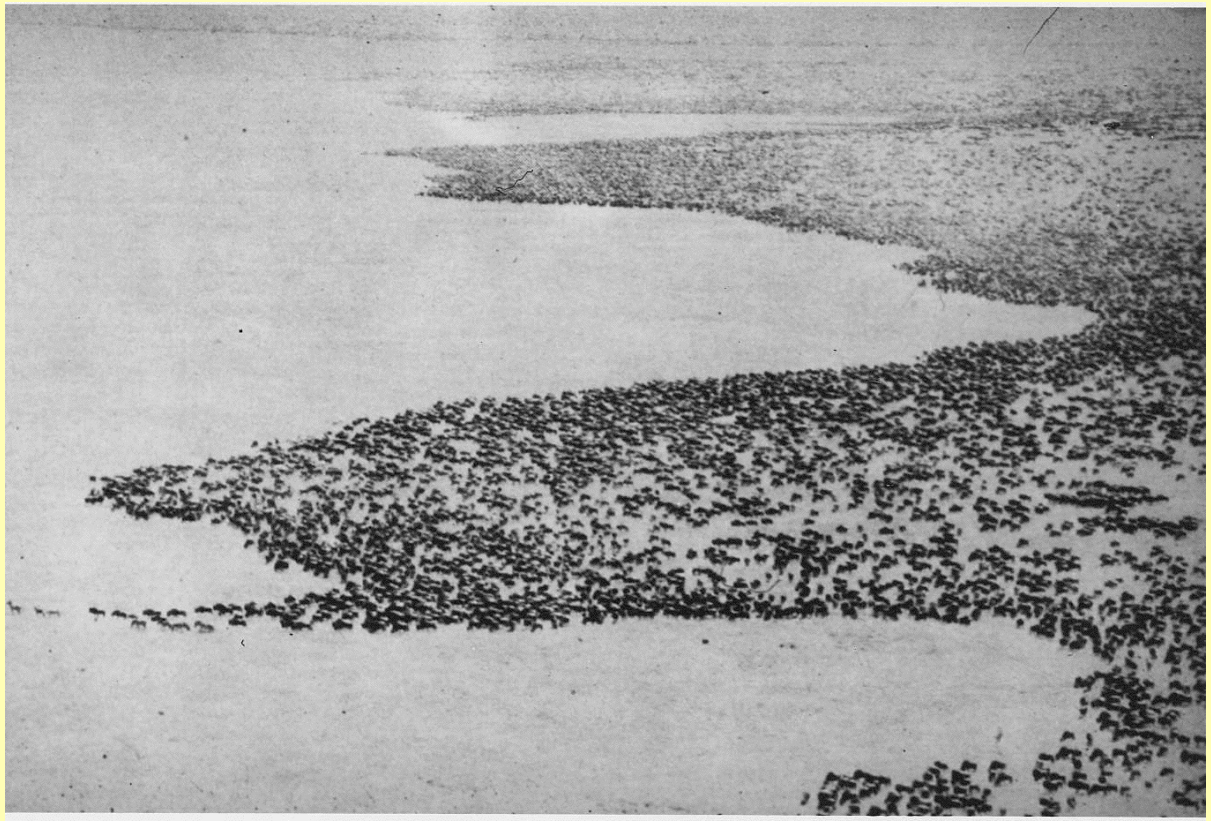
From microbial systems to socioeconomic systems, macroscopic patterns *emerge* from microscopic interactions

- **Cellular slime molds**



Bonner: The social cell
Keller and Segel: Initiation of aggregation as an instability

Large animal aggregations emerge from local interactions

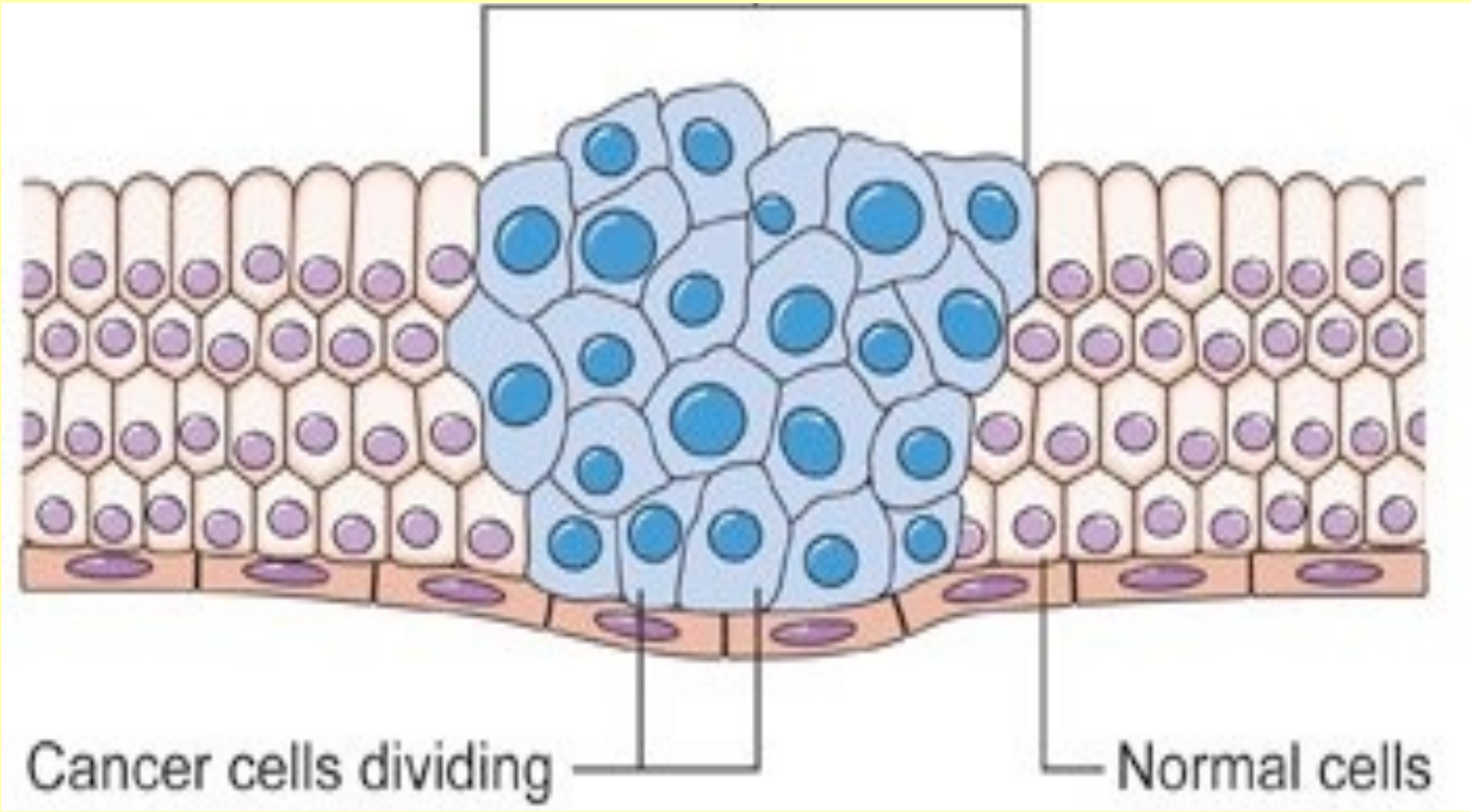


Aerial photograph of a large wildebeest herd, courtesy A.R.E. Sinclair (plate 3 from A.R.E. Sinclair, *The African Buffalo*).

With possible benefits for all-
These are “public goods”

Photo by James Crombie

This inescapably leads to conflicts between levels



http://www.cancerresearchuk.org/

Creating challenges for societies

laternaeducation.com

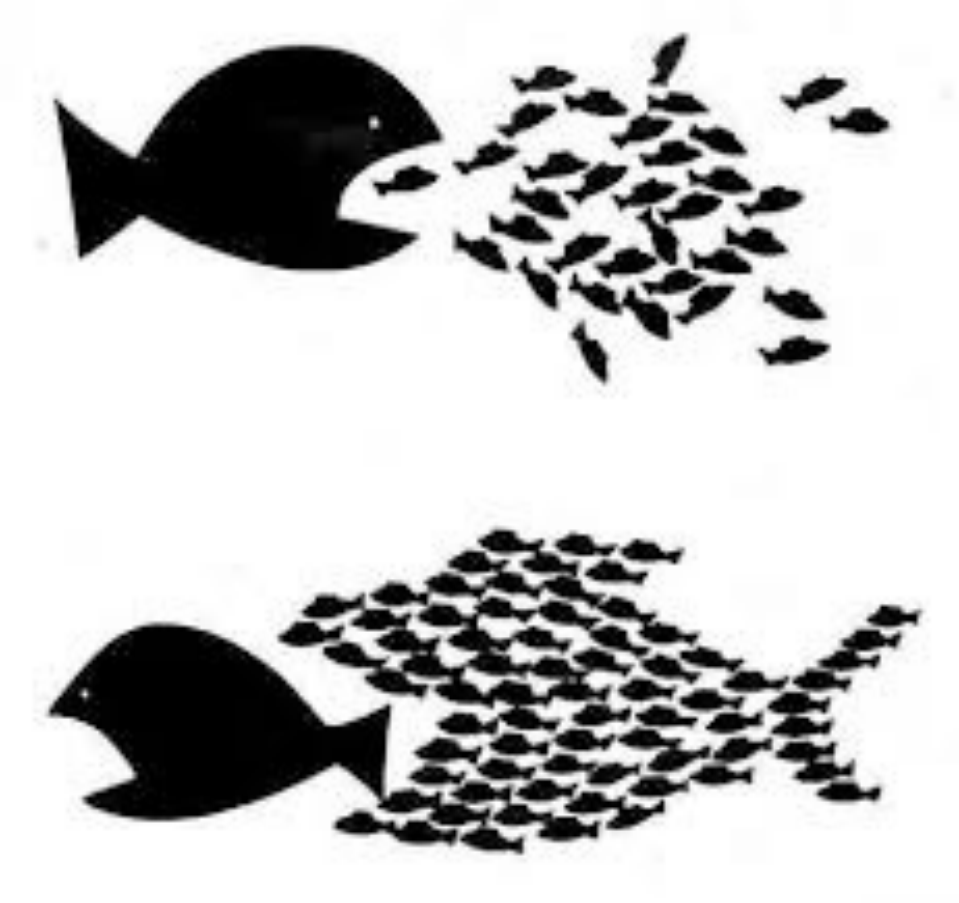
And the need to scale from individuals to ensembles….and back

Claudo Carere
StarFLAG EU FP6 project

Can cooperation be achieved at the global level on climate change and other environmental problems?

How can we achieve cooperation in the collective good?

- How does nature achieve it?



http://www.denizsozluk.com

In starling flocks, birds pay attention to about 7 nearest neighbors

Naomi Leonard's group shows that this maximizes robustness, a public good

Claudo Carere
StarFLAG EU FP6 project

But what's best for the group may not be best for the individual

J. theor. Biol. (1971) **31**, 295–311

Geometry for the Selfish Herd

W. D. Hamilton

Department of Zoology,
Imperial College, London, S.W.7, England

(*Received* 28 *September* 1970)

This paper presents an antithesis to the view that gregarious behaviour is evolved through benefits to the population or species. Following Galton (1871) and Williams (1964) gregarious behaviour is considered as a form of cover-seeking in which each animal tries to reduce its chance of being caught by a predator.

It is easy to see how pruning of marginal individuals can maintain centripetal instincts in already gregarious species; some evidence that marginal pruning actually occurs is summarized. Besides this, simply defined models are used to show that even in non-gregarious species selection is likely to favour individuals who stay close to others.

Although not universal or unipotent, cover-seeking is a widespread and important element in animal aggregation, as the literature shows. Neglect

The content and availability of information affects the evolution of social-information gathering strategies

Eleanor Redstart Brush, Naomi Ehrich Leonard & Simon A. Levin

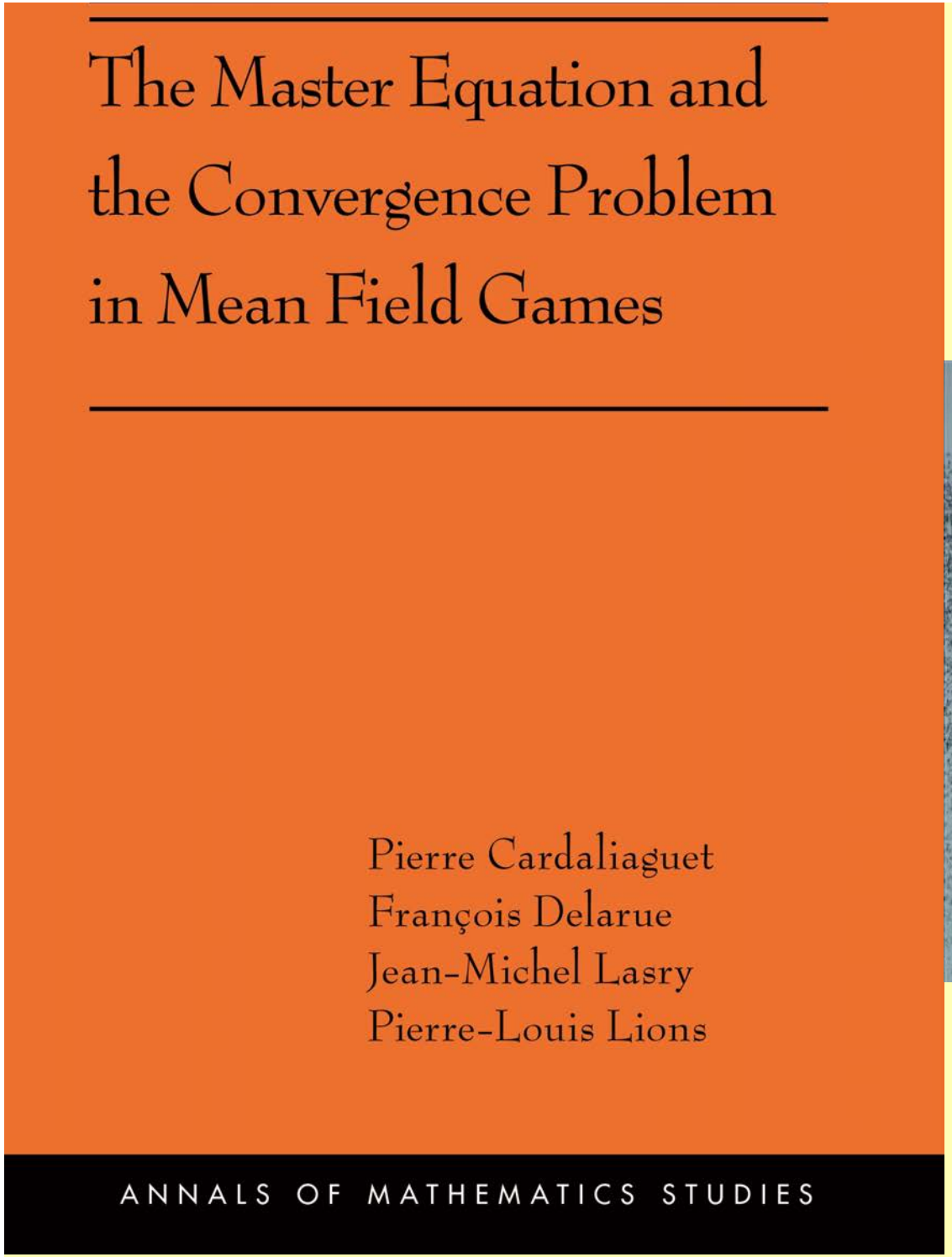
Theoretical Ecology

ISSN 1874-1738

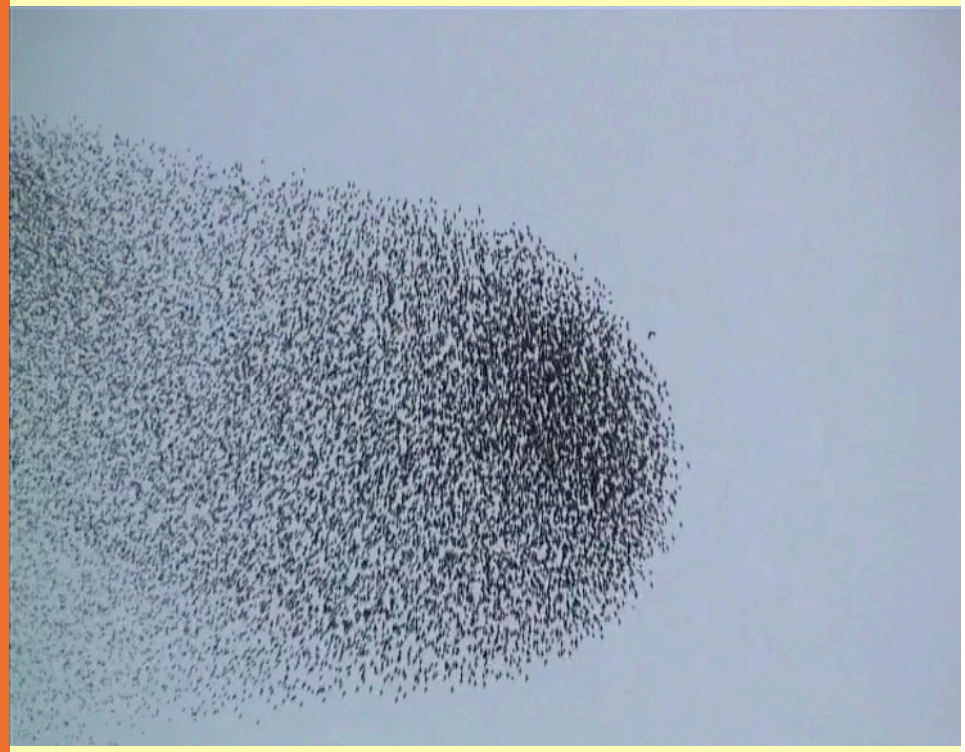
Theor Ecol
DOI 10.1007/s12080-016-0301-4

Results

- ESS # of neighbors is less when goal is finding resources than when avoiding predation



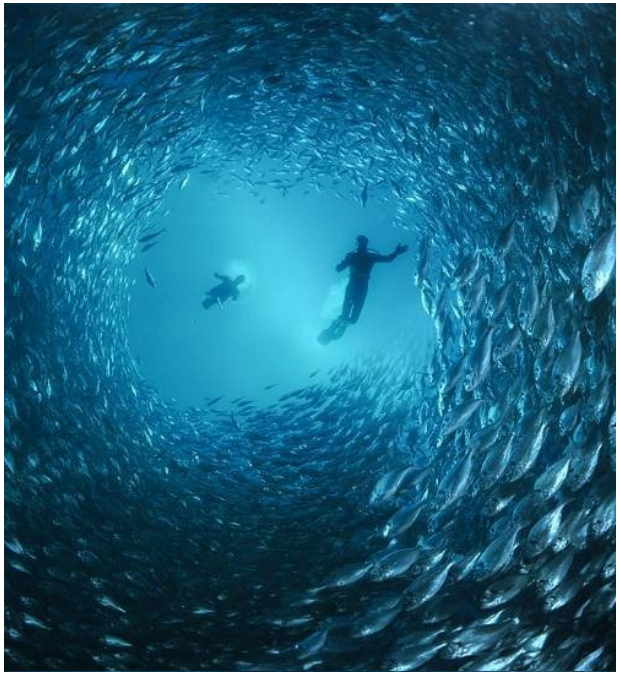
These are game-theoretic problems with many players



Science4All
Quality Popular Science by Lê

The New Big Fish Called Mean-Field Game Theory

Many people believe that mathematics research is over. Yet, as I often retort to them, we still only know little of the immense ocean of mathematical structures, which, yet, fill the world we live in. One recent advancement is that of **mean-field games** around 2006, independently by Minyi Huang, Roland Malhamé and Peter Caines in Montreal, and by Jean-Michel Lasry and Fields medalist Pierre-Louis Lions in Paris. This revolutionary model has since been greatly developed by other mathematicians and largely applied to describe complex multi-agent dynamic systems, like Mexican waves, stock markets or fish schoolings.



Applications of mean-field games go way beyond the realm of animal swarms! Recently, Lasry and Lions exploited mean-

Write Fokker-Planck equation for mass

J. theor. Biol. (1999) **196,** 397–454
Article No. jtbi.1998.0842, available online at http://www.idealibrary.com on IDEAL

From Individuals to Aggregations: the Interplay between Behavior and Physics

G. Flierl*†, D. Grünbaum‡, S. Levin§ and D. Olson¶

* *Department of Earth, Atmospheric and Planetary Sciences, M.I.T., Cambridge, MA* 02139, *U.S.A.*, ‡ *Department of Zoology, University of Washington, Box* 351800, *Seattle, WA* 98195, *U.S.A.* § *Ecology and Evolutionary Biology, Princeton University, Princeton, NJ* 08544-1003, *U.S.A. and* ¶ *Rosenstiel School of Marine and Atmospheric Science, University of Miami*, 4600 *Rickenbacker Cswy, Miami, FL* 33149, *U.S.A.*

(*Received on* 20 *May* 1997, *Accepted in revised form on* 18 *September* 1998)

This paper analyses the processes by which organisms form groups and how social forces interact with environmental variability and transport. For aquatic organisms, the latter is especially important—will sheared or turbulent flows disrupt organism groups? To analyse such problems, we use individual-based models to study the environmental and social forces leading to grouping. The models are then embedded in turbulent flow fields to gain an understanding of the interplay between the forces acting on the individuals and the transport induced by the fluid motion. Instead of disruption of groups, we find that flows often enhance grouping by increasing the encounter rate among groups and thereby promoting merger into larger groups; the effect breaks down for strong flows.

We discuss the transformation of individual-based models into continuum models for the

In Press, SIAM News

Modeling Natural Selection at Multiple Levels of Organization

By Daniel B. Cooney, Simon A. Levin, Yoichiro Mori, and Joshua B. Plotkin

Natural selection in complex biological and social systems can simultaneously operate across multiple levels of organization, ranging from genes and cells to animal groups and complex human societies. A common aspect of these scenarios is an evolutionary tug-of-war in which a trait or behavior that benefits a single individual may detrimentally affect the group to which the individual belongs (and vice versa). Such conflicts arise in the supply of common goods—like the production of diffusiblemetabolic enzymes in yeast populations [13] and collective hunting in animal groups [2]—as well as the evolution of virulence, during which pathogens that spread rapidly within a host's cells may decrease the opportunity for onward transmission to subsequent hosts [8, 10]. One can also fundamentally think of cancer as a problem of multilevel selection; tumor cells benefit in the short term from rapid replication at the detriment of the organism's long-term health [1]. This tension between the interests of individuals and groups features heavily in the study of major evolutionary transitions, during which new levels of selection arise through innovations in biological complexity (such as the emergence of multicellular life and the evolution of language) [17].

To investigate the evolutionary competition between the interests of individualsand groups, we use

Even whether to be part of the group is a game-theoretic problem

Evolution of cooperation and skew under imperfect information

Erol Akçay[a,1], Adam Meirowitz[b], Kristopher W. Ramsay[b], and Simon A. Levin[a,1]

Departments of [a]Ecology and Evolutionary Biology and [b]Politics, Princeton University, Princeton, NJ 08544

Contributed by Simon A. Levin, July 27, 2012 (sent for review March 26, 2012)

The evolution of cooperation in nature and human societies depends crucially on how the benefits from cooperation are divided and whether individuals have complete information about their payoffs. We tackle these questions by adopting a methodology from economics called mechanism design. Focusing on reproductive skew as a case study, we show that full cooperation may not be achievable due to private information over individuals' outside options, regardless of the details of the specific biological or social interaction. Further, we consider how the structure of the interaction can evolve to promote the maximum amount of cooperation in the face of the informational constraints. Our results point to a distinct avenue for investigating how cooperation can evolve when the division of benefits is flexible and individuals have private information.

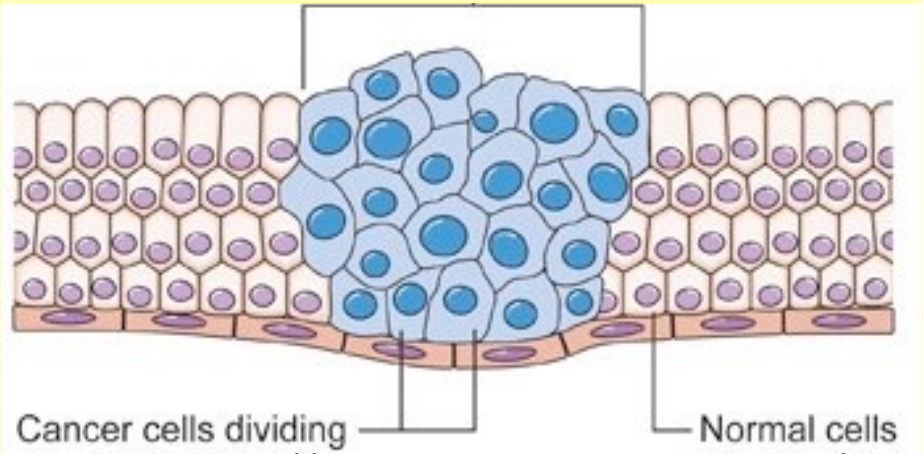
other-regarding preferences | social evolution | incentive compatibility | reproductive transactions | cheap-talk bargaining

Cooperative interactions drive much of the ecological, evolutionary, and social dynamics of organisms ranging from soil bacteria to primates, including—and especially—humans. Whereas much theory focuses on various mechanisms that promote cooperative behaviors (1–6), some fundamental questions remain unresolved. Among them is how the benefits of cooperation are to be divided among cooperating agents. Most theoretical work conceives of cooperation as a binary affair with payoffs to individuals from each outcome set a priori. However, frequently, the do not conform to theoretical predictions. We suggest that these failures occur because existing theory (14–16) assumes that reproductive skew evolves under perfect information about all relevant variables (17). In reality, however, individuals might be expected to have private information about themselves or the environment, which as we show dramatically affects both the scope of cooperation and the division of the benefits when cooperating. A related problem is that the proliferation of models in skew theory, driven in part by the empirical difficulties, has resulted in a situation where many contradictory patterns can be predicted, depending on the details of the model (14). Together with a systematic theory of which models apply in different settings, this could be a desirable property, but there is currently no such theory; hence the abundance of models fails to generate the clarity that theory is supposed to provide. Our approach avoids this problem by obtaining results independent of the precise game structure for a large class of games and also provides a first step in asking how the transactions game itself might evolve.

Our basic setup is a twist on the canonical reproductive skew model. Consider two individuals, labeled 1 and 2, who have the option of forming a group and breeding together or breeding alone. Label their expected success when breeding alone—their outside options—as o_1 and o_2, respectively. We depart from the canonical model in assuming that these options are not observed directly by both individuals; individual 1 only "knows," i.e., can condition its behavior on, o_1, but cannot condition on o_2, and vice versa. The outside options are distributed according to some

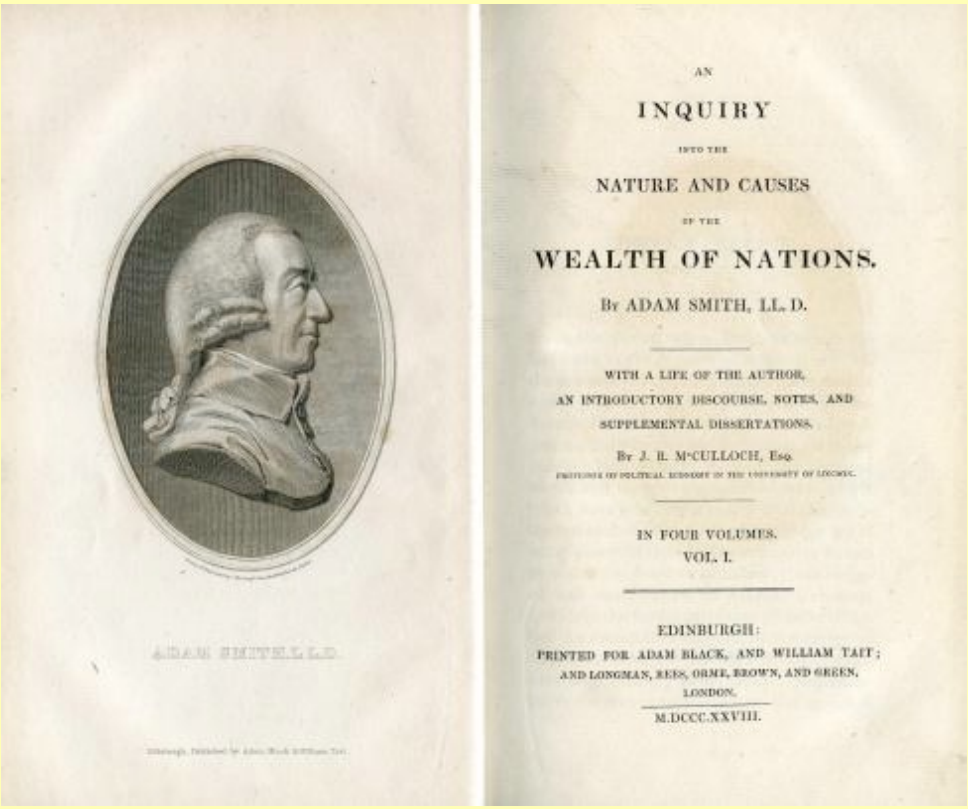
Public goods problems are widespread in socio-economic and ecological contexts

Patrick Semansky/AP



http://www.cancerresearchuk.org/

Hence, economic perspectives can inform evolutionary questions, and vice versa



AN

INQUIRY

INTO THE

NATURE AND CAUSES

OF THE

WEALTH OF NATIONS.

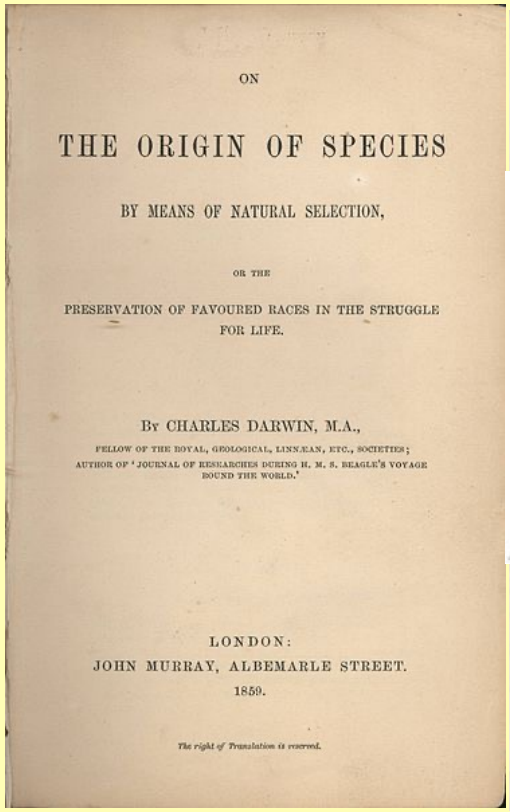
By ADAM SMITH, LL. D.

WITH A LIFE OF THE AUTHOR,
AN INTRODUCTORY DISCOURSE, NOTES, AND
SUPPLEMENTAL DISSERTATIONS.

By J. R. M'CULLOCH, Esq.
PROFESSOR OF POLITICAL ECONOMY IN THE UNIVERSITY OF LONDON.

IN FOUR VOLUMES.
VOL. I.

EDINBURGH:
PRINTED FOR ADAM BLACK, AND WILLIAM TAIT;
AND LONGMAN, REES, ORME, BROWN, AND GREEN,
LONDON.
M.DCCC.XXVIII.



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

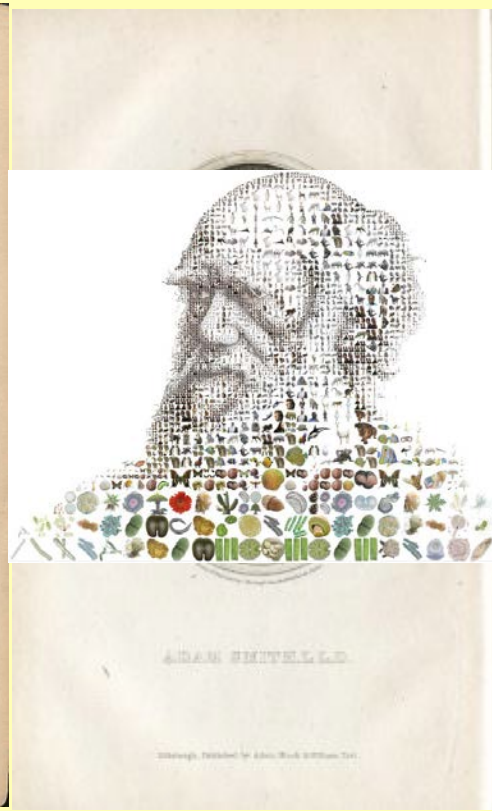
OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE
FOR LIFE.

By CHARLES DARWIN, M.A.,
FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE
ROUND THE WORLD.'

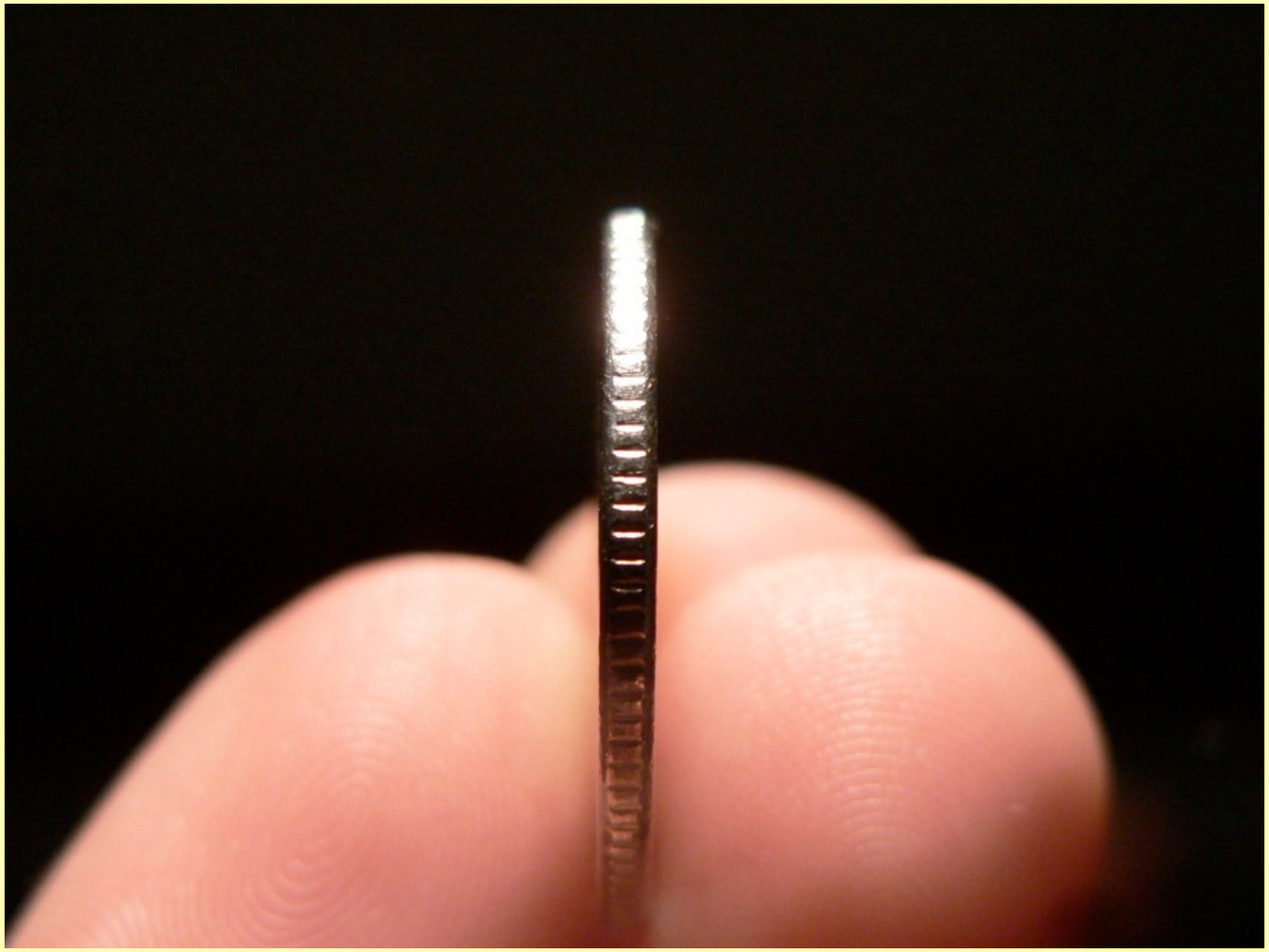
LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.



www.neoformix.com

Indeed, ecology and economics are two sides of the same coin



http://ecoopportunity.net/2013/07/sustainability-and-innovation-two-sides-of-the-same-coin/

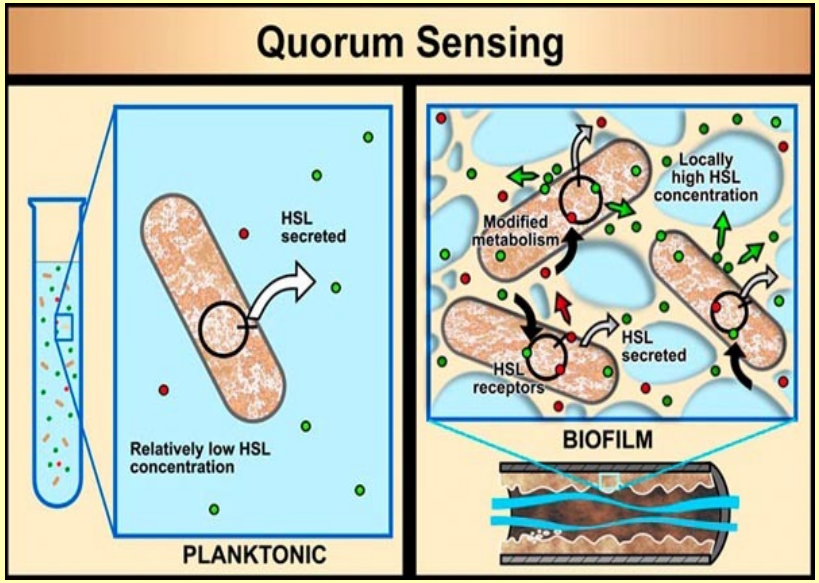
Public goods and CPR problems are central in ecology

- Information
- Tumors
- Chelation and siderophores
- Water-use

Eduardo Zea

Even bacteria cooperate

Livescience.com



www.cs.montana.edu/~ross

Dental biofilms

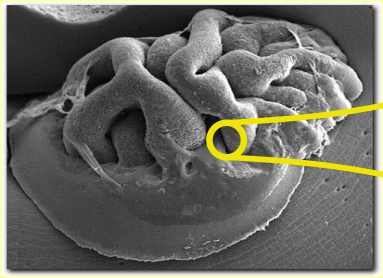
Little Shop of Horrors

Livescience.com

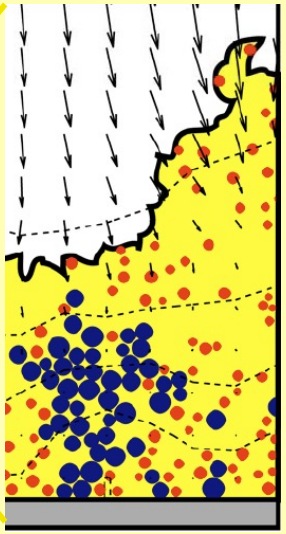
Link between group living and communication

Nadell, Xavier, Levin, Foster

Quorum Sensing ⟷ Slime ⟷ Biofilms



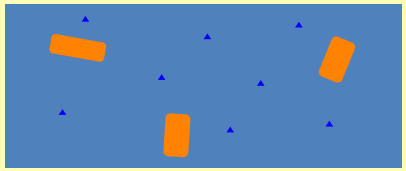
Extracellular Polymers (Slime)



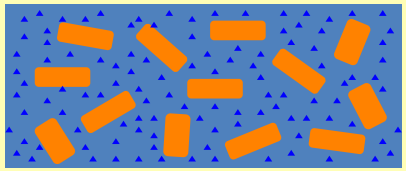
Key

- Cell that cannot make polymer
- Cell that makes polymer
- Extracellular polymer
- Nutrient Diffusion

Low cell density



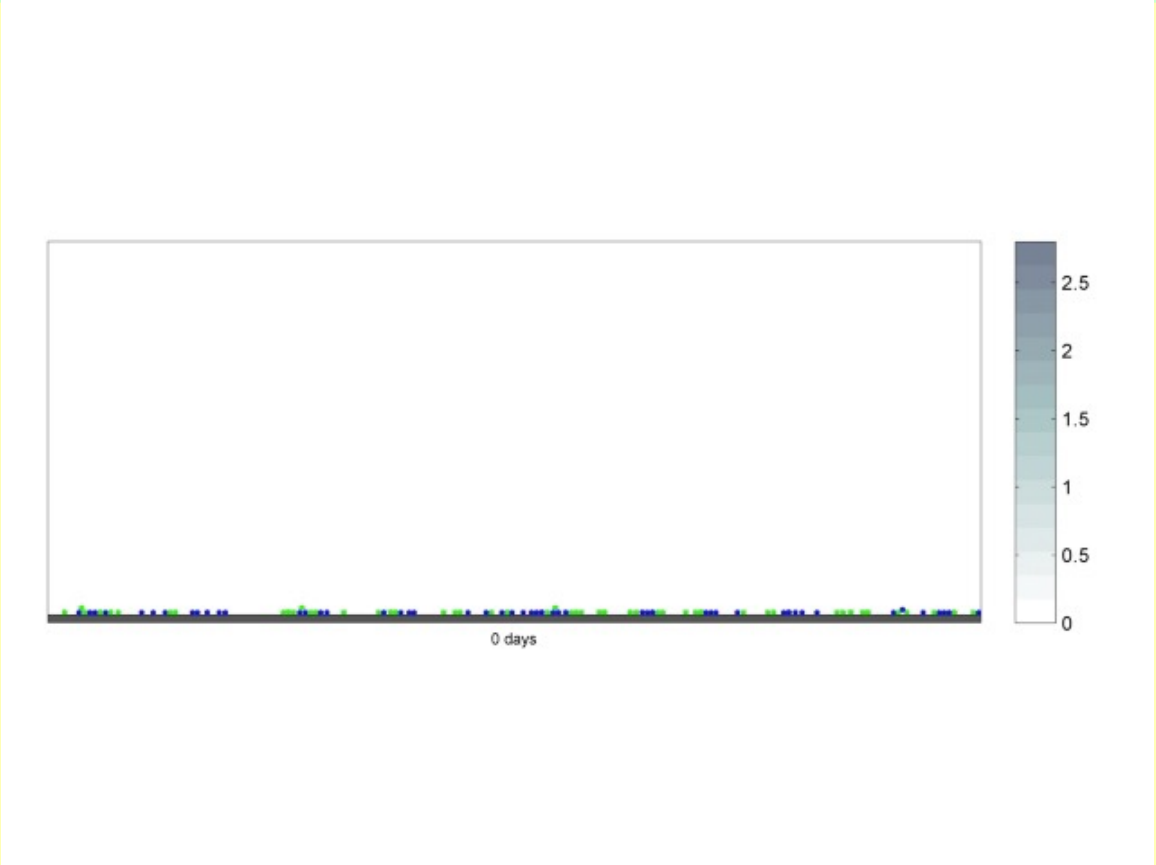
High cell density



Pseudomonas aeruginosa — Slime OFF — Slime ON

Vibrio cholerae — Slime ON — Slime OFF

Biofilm public goods production

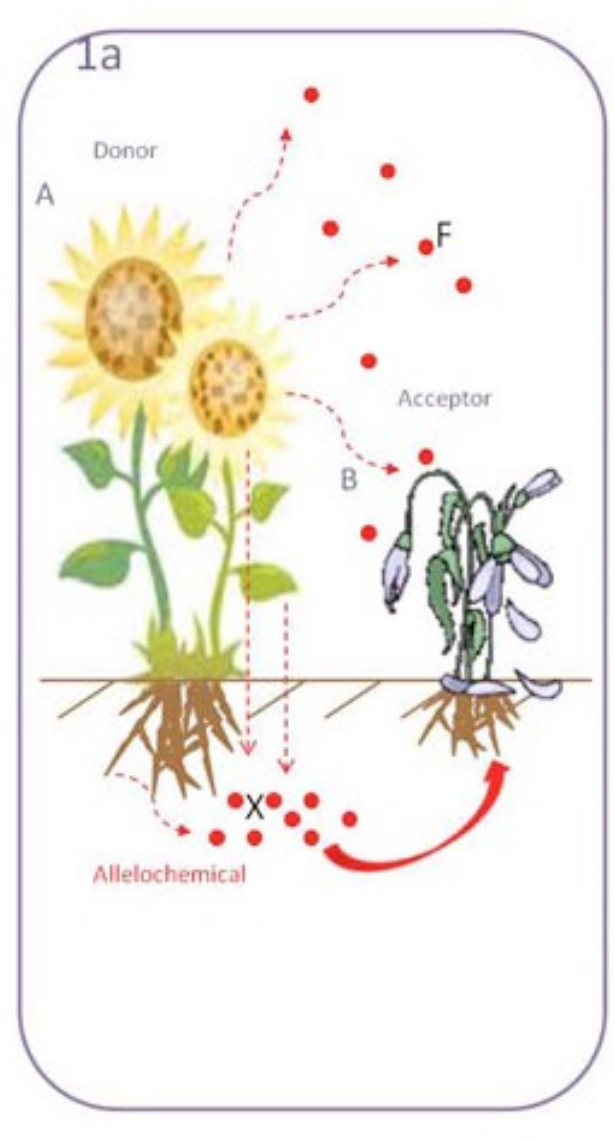


- Constitutive Slime-producer
- QS Strain (below quorum)
- Slime
- QS Strain (above quorum)

Nadell, Xavier, Levin, Foster

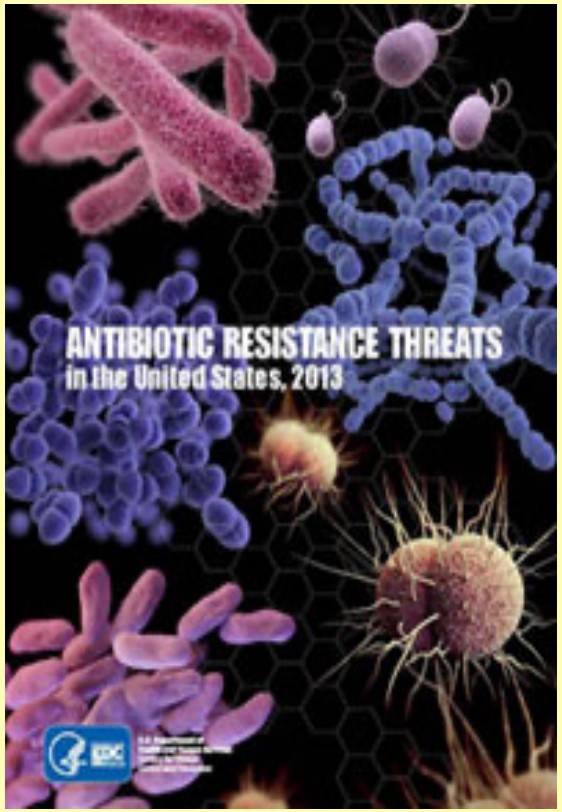
Public goods and CPR problems are central in ecology

- Information
- Tumors
- Chelation and siderophores
- Water use
- N fixation
- Extracellular proteins
- Antibiotics



http://www.intechopen.com/

Of course, antibiotic use in human societies (including agriculture) involves public goods and the Commons



Public goods and CPR problems are central in ecology

- Information
- Tumors
- Chelation and siderophores
- Water use
- N fixation
- Extracellular proteins
- Antibiotics
- Vaccination and mask wearing

Business-standard.com

Vaccination is another public-goods problem

images.usatoday.com

pubs.acs.org

Public goods maintenance is essential to sustainability of our societies

William Forster Lloyd (1832)

The Commons

Aelbert_Cuyp

The tragedy of the (unregulated) Commons

Garrett Hardin

http://www.physics.ohio-state.edu/~wilkins

The solution (Hardin)

"Mutual coercion, mutually agreed upon"

http://www.physics.ohio-state.edu/~wilkins

The maintenance of cooperation in small societies depends on shared and mutually agreed-upon norms

Lin Ostrom

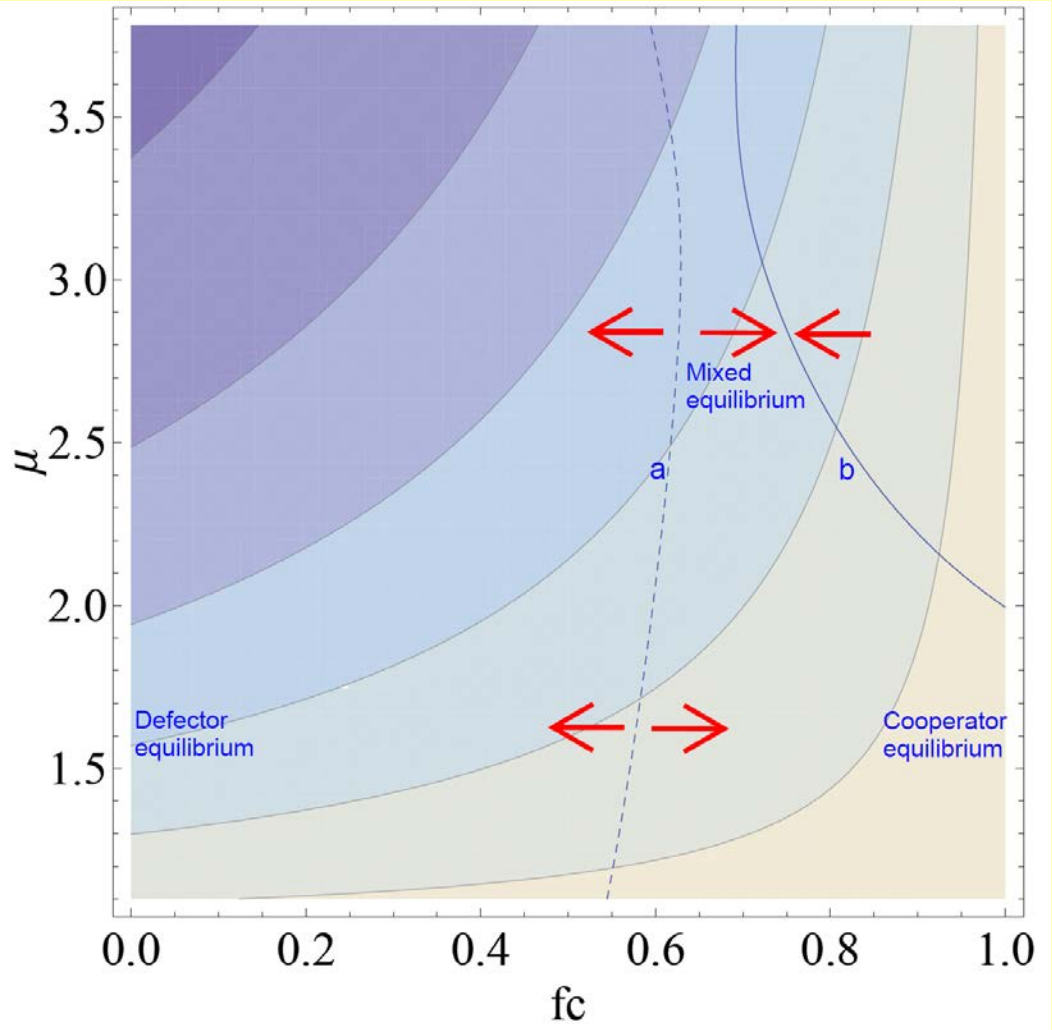
Fairness norms can provide "mutual coercion, mutually agreed upon"

with Alessandro Tavoni and Maja Schlüter

http://geo.coop/node/654

Tavoni, Schlueter, Levin
Coordination game

Selfishness



Frequency of cooperators

Journal of Theoretical Biology
Volume 299, 21 April 2012

Pastoralism and sharing of grazing grounds

- With Avinash Dixit and Daniel Rubenstein

meshakenya.wordpress.com

Basic framework

- Good years A_H, bad years A_L
- When one has a good year, and other has a bad year, m cattle moved from bad to good
- x, z are investments in cattle, land

Variety of mechanisms: Repeated game

- Social optimum: Choose transfers to maximize total welfare
- $W = A_1(x_1 + m)^{\alpha} z_1{}^{\beta} + A_2(x_2 - m)^{\alpha} z_2{}^{\beta} - \left(\frac{1}{2}\right) c(x_1 + z_1)^2 - \left(\frac{1}{2}\right) c(x_2 + z_2)^2$
- Nash? Depends on discount rate

Variety of mechanisms: Repeated game

- Social optimum
- Nash?
- If not, second-best solutions to make them Nash

In herder societies, kinship and prosociality can be important

http://gordonkilgore.com/gallery/countries-h-m/kenya/

Gintis, Rationality and Society 2003

SOLVING THE PUZZLE OF PROSOCIALITY

Herbert Gintis

ABSTRACT

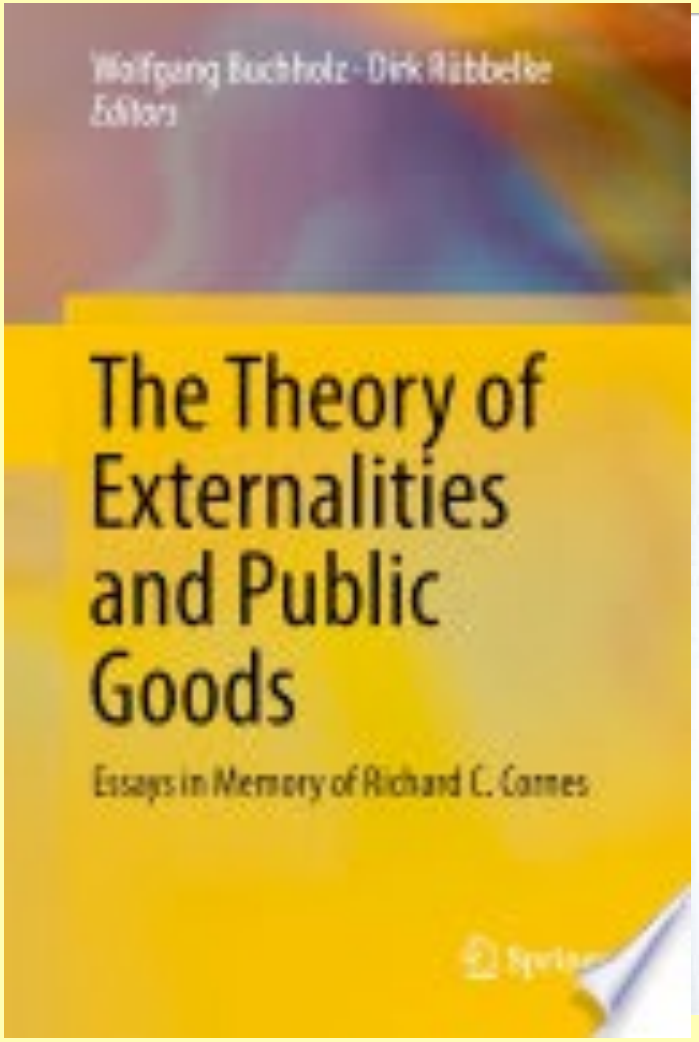
Homo sapiens is the only species in which we observe extensive cooperation among large numbers of genetically unrelated individuals. Incompatible approaches to explaining cooperation among humans have been offered by sociologists, biologists, and economists. None is wholly successful. Each discipline, moreover, has ignored basic insights of the others. This article explains cooperation by combining central contributions of these disciplines, developing a model of cultural evolution in which we use (a) the sociological concept of the internalization of norms to explain cultural transmission; (b) the biological concepts of vertical and oblique transmission to model the interaction of cultural and biological adaptation; and (c) the economic concepts of rational action and the replicator dynamic to model the interaction between self-interested and altruistic behavior. The article closes with a bioeconomic explanation of the human capacity to internalize norms.

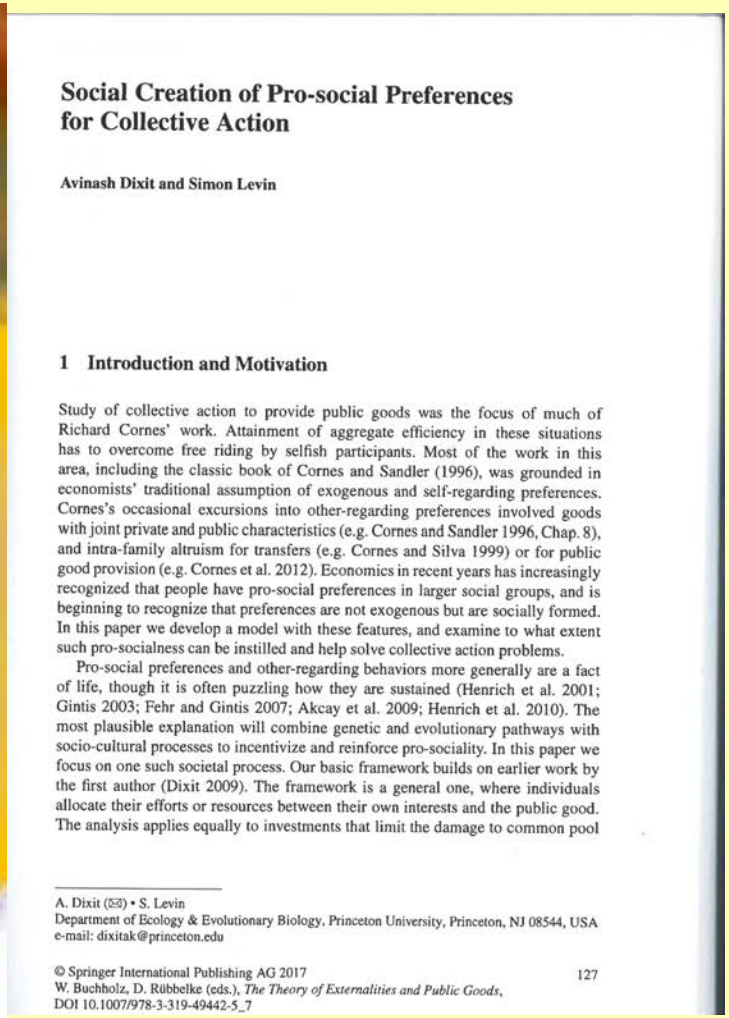
KEY WORDS • altruism • conditional cooperation • conditional punishment • cultural dynamics • cultural evolution • strong reciprocity

1. Introduction

Homo sapiens is the only species in which we observe extensive co-

Prosociality can emerge endogenously





Social Creation of Pro-social Preferences for Collective Action

Avinash Dixit and Simon Levin

1 Introduction and Motivation

Study of collective action to provide public goods was the focus of much of Richard Cornes' work. Attainment of aggregate efficiency in these situations has to overcome free riding by selfish participants. Most of the work in this area, including the classic book of Cornes and Sandler (1996), was grounded in economists' traditional assumption of exogenous and self-regarding preferences. Cornes's occasional excursions into other-regarding preferences involved goods with joint private and public characteristics (e.g. Cornes and Sandler 1996, Chap. 8), and intra-family altruism for transfers (e.g. Cornes and Silva 1999) or for public good provision (e.g. Cornes et al. 2012). Economics in recent years has increasingly recognized that people have pro-social preferences in larger social groups, and is beginning to recognize that preferences are not exogenous but are socially formed. In this paper we develop a model with these features, and examine to what extent such pro-socialness can be instilled and help solve collective action problems.

Pro-social preferences and other-regarding behaviors more generally are a fact of life, though it is often puzzling how they are sustained (Henrich et al. 2001; Gintis 2003; Fehr and Gintis 2007; Akcay et al. 2009; Henrich et al. 2010). The most plausible explanation will combine genetic and evolutionary pathways with socio-cultural processes to incentivize and reinforce pro-sociality. In this paper we focus on one such societal process. Our basic framework builds on earlier work by the first author (Dixit 2009). The framework is a general one, where individuals allocate their efforts or resources between their own interests and the public good. The analysis applies equally to investments that limit the damage to common pool

A. Dixit (✉) • S. Levin
Department of Ecology & Evolutionary Biology, Princeton University, Princeton, NJ 08544, USA
e-mail: dixitak@princeton.edu

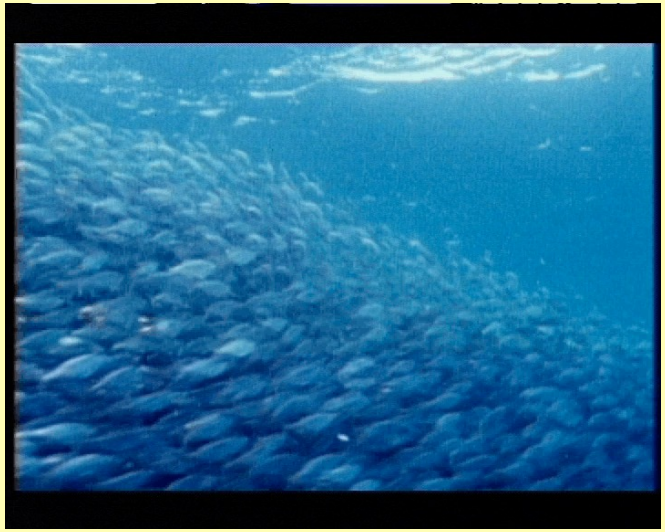
W. Buchholz, D. Rübbelke (eds.), *The Theory of Externalities and Public Goods*,
DOI 10.1007/978-3-319-49442-5_7

- Prosociality facilitates cooperation
- Local prosociality with leakage of benefits can lead to global cooperation
- Prosociality can be selected for because it leave offspring with better life

Summary so far:

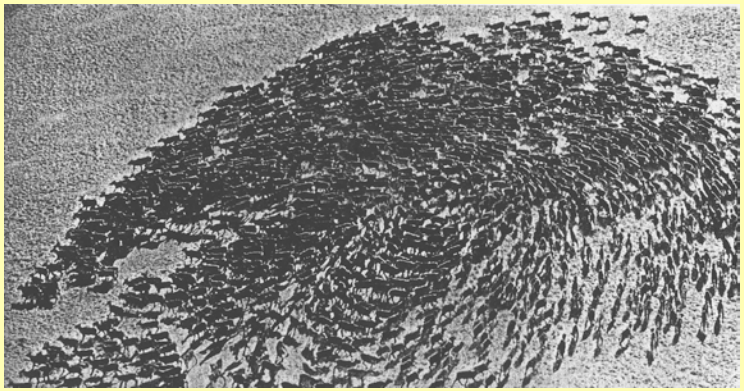
- Collective action can be effective if it includes enforcement
- Prosociality is an important contributor to the maintenance of public goods and common pool resources
- How are collective decisions made?

Animal flocks, herds and swarms



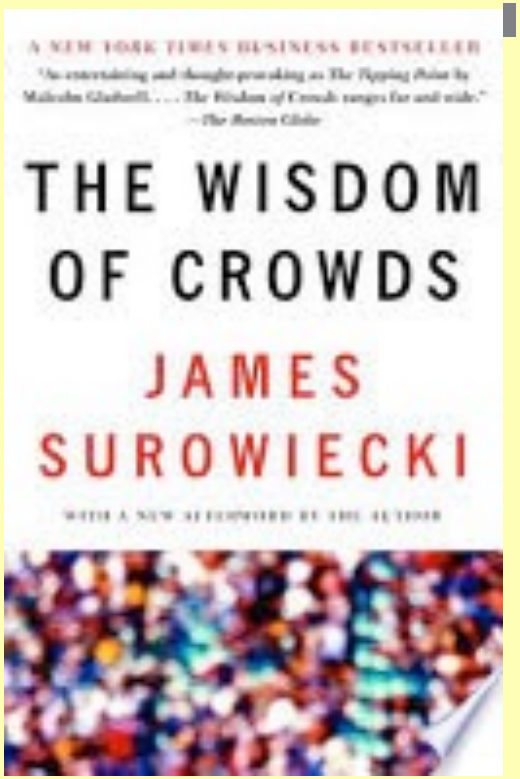
Couzin/BBC

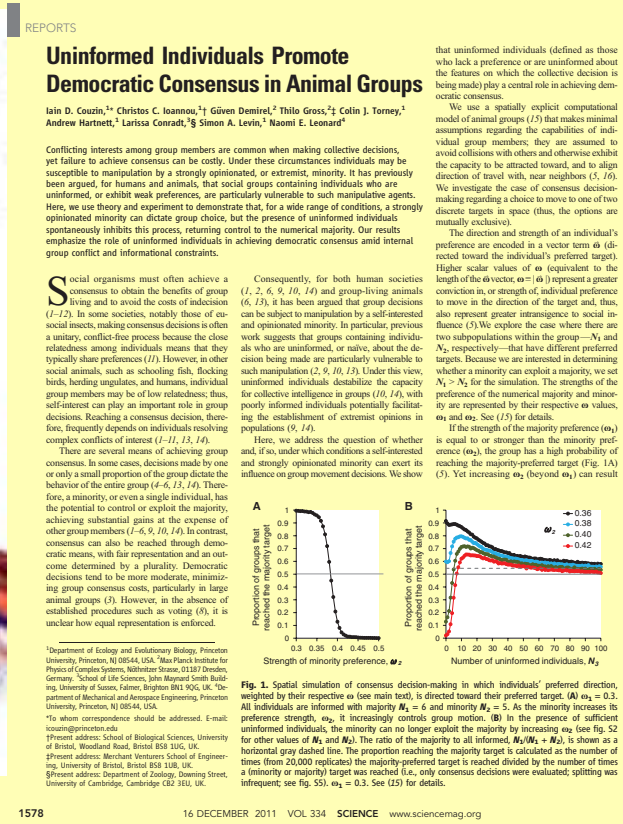
Claudio Carere + StarFLAG EU FP6 project



Source Unknown

Can we learn from Nature?
What can we add?





REPORTS

Uninformed Individuals Promote Democratic Consensus in Animal Groups

Iain D. Couzin,[1,*] Christos C. Ioannou,[1]† Güven Demirel,[2] Thilo Gross,[2]‡ Colin J. Torney,[1] Andrew Hartnett,[1] Larissa Conradt,[3]§ Simon A. Levin,[1] Naomi E. Leonard[4]

Conflicting interests among group members are common when making collective decisions, yet failure to achieve consensus can be costly. Under these circumstances individuals may be susceptible to manipulation by a strongly opinionated, or extremist, minority. It has previously been argued, for humans and animals, that social groups containing individuals who are uninformed, or exhibit weak preferences, are particularly vulnerable to such manipulative agents. Here, we use theory and experiment to demonstrate that, for a wide range of conditions, a strongly opinionated minority can dictate group choice, but the presence of uninformed individuals spontaneously inhibits this process, returning control to the numerical majority. Our results emphasize the role of uninformed individuals in achieving democratic consensus amid internal group conflict and informational constraints.

Social organisms must often achieve a consensus to obtain the benefits of group living and to avoid the costs of indecision (*1–12*). In some societies, notably those of eusocial insects, making consensus decisions is often a unitary, conflict-free process because the close relatedness among individuals means that they typically share preferences (*11*). However, in other social animals, such as schooling fish, flocking birds, herding ungulates, and humans, individual group members may be of low relatedness; thus, self-interest can play an important role in group decisions. Reaching a consensus decision, therefore, frequently depends on individuals resolving complex conflicts of interest (*1–11, 13, 14*).

There are several means of achieving group consensus. In some cases, decisions made by one or only a small proportion of the group dictate the behavior of the entire group (*4–6, 13, 14*). Therefore, a minority, or even a single individual, has the potential to control or exploit the majority, achieving substantial gains at the expense of other group members (*1–6, 9, 10, 14*). In contrast, consensus can also be reached through democratic means, with fair representation and an outcome determined by a plurality. Democratic decisions tend to be more moderate, minimizing group consensus costs, particularly in large animal groups (*3*). However, in the absence of established procedures such as voting (*8*), it is unclear how equal representation is enforced.

Consequently, for both human societies (*1, 2, 6, 9, 10, 14*) and group-living animals (*6, 13*), it has been argued that group decisions can be subject to manipulation by a self-interested and opinionated minority. In particular, previous work suggests that groups containing individuals who are uninformed, or naïve, about the decision being made are particularly vulnerable to such manipulation (*2, 9, 10, 13*). Under this view, uninformed individuals destabilize the capacity for collective intelligence in groups (*10, 14*), with poorly informed individuals potentially facilitating the establishment of extremist opinions in populations (*9, 14*).

Here, we address the question of whether and, if so, under which conditions a self-interested and strongly opinionated minority can exert its influence on group movement decisions. We show that uninformed individuals (defined as those who lack a preference or are uninformed about the features on which the collective decision is being made) play a central role in achieving democratic consensus.

We use a spatially explicit computational model of animal groups (*15*) that makes minimal assumptions regarding the capabilities of individual group members; they are assumed to avoid collisions with others and otherwise exhibit the capacity to be attracted toward, and to align direction of travel with, near neighbors (*5, 16*). We investigate the case of consensus decision-making regarding a choice to move to one of two discrete targets in space (thus, the options are mutually exclusive).

The direction and strength of an individual's preference are encoded in a vector term $\vec{\omega}$ (directed toward the individual's preferred target). Higher scalar values of ω (equivalent to the length of the $\vec{\omega}$ vector, $\omega = |\vec{\omega}|$) represent a greater conviction in, or strength of, individual preference to move in the direction of the target and, thus, also represent greater intransigence to social influence (*5*).We explore the case where there are two subpopulations within the group—N_1 and N_2, respectively—that have different preferred targets. Because we are interested in determining whether a minority can exploit a majority, we set $N_1 > N_2$ for the simulation. The strengths of the preference of the numerical majority and minority are represented by their respective ω values, ω_1 and ω_2. See (*15*) for details.

If the strength of the majority preference (ω_1) is equal to or stronger than the minority preference (ω_2), the group has a high probability of reaching the majority-preferred target (Fig. 1A) (*5*). Yet increasing ω_2 (beyond ω_1) can result

[1]Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544, USA. [2]Max Planck Institute for Physics of Complex Systems, Nöthnitzer Strasse, 01187 Dresden, Germany. [3]School of Life Sciences, John Maynard Smith Building, University of Sussex, Falmer, Brighton BN1 9QG, UK. [4]Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ 08544, USA.

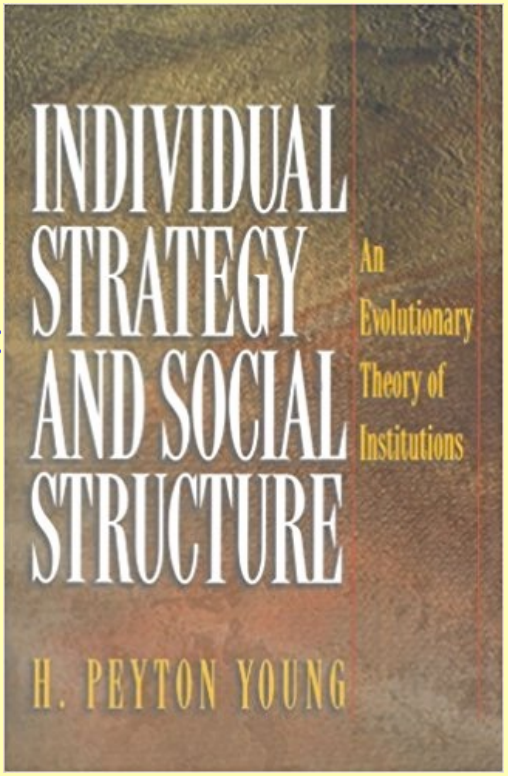
*To whom correspondence should be addressed. E-mail: icouzin@princeton.edu

†Present address: School of Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, UK.

‡Present address: Merchant Venturers School of Engineering, University of Bristol, Bristol BS8 1UB, UK.

§Present address: Department of Zoology, Downing Street, University of Cambridge, Cambridge CB2 3EU, UK.

Fig. 1. Spatial simulation of consensus decision-making in which individuals' preferred direction, weighted by their respective ω (see main text), is directed toward their preferred target. **(A)** $\omega_1 = 0.3$. All individuals are informed with majority $N_1 = 6$ and minority $N_2 = 5$. As the minority increases its preference strength, ω_2, it increasingly controls group motion. **(B)** In the presence of sufficient uninformed individuals, the minority can no longer exploit the majority by increasing ω_2 (see fig. S2 for other values of N_1 and N_2). The ratio of the majority to all informed, $N_1/(N_1 + N_2)$, is shown as a horizontal gray dashed line. The proportion reaching the majority target is calculated as the number of times (from 20,000 replicates) the majority-preferred target is reached divided by the number of times a (minority or majority) target was reached (i.e., only consensus decisions were evaluated; splitting was infrequent; see fig. S5). $\omega_1 = 0.3$. See (*15*) for details.



Science, 2011

Ecosystems
https://doi.org/10.1007/s10021-021-00680-2

ORIGINAL ARTICLE

Governance in the Face of Extreme Events: Lessons from Evolutionary Processes for Structuring Interventions, and the Need to Go Beyond

Simon A. Levin,[1]* John M. Anderies,[2] Neil Adger,[3] Scott Barrett,[4,5] Elena M. Bennett,[6] Juan Camilo Cardenas,[7] Stephen R. Carpenter,[8] Anne-Sophie Crépin,[9,10] Paul Ehrlich,[11] Joern Fischer,[12] Carl Folke,[9,10] Nils Kautsky,[13] Catherine Kling,[14] Karine Nyborg,[15] Stephen Polasky,[16] Marten Scheffer,[17] Kathleen Segerson,[18] Jason Shogren,[19] Jeroen van den Bergh,[20,21] Brian Walker,[22] Elke U. Weber,[23,24,25] and James Wilen[26]

[1]Department of Ecology and Evolutionary Biology, Princeton University, 106A Guyot Hall, Princeton, New Jersey 08544, USA; [2]School of Sustainability, Arizona State University, Tempe, Arizona 85287, USA; [3]College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4RJ, UK; [4]School of International and Public Affairs, Columbia University, New York, New York 10025, USA; [5]The Earth Institute, Columbia University, New York, New York 10025, USA; [6]Department of Natural Resource Sciences, McGill School of Environment, McGill University, Québec H9X 3V9, Canada; [7]School of Economics, Los Andes University, 111711 Bogotá, Colombia; [8]Center for Limnology, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA; [9]The Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, SE-10405 Stockholm, Sweden; [10]Stockholm Resilience Centre, Stockholm University, SE-10691 Stockholm, Sweden; [11]Department of Biological Sciences, Stanford University, Stanford, California 94305, USA; [12]Faculty of Sustainability, Leuphana University, 21335 Lueneburg, Germany; [13]Department of Ecology, Environment and Plant Sciences, Stockholm University, 10691 Stockholm, Sweden; [14]Dyson School of Applied Economics and Management, Cornell University, Ithaca, New York 14853, USA; [15]Department of Economics, University of Oslo, 0317 Oslo, Norway; [16]Department of Applied Economics, University of Minnesota, St. Paul, Minnesota 55108, USA; [17]Department of Environmental Sciences, University of

Urgent challenges

- Global Health
- Climate Change

Public goods and CPR problems are central in ecology

- Information
- Tumors
- Chelation and siderophores
- Water use
- N fixation
- Extracellular proteins
- Antibiotics
- Vaccination and maskwearing

Business-standard.com

Original Contribution

Hesitancy Toward a COVID-19 Vaccine

Linda Thunström,[1] Madison Ashworth,[1] David Finnoff,[1] and Stephen C. Newbold[1]

Department of Economics, University of Wyoming, Laramie, WY 82071

Abstract: The scientific community has come together in a mass mobilization to combat the public health risks of COVID-19, including efforts to develop a vaccine. However, the success of any vaccine depends on the share of the population that gets vaccinated. We designed a survey experiment in which a nationally representative sample of 3,133 adults in the USA stated their intentions to vaccinate themselves and their children for COVID-19. The factors that we varied across treatments were: the stated severity and infectiousness of COVID-19 and the stated source of the risk information (White House or the Centers for Disease Control). We find that 20% of people in the USA intend to decline the vaccine. We find no statistically significant effect on vaccine intentions from the severity of COVID-19. In contrast, we find that the degree of infectiousness of the coronavirus influences vaccine intentions and that inconsistent risk messages from public health experts and elected officials may reduce vaccine uptake. However, the most important determinants of COVID-19 vaccine hesitancy seem to be distrust of the vaccine safety (including uncertainty due to vaccine novelty), as well as general vaccine avoidance, as implied by not having had a flu shot in the last two years.

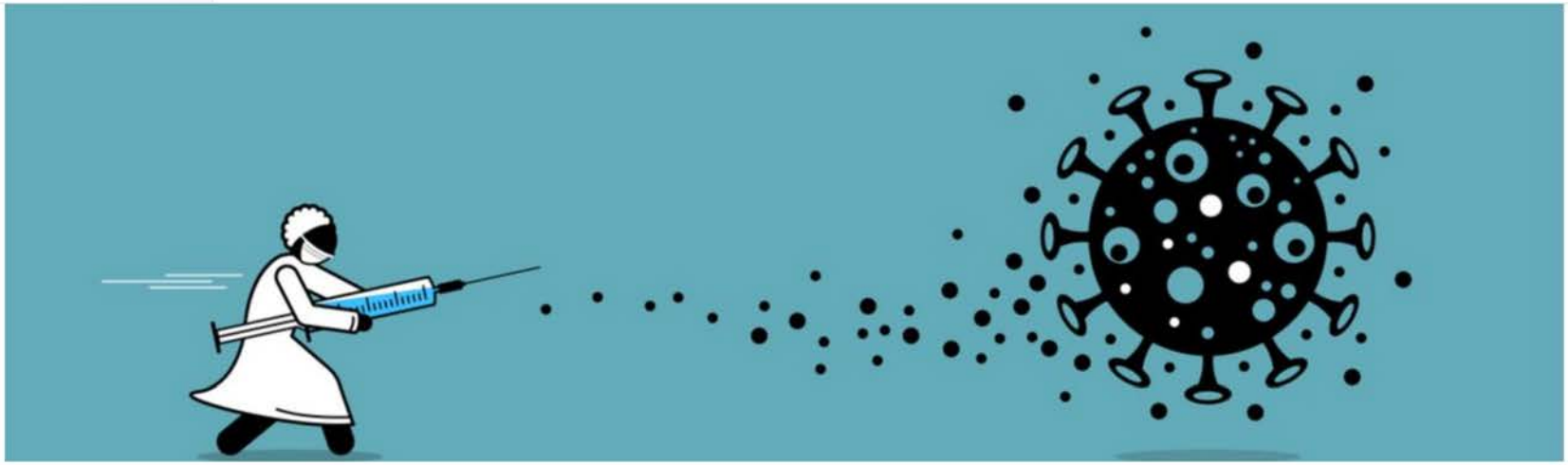
Introduction

Vaccines have historically proven to be highly successful and cost-effective tools for disease prevention in humans (Rémy et al., 2015), domesticated species (Roth, 2011), and expansion of their use in wild species has been advocated

dates had been developed, several of which quickly advanced to being tested on humans (Le et al., 2020).

However, the effectiveness of a COVID-19 vaccine in controlling the spread of disease depends on the coverage, or uptake level, of the vaccine across a population. A sufficiently high uptake of an effective vaccine may generate

MOST POPULAR
Does Theranos Mark the Peak of the Silicon Valley Bubble?
The Smaller the Theater, the Faster the Music
What Time Feels Like When You're Improvising
A New View of Time



CULTURE | HEALTH

How to Build Trust in Covid-19 Vaccines

Why people distrust vaccines and how they can be convinced otherwise.

BY RAMANAN LAXMINARAYAN, SUSAN FITZPATRICK, & SIMON LEVIN
DECEMBER 9, 2020

Vaccine Hesitancy vs. Climate Change

Vaccination-hesitancy and Global-warming: distinct challenges with a similar behavioural solution

Ilan Fischer[1], Daniel I. Rubenstein[2], Simon A. Levin[2]

[1]Department of Psychology, University of Haifa,

[2] Department of Ecology and Evolutionary Biology, Princeton University

Abstract

Although the COVID-19 vaccine has dramatically changed the fight against the pandemic, many exhibit vaccination-hesitancy. At the same time, continued human-induced emissions of greenhouse gases pose an alarming threat to humanity. Based on a recent international study that drastically modified COVID-19 health related attitudes, we explain why a similar approach is expected to help resolve both behavioral issues: reduce vaccination hesitancy and motivate climate actions.

Main text

Vaccine Hesitancy vs. Climate Change

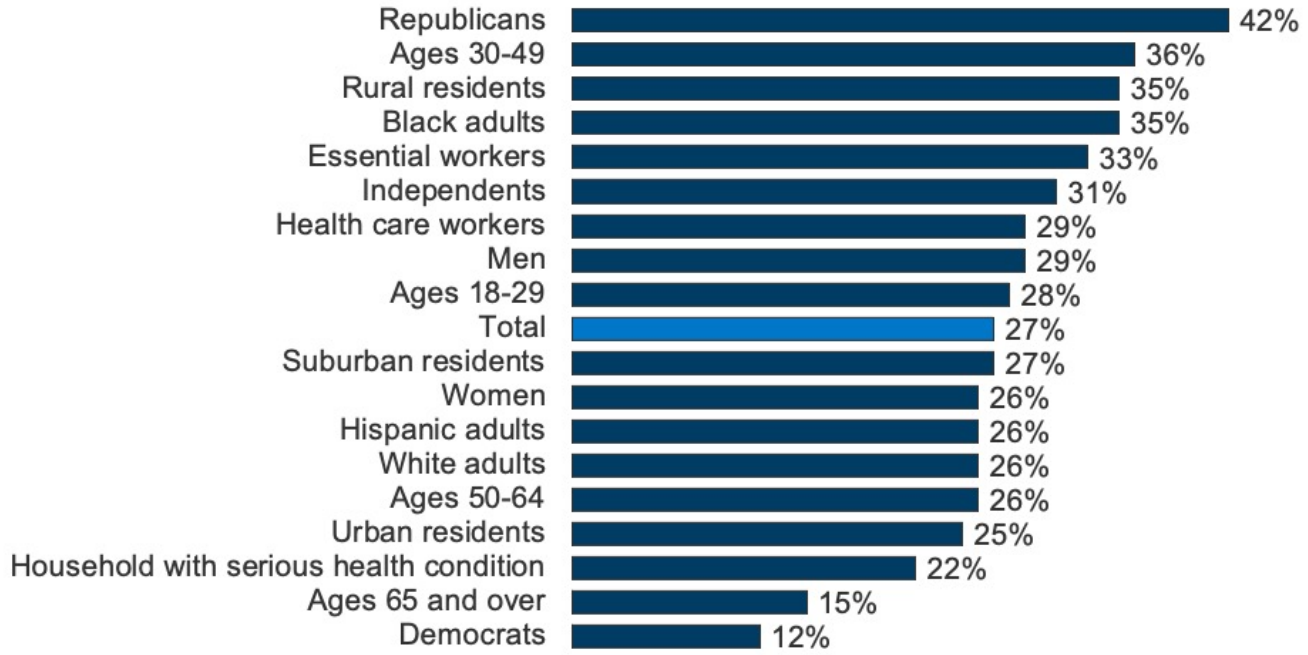
- Vaccine hesitancy is a Chicken Game
  - Getting vaccinated more likely if others don’t
- Climate change is PD
  - Inaction a dominant strategy in most simplistic form

Hesitancy is socially mediated

Figure 4

Which Groups Are Most Likely To Be COVID-19 Vaccine Hesitant?

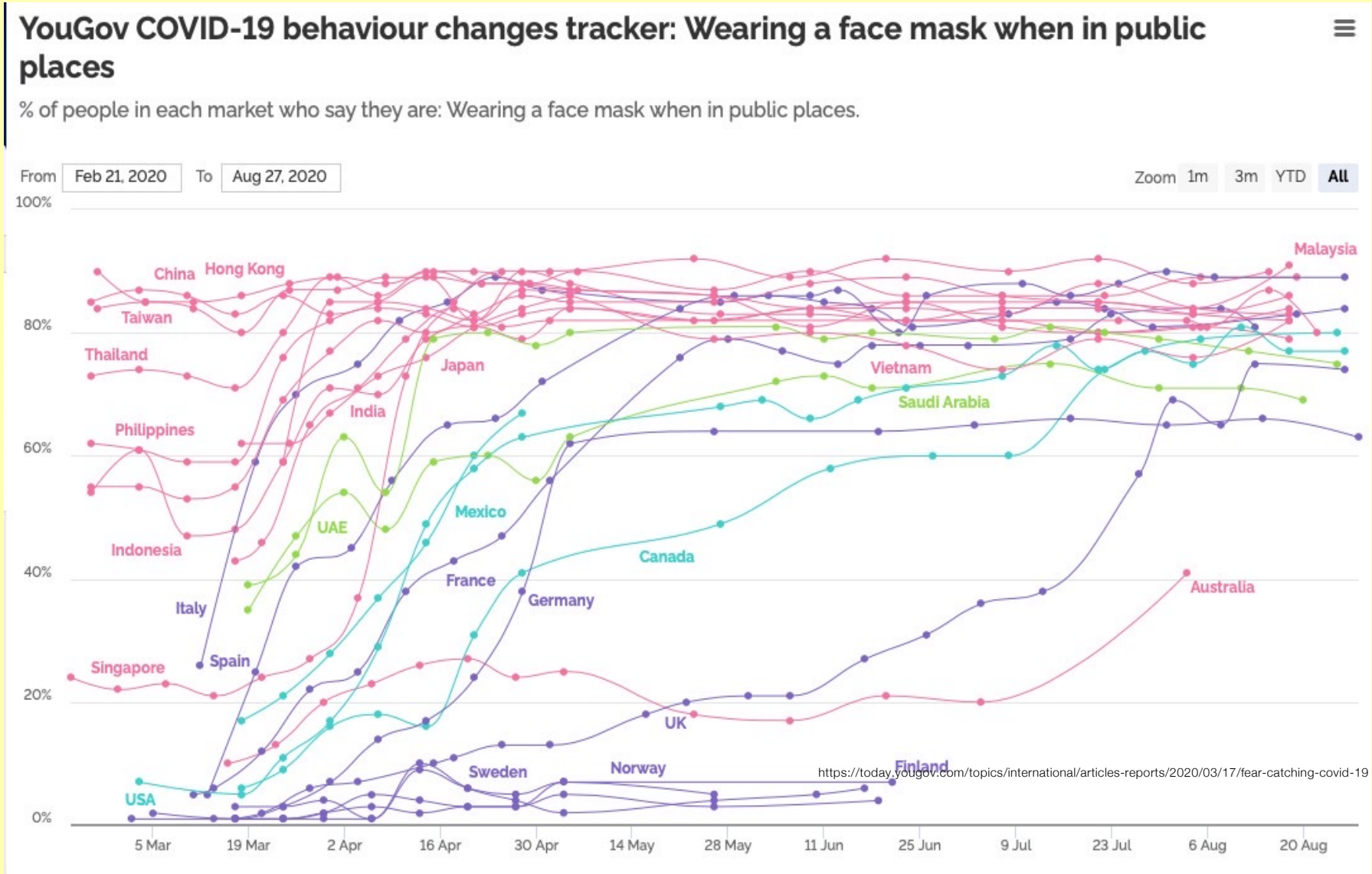
Percent within each group who say, if a COVID-19 vaccine was determined to be safe by scientists and available for free to everyone who wanted it, they would **probably not get it** or **definitely not get it**:



KFF COVID-19 Vaccine Monitor

SOURCE: KFF COVID-19 Vaccine Monitor (KFF Health Tracking Poll, Nov. 30-Dec. 8, 2020). See topline for full question wording.

Cultural and Political Influences are Crucial



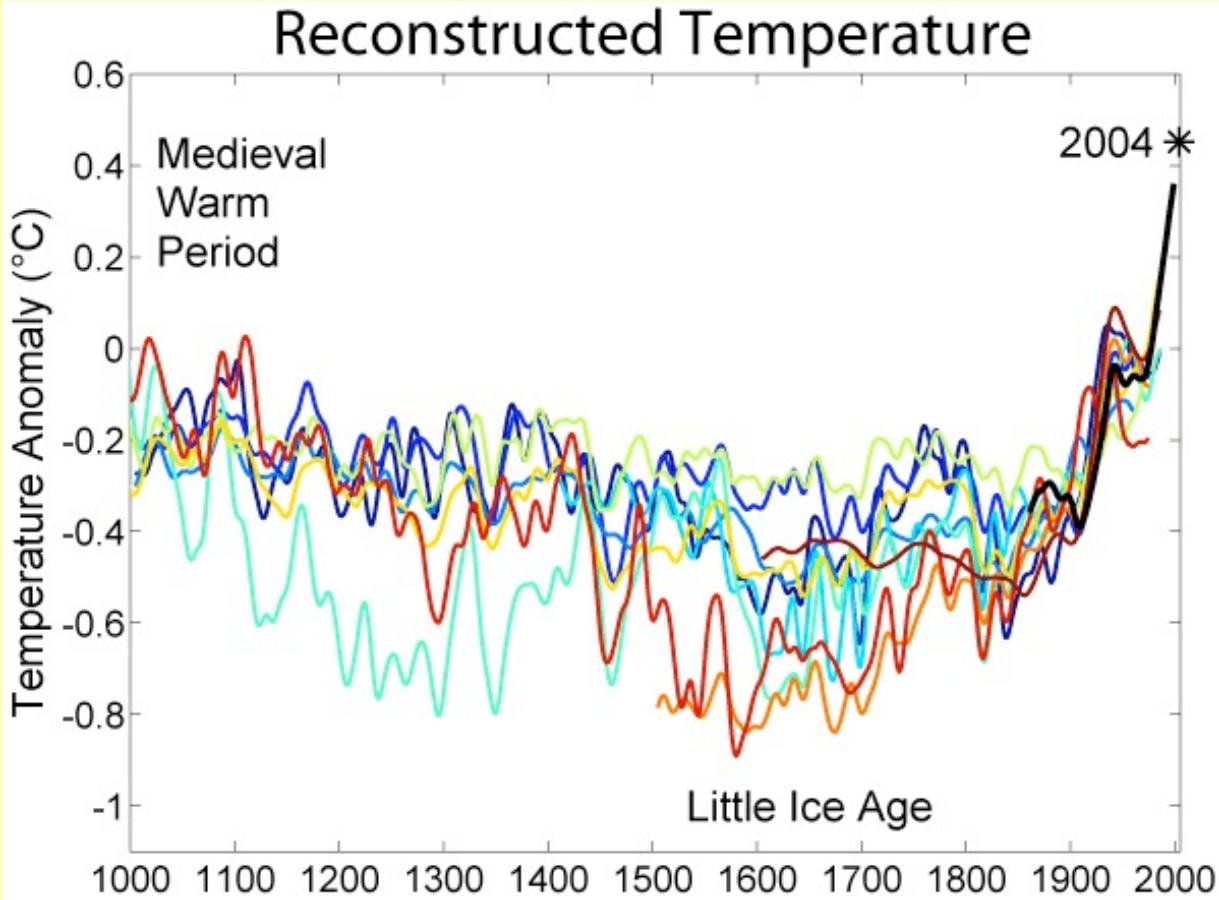
Current work with Luojun Yang, Joergen Weibull, Kaushik Basu, Avinash Dixit, others

Humans have the advantage of prediction and calculation

- We should be able to do even better than other species
- But will we?

Towardsdatascience.com

Scientific consensus is strong on many core environmental issues



Robert Rohde, for [Global Warming Art]

But adequate action to address them has been lacking

- Primary limitations to solutions not scientific knowledge, but rather
- Willingness of people and governments to commit to the common good
- And to cooperate in finding solutions that benefit all

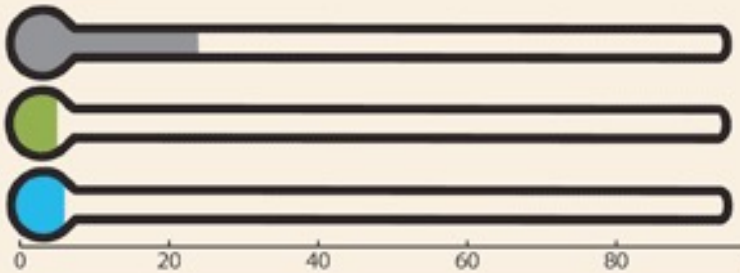
www.edie.net

ATTITUDES TOWARD CLIMATE CHANGE

RFF

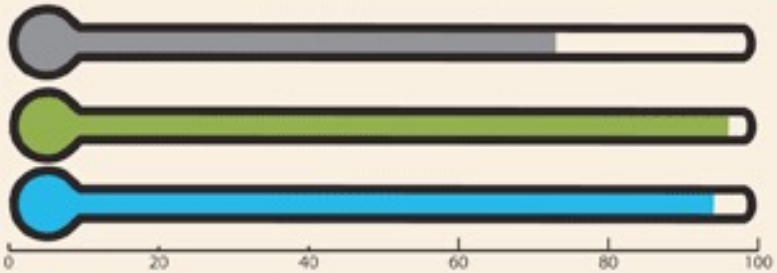
A Multiple Country Study

The temperature has not increased globally.



U.S. 24% CHINA 5% SWEDEN 6%

Humans have affected the temperature increase.



U.S. 73% CHINA 96% SWEDEN 94%

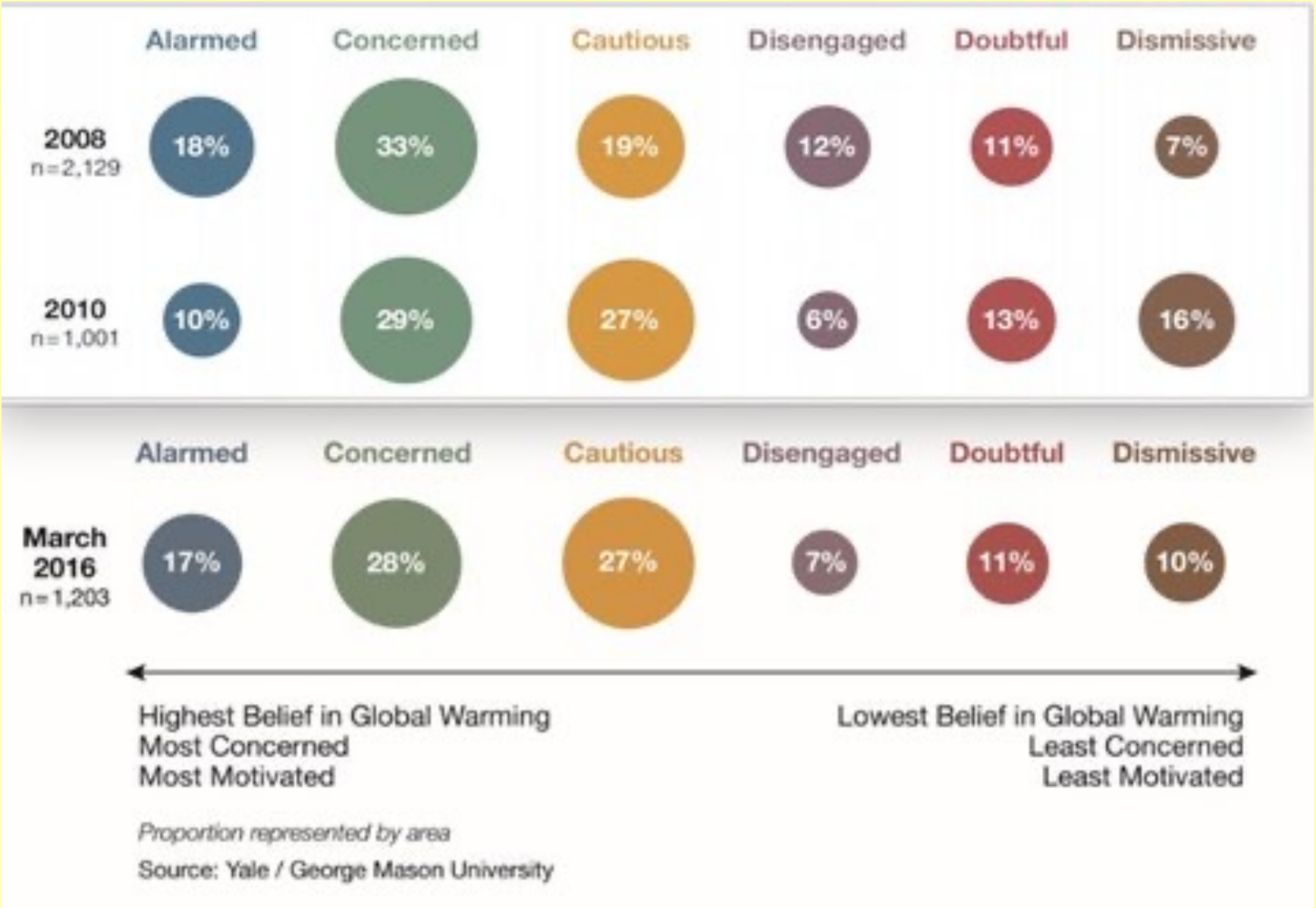
We cannot do anything to stop climate change.

U.S. 17%
CHINA 10%
SWEDEN 6%

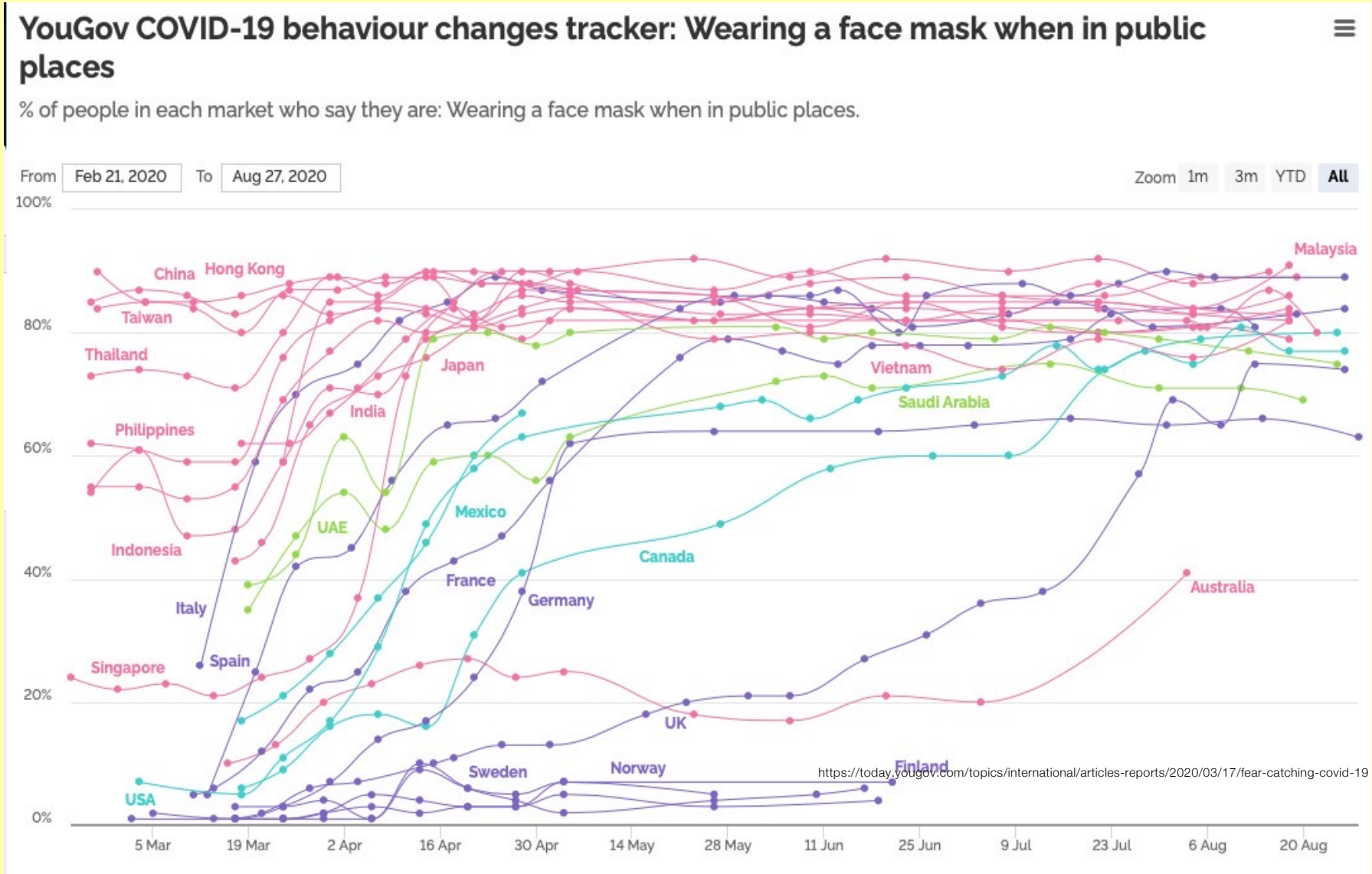
We can stop climate change.

U.S. 11%
CHINA 9%
SWEDEN 12%

rff.org


Alarmed
Concerned
Cautious
Disengaged
Doubtful
Dismissive
2008
n=2,129
18%
33%
19%
12%
11%
7%
2010
n=1,001
10%
29%
27%
6%
13%
16%
Alarmed
Concerned
Cautious
Disengaged
Doubtful
Dismissive
March 2016
n=1,203
17%
28%
27%
7%
11%
10%
Highest Belief in Global Warming
Most Concerned
Most Motivated
Lowest Belief in Global Warming
Least Concerned
Least Motivated
Proportion represented by area
Source: Yale / George Mason University

Cultural and Political Influences are Crucial



Current work with Luojun Yang, Joergen Weibull, Kaushik Basu, Avinash Dixit, others

Social norms are key

COLLECTIVE ACTION

Social norms as solutions

Policies may influence large-scale behavioral tipping

By **Karine Nyborg, John M. Anderies, Astrid Dannenberg, Therese Lindahl, Caroline Schill, Maja Schlüter, W. Neil Adger, Kenneth J. Arrow, Scott Barrett, Stephen Carpenter, F. Stuart Chapin III, Anne-Sophie Crépin, Gretchen Daily, Paul Ehrlich, Carl Folke, Wander Jager, Nils Kautsky, Simon A. Levin, Ole Jacob Madsen, Stephen Polasky, Marten Scheffer, Brian Walker, Elke U. Weber, James Wilen, Anastasios Xepapadeas, Aart de Zeeuw**

Climate change, biodiversity loss, antibiotic resistance, and other global challenges pose major collective action problems: A group benefits from a certain action, but no individual has sufficient incentive to act alone. Formal institutions, e.g., laws and treaties, have helped address issues like ozone depletion, lead pollution, and acid rain. However, cooperation (*1*). Solutions can be specific to context (e.g., small-scale irrigated rice paddies in Nepal) and local in nature. Yet social norms can affect behavior on larger scales, e.g., cessation of smoking in public places (*2*, *3*), abandonment of foot-binding in China (*4*), and changed fertility norms (*4*)—all striking large-scale transformations of social (dis)approval and behavior.

to understanding social norm changes (*6*). Here, we try to integrate these views.

IS THERE A TIPPING POINT?

For vicious and virtuous behavioral cycles to arise, people must be more willing to choose a behavior the more widespread it is. The tipping point is where a vicious cycle turns into a virtuous one, or vice versa. Social, economic, and technical factors often invoke a need for people to coordinate their behavior. Striking cases are provided by network externalities, in which a good's value to the individual increases with the frequency of others consuming that same type of good. For example, if few own electric cars, charging stations are rare and few will buy electric cars; if most cars are electric, gas stations are rare, and few buy gas-fueled cars.

Similar coordination benefits occur in social life. Diet variation across countries cannot be fully explained by prices, incomes, and nutrition content (*7*); it appears that other forces, like norms, are involved. Differing diets make cooking shared meals cumbersome. If people tend to prefer the foods they are used to, sticking to the most common diet is convenient. The availability and quality of particular foods in stores and restaurants may increase with demand. Hence, if a less meat-intensive diet became the norm, individuals might conform partly owing to social pressure or a wish to be environmentally friendly; but a primary motive may simply be to enjoy pleasant and convenient joint meals.

When behavior is easily observable (e.g., smoking), social sanctioning can create tipping points. If norm followers sanction norm violators, the social sanctioning of violators increases as the share of followers grows (*2*). Other mechanisms inducing people to act like others include conditional cooperation—an often observed willingness to cooperate more when others cooperate

Social norms can change rapidly

- Attitudes towards
  - Foot binding
  - Smoking in public places
  - Racial equality
  - Gender equality
  - Climate change
  - Pandemic?

http://message.snopes.com

Open access, freely available online

Essay

The Evolution of Norms

Paul R. Ehrlich, Simon A. Levin*

Over the past century and a half, we have made enormous progress in assembling a coherent picture of genetic evolution—that is, changes in the pools of genetic information possessed by populations, the genetic differentiation of populations (speciation) (see summaries in [1,2]), and the application of that understanding to the physical evolution of *Homo sapiens* and its forebears ([3]; e.g., [4,5]). But human beings, in addition to being products of biological evolution, are—vastly more than any other organisms—also products of a process of "cultural evolution." Cultural evolution consists of changes in the nongenetic information stored in brains, stories, songs, books, computer disks, and the like. Despite some important first steps, no integrated picture of the process of cultural evolution that has the explanatory power of the theory of genetic evolution has yet emerged.

Much of the effort to examine cultural evolution has focused on interactions of the genetic and cultural processes (e.g., [6], see also references in [7]). This focus, however, provides a sometimes misleading perspective, since most of the behavior of our species that is of interest to policy makers is a product of the portion of cultural evolution [8] that occurs so rapidly that genetic change is irrelevant. There is a long-recognized need both to understand the process of human cultural evolution per se and to find ways of altering its course (an operation in which institutions as diverse as schools, prisons, and governments have long been engaged). In a world threatened by weapons of mass destruction and escalating environmental deterioration, the need to change our behavior to avoid a global collapse [9] has become urgent. A clear understanding of how cultural changes interact with individual actions is central to informing democratically and humanely guided efforts to influence cultural evolution. While most of the effort to understand that evolution has come from the social sciences, biologists have also struggled with the issue (e.g., p. 285 of [10], [11–16], and p. 62 of [17]). We argue that biologists and social scientists need one another and must collectively direct more of their attention to understanding how social norms develop and change. Therefore, we offer this review of the challenge in order to emphasize its multidisciplinary dimensions and thereby to recruit a broader mixture of scientists into a more integrated effort to develop a theory of change in social norms—and, eventually, cultural evolution as a whole.

Essays articulate a specific perspective on a topic of broad interest to scientists.

What Are the Relevant Units of Culture?

Norms (within this paper understood to include conventions or customs) are representative or typical patterns and rules of behavior in a human group [18], often supported by legal or other sanctions. Those sanctions, norms in themselves, have been called "metanorms" when failure to enforce them is punished [17,19,20]. In our (liberal) usage, norms are standard or ideal behaviors "typical" of groups. Whether these indeed represent the average behaviors of individuals in the groups is an open question, and depends on levels of conformity. Conformity or nonconformity with these norms are attributes of individuals, and, of course, heterogeneity in those attributes is important to how norms evolve. Norms and metanorms provide a cultural "stickiness" (p. 10 of [21]) or viscosity that can help sustain adaptive behavior and retard detrimental changes, but that equally can inhibit the introduction and spread of beneficial ones. It is in altering normative attitudes that changes can be implemented.

Here, we review the daunting problem of understanding how norms change, discuss some basic issues, argue that progress will depend on the development of a comprehensive quantitative theory of the initiation and spread of norms (and ultimately all elements of culture), and introduce some preliminary models that examine the spread of norms in space or on social networks. Most models of complex systems are meant to extract signal from noise, suppressing extraneous detail and thereby allowing an examination of the influence of the dominant forces that drive the dynamics of pattern and process. To this end, models necessarily introduce some extreme simplifying assumptions.

Early attempts to model cultural evolution have searched for parallels of the population genetic models used to analyze genetic evolution. A popular analogy, both tempting and facile, has been that there are cultural analogues of genes, termed "memes" [22,23], which function as replicable cultural units. Memes can be ideas, behaviors, patterns, units of information, and so on. But the differences between genes and memes makes the analogy inappropriate, and "memetics" has not led to real understanding of cultural evolution. Genes are relatively stable, mutating rarely, and those changes that do occur usually result in nonfunctional products. In contrast, memes are extremely mutable, often transforming considerably with each transmission. Among humans, genes can only pass unidirectionally from

Citation: Ehrlich PR, Levin SA (2005) The evolution of norms. PLoS Biol 3(6): e194.

Paul R. Ehrlich is with the Department of Biological Sciences, Stanford University (Stanford, California, United States of America). Simon A. Levin is with the Department of Ecology and Evolutionary Biology, Princeton University (Princeton, New Jersey, United States of America).

*To whom correspondence should be addressed. E-mail: slevin@princeton.edu

DOI: 10.1371/journal.pbio.0030194

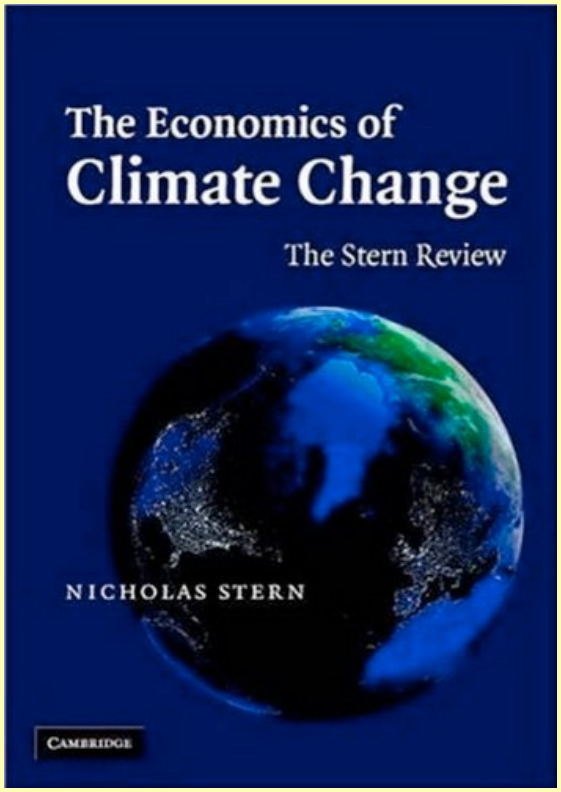
The central issues are issues of behavior and culture

- Intergenerational and intragenerational equity
- Public goods and common pool resources
- Cooperation in the Commons
- Social norms and institutions
- Leadership and developing consensus

http://message.snopes.com

Equity:
We discount

- The future



www.elements4health.com

We discount

- The future
- The interests of others

info.acoustiblok.com

How do we protect ourselves, others and future generations against the consequences of our overuse of resources?

https://i.ytimg.com/vi/ifrHogDujXw/maxresdefault.jpg

Can cooperation be extended to the global level?

https://timedotcom.files.wordpress.com/2018/06/

Ostrom: Climate change

ANNALS OF ECONOMICS AND FINANCE **15-1**, 97–134 (2014)

A Polycentric Approach for Coping with Climate Change

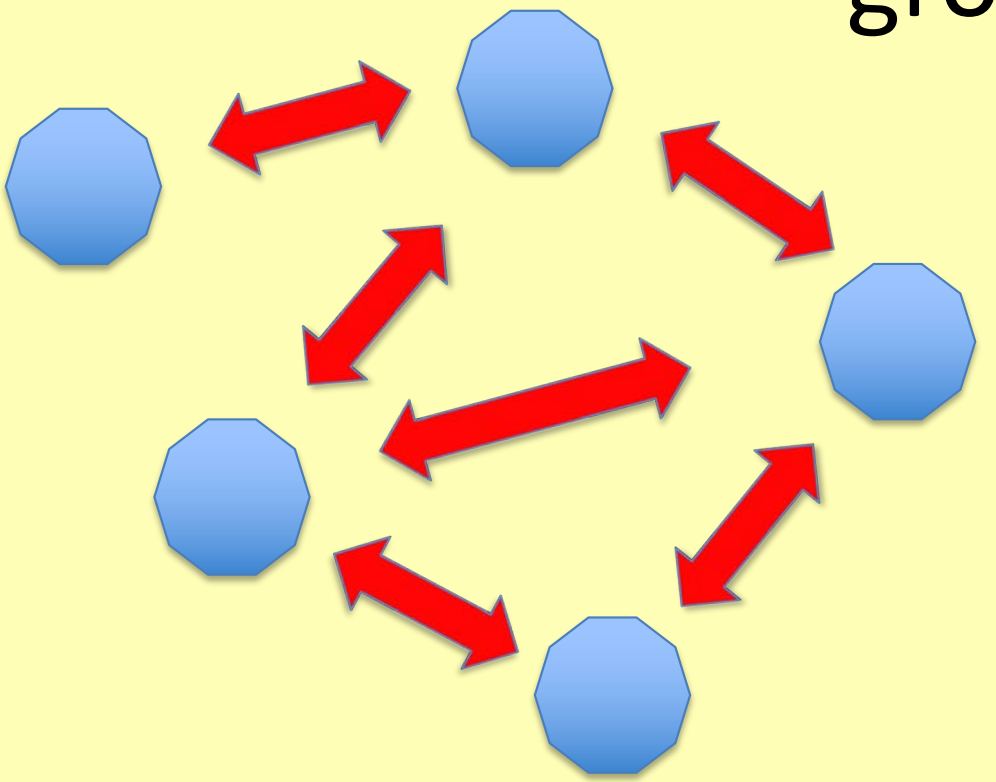
Elinor Ostrom

Indiana University

This paper proposes an alternative approach to addressing the complex problems of climate change caused by greenhouse gas emissions. The author, who won the 2009 Nobel Prize in Economic Sciences, argues that single policies adopted only at a global scale are unlikely to generate sufficient trust among citizens and firms so that collective action can take place in a comprehensive and transparent manner that will effectively reduce global warming. Furthermore, simply recommending a single governmental unit to solve global collective action problems is inherently weak because of free-rider problems. For example, the Carbon Development Mechanism (CDM) can be 'gamed' in

Tilman-Dixit- Levin Prosociality and multiple groups

Theoretical Ecology



Localized Pro-Social Preferences, Public Goods and Common-Pool Resources

Andrew Tilman, Avinash Dixit, and Simon Levin

June 11, 2018

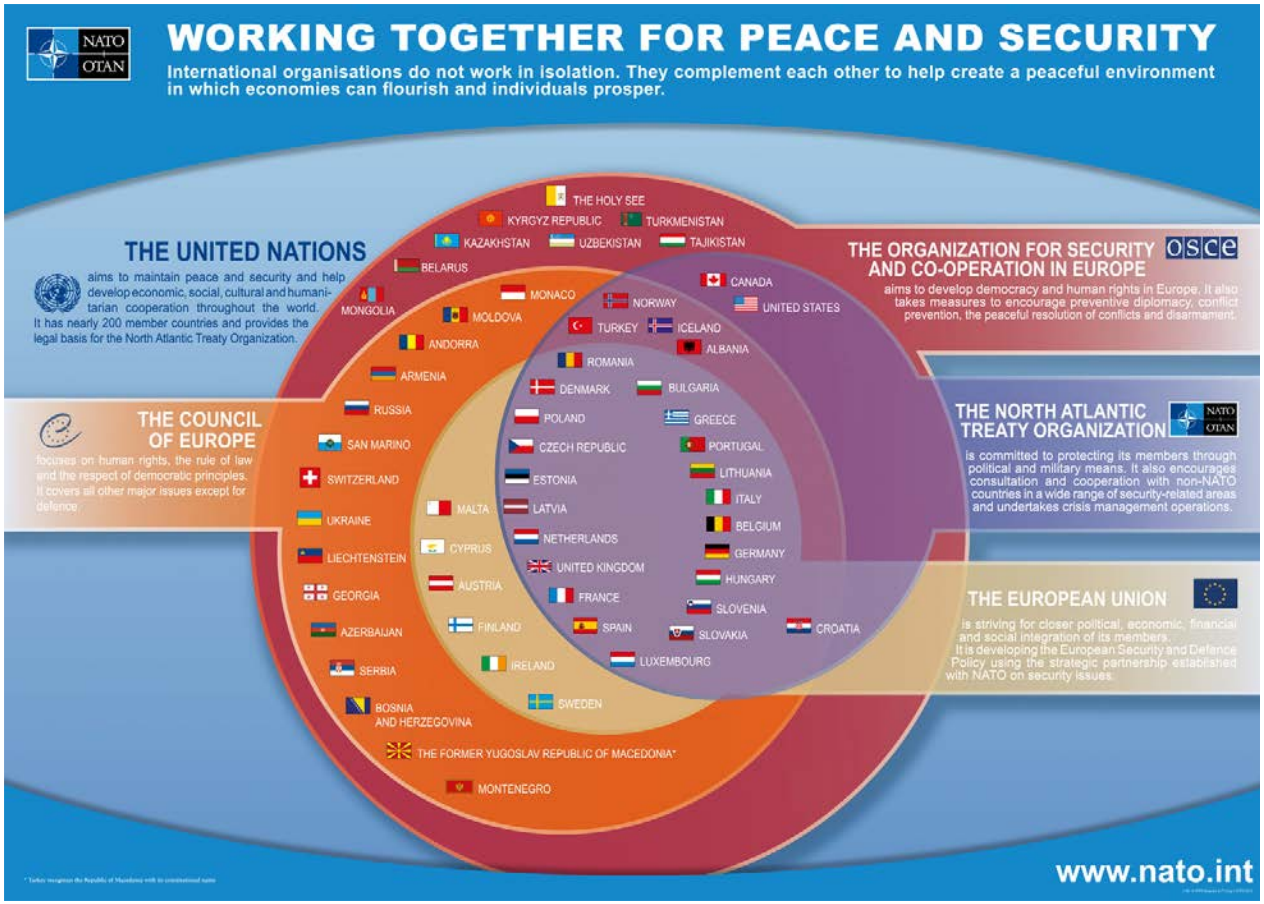
Abstract

The presence of pro-social preferences is thought to reduce significantly the difficulty of solving our societal collective action problems such as providing public goods (or reducing public bads). However, pro-sociality is often limited to members of an in-group. We present a general theoretical model where society is split into subgroups and people care more about the welfare of others within their own subgroup than they do about others. Additionally, individual contributions to the public good spill over and benefit members in each group to some degree. We then consider special cases of our general model under which we can examine the consequences of localized pro-sociality for the economic outcomes of society as a whole. We find that relative public-good provision can be either a concave or a convex function of the level of pro-sociality. The former arises when public and private efforts are poor substitutes, and in that case even low levels of pro-sociality can lead to public-goods provision near the social optimum.

1 Introduction and motivation

As the world becomes more interconnected, we increasingly are faced with problems of the Commons and their governance (Hardin, 1968; Ostrom, 1990; Levin, 1999). Individuals and nations withdraw water, fish and other resources from a finite pool; overuse of antibiotics erodes their effectiveness (Smith et al., 2005); and the emission of pollutants and greenhouse gases fouls the atmosphere. In most such situations, individual incentives are insufficient to restrain usage of finite resources and sustain public goods in the Commons; governments must find ways to change the incentive structure to overcome the tendency to overexploit. The task may be easier in smaller societies, where pro-social preferences may play a greater

Nations have interlocking memberships



Incomplete cooperation and co-benefits: Deepening climate cooperation with a proliferation of small agreements

Phillip M. Hannam[a,1], Vítor V. Vasconcelos[b,c,d], Simon A. Levin[d,e,f], Jorge M. Pacheco[g,b,h]

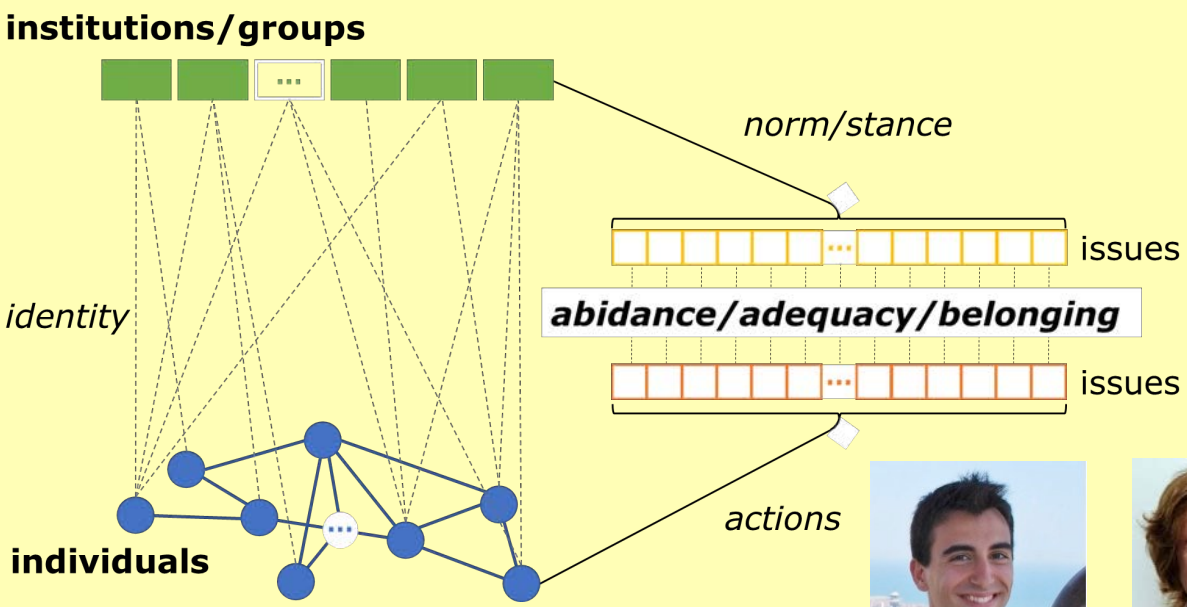
Climatic Change

www.princeton.edu

https://pt.linkedin.com

http://www.cienciahoje.pt

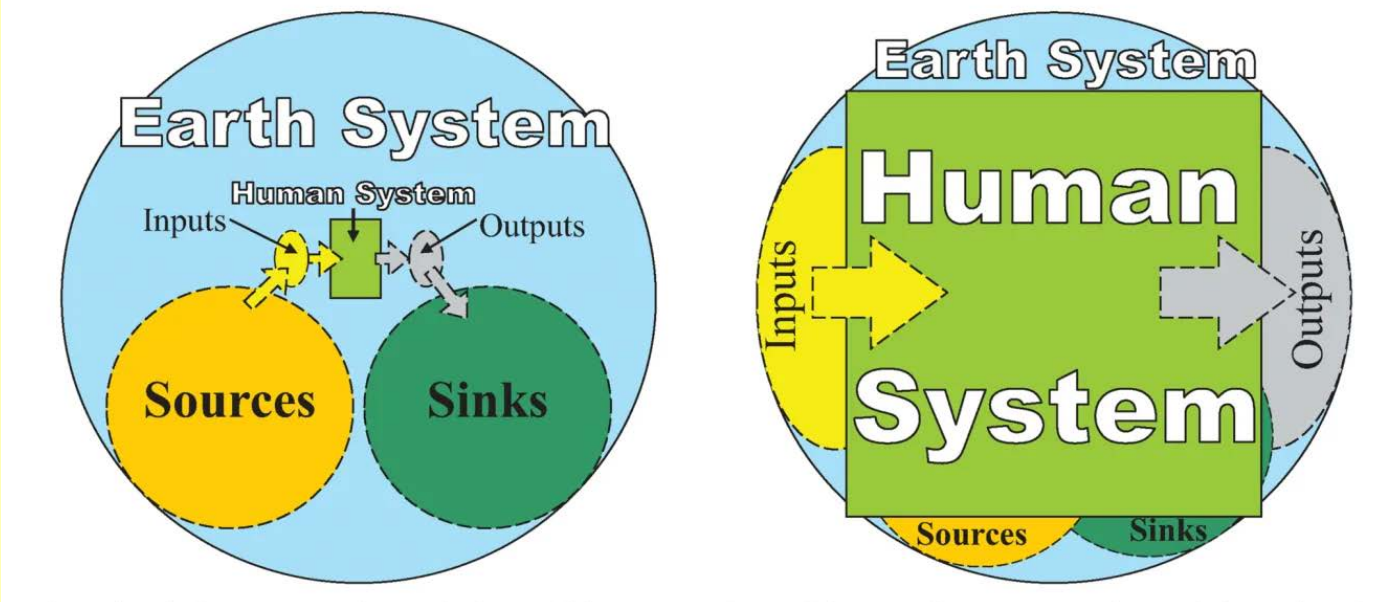
DECARBONIZATION



National Science Foundation
WHERE DISCOVERIES BEGIN

Directorate for Geosciences (/dir/index.jsp?org=GEO)

Dynamics of Integrated Socio-Environmental Systems (DISES)



Blog.greenplanetmanagement.org

Conclusions

- Public goods and common pool resource problems represent fundamental challenges in economics and in evolutionary biology
- Collective action can emerge from local interactions
- Multiple scales: Collective decisions can impose “mutual coercion, mutually agreed upon”
- Linking these is key to understanding the management of the Commons

Can cooperation be extended to the global level?

http://www.c2es.org/international/2015-agreement

Emergence of cooperation within groups is often for the benefit of conflict with *other* groups

http://www.twcenter.net/forums/showthread.
php?284308-RTR-AAR-Alexander-Reborn-A-Makedonian-AAR

In the global commons, there is no "other"

Walt Kelly

Understanding how to achieve international cooperation is at the core of achieving sustainability in dealing with our common enemy: environmental degradation

…so that we can achieve a sustainable future for our children and grandchildren

Thank you

Carole Levin