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Does Society Need Altruists?
Coevolution of General Trust and Social Intelligence

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Abstract

Most social scientists, especially economists, believe that altruists do not exist because they cannot survive exploitation by egoists. An agent-based model demonstrates, however, that altruists can survive natural selection if society comprises four types of individuals: altruists, reciprocal altruists, egoists and reciprocal egoists. These individuals are characterized by different combinations of two phenotypes: general trust and social intelligence. In a society of four types of individuals, coevolution of general trust and social intelligence will emerge. Coevolution constitutes a new mechanism of the emergence of cooperation. If coevolution is strong, altruists will be able to survive and help society evolve into a high-trust and high-growth society. Without altruists, coevolution does not work and society fails to grow. Thus society needs altruists.

Keywords: coevolution, altruism, cooperation, general trust, social intelligence, natural selection, agent-based model, simulation, social dilemma, open society, strong and weak reciprocity.

Ⅰ. Introduction

Social scientists generally dismiss altruism. In particular, most economists deny the existence of altruists. The main reason for their dismissal is the proposition that altruists will be exploited by egoists and therefore will not survive the test of natural selection.[1)] Given this proposition, social scientists can go about modeling a society on the assumption that all human beings are selfish; they do not need to consider the possible effects of altruists on the workings and performance of society. However, using an agent-based model, this paper will argue that the proposition is not generally true. The model will demonstrate that, in spite of exploitation by egoists, altruists can not only survive but also help society evolve into a high-trust and high-growth society.

Does society need altruists to survive and prosper? According to the standard economic theory, the answer is no. The market economy works extremely well without any altruists. Indeed egoists will suffice for the economy to bring about a socially optimal outcome. To state it more precisely, the market economy can achieve a Pareto-optimal outcome with self-interest maximizing individuals under the standard conditions of perfect competition, complete markets, perfect information, and no externality. This is the most important proposition in economic theory and thus justifiably called the "first fundamental theorem of welfare economics."[2)]

Our society, however, is more than an economy. We face social problems of which economic problems are a subset. Moreover the essential characteristic of social problems is *externality*: one's best action and its payoffs depend

1) In a mixed population of altruists and egoists, egoists have a higher payoff (fitness) than altruists. Therefore natural selection continuously reduces the share of altruists in the population until they are extinct. See Nowak (2006).

2) See Debreu (1959), Arrow and Hahn (1971).

on the actions of others and their frequencies in the population. Therefore the "first fundamental theorem" does not generally hold in society. Indeed coordination failures are ubiquitous. Consider the Social Dilemma (the n-person Prisoner's Dilemma) that captures the essential structure of many social problems we face in the real world. In the Social Dilemma (SD) game, egoists will fall into an inferior Nash equilibrium and, once fallen, they cannot get out of it. In other words the society of egoists will fail to resolve the SD problem and get stuck with an inferior social outcome. In this way the SD represents a typical social problem that cannot be resolved by the society of egoists acting alone.

The aim of the paper is to demonstrate that altruists can exist and will critically affect the workings and performance of society. The paper presents an agent-based simulation model of a two-dimensional lattice society with mobile heterogeneous individuals. The society consists of four types of individuals: altruists, reciprocal altruists, egoists, and reciprocal egoists. They are characterized by different combinations of two phenotypes: general trust and social intelligence. Initially they are randomly distributed throughout society. They interact with each other and play a multi-person repeated SD game as they move around society. As individuals interact with each other, they accumulate payoffs from playing the repeated SD game. The average payoffs (incomes) of each individual over time measure the degree of his fitness in the society. Their aggregation measures the overall performance (output) of the society.

The method of agent-based simulation modeling allows us to *generate* social phenomena from micro-specifications. The simulation model demonstrates that a certain set of micro-specifications is *sufficient* to generate the macro-phenomena under investigation. Every realization of an agent-based simulation is a strictly logical *deduction* even if it involves the generation of a pseudo-random number series. If a social outcome based on interactions of individual agents turns out to be contradictory to our expectation, it will often offer a powerful and counter-intuitive insight. Such insight deepens our understanding of the macro-phenomena.[3] Therefore the methodology of agent-based simulation modeling is congruent with Karl Popper's logic of scientific discovery: that is, the growth of scientific knowledge by means of conjectures and refutations.[4]

Simulations will demonstrate that altruists can survive exploitation by egoists, and that the *coevolution* of altruists and reciprocal altruists helps society evolve into a high-trust and high-growth society.[5] It implies that altruists can emerge from evolution by means of natural selection, despite the fact that they will be exploited by egoists. Simulations will also demonstrate that too many altruists breed egoists in society. Nevertheless, a surprising general proposition will emerge that everybody in society including altruists can survive and prosper over time if there is a large share of altruists in population. Conversely society will fail to grow if it starts with a small share of altruists. Thus society needs altruists after all.

These results will emerge from the mechanism of *coevolution (symbiosis)* between different types of individuals. Coevolution is different from the five mechanisms of cooperation (direct reciprocity, indirect reciprocity, spatial

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3) See Epstein and Axtell (1996) and Epstein (2006) for *Generative Social Science,* which shows the essential role of agent-based simulation modeling in the social sciences.

4) Suppose that people believe in proposition B about a macro-phenomenon. If we can demonstrate that a set of micro-specifications A is sufficient to reject B (that is, $A \rightarrow \neg B$), then our attempt to reject B under condition A will deepen our understanding of the macro-phenomenon under investigation. The repeated process of such conjectures and refutations is the essential method of scientific investigation. See Popper (1959, 1963).

5) Zak and Knack (2001) have also indicated a positive correlation between trust and economic growth, using a different model.

selection, group selection and kin selection) that depend on *assortative (correlated) interactions* among the same type of individuals. The five mechanisms each produce a condition very similar to Hamilton's rule because they represent five different ways to generate assortative interactions.[6] The literature includes Hamilton (1964, 1975), Trivers (1971), Axelrod (1984), Ellison (1993), Nowak and May (1994), Eshel, Samuelson, and Shaked (1998), Alger and Weibull (2010). Nowak (2006, 2012) gives a good survey of the literature. In contrast, this paper will study the effects of *coevolution* of different types of individuals or different *phenotypes* (general trust and social intelligence) on the survival of altruists, the emergence of cooperation, and the performance of society.

There is a critical difference between *coevolution* and *assortative interactions* as a mechanism of cooperation because they should produce two different kinds of society. Coevolution generates a symbiotic relationship between different types of individuals while assortative interactions generate a group of the same type of individuals. Thus I conjecture that a society based on coevolution will be characterized by open cooperation, while a society based on assortative interactions will be characterized by inward cooperation and outward hostility (supported by morality, territoriality, xenophobia, and ethnocentrism). In other words, coevolution between different types of individuals will give rise to an *open society* while assortative interactions among the same type of individuals will give rise to a *closed society*.[7] This conjecture implies the special importance of *coevolution*

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6) See Nowak (2006, 2012).

7) The open versus closed society is a concept originally suggested by Bergson (1935, 1977) in relation to the open versus closed morality. The concept has been further developed by Popper (1945). According to Bergson (1977: p.266–7), "The closed society is that whose members hold together, caring nothing for the rest of humanity, ... The open society is the society which is deemed in principle to

as a mechanism of the emergence of cooperation.

Ⅱ. The Structure of Society

This section models a society of four types of mobile individuals: that is, altruists, reciprocal altruists, egoists, and reciprocal egoists. They form a (n x n) lattice society and interact with each other in a repeated SD game. The society is a square (n x n) lattice with wraparound boundary conditions. There is a population density p of individuals occupying lattice sites and the remaining sites are empty. Individuals move into a neighboring site subject to the excluded volume constraint.

Let us define the four types of individuals (strategies) in a repeated SD game as follows:

(1) An *altruist* is defined as a person who always chooses cooperation.

(2) A *reciprocal altruist* is defined as a Tit-for-Tat strategist who chooses cooperation in the first interaction with a person and then behaves in the same manner as that person did in the previous encounter.[8)]

(3) An *egoist* is defined as a person who always chooses defect.

(4) A *reciprocal egoist* is defined as a Tit-for-Tat strategist who chooses defect in the first interaction with a person and then behaves in the same manner as that person did in the previous encounter.

The SD game has the following payoff matrix:

	C	D
C	(R, R)	(S, T)
D	(T, S)	(P, P)

embrace all humanity."

8) See Trivers (1971, 2009) for reciprocal altruism.

where C stands for cooperation and D stands for defect or sharking. We also assume that T > R > P > S and R > (T + S) / 2 > P, which imply the following order of socially desirable outcomes: (R + R) > (S + T) > (P + P). We may interpret the payoffs as individual incomes and the sums of two payoffs as the joint output of two individuals.

Social psychology defines *general trust* as the default expectation of another person's trustworthiness in the absence of information about that person.[9] Thus, if an individual chooses cooperation in the first interaction with a stranger, we may call the individual a person with high general trust or a high-trust person. Accordingly *altruistic people* (altruists and reciprocal altruists) are high-trust people while *egoistic peopl*e (egoists and reciprocal egoists) are low-trust people. In this way, we can distinguish between altruistic and egoistic people by general trust.

Given the close relationship between *altruism* and *trust* in the repeated SD game, we can distinguish between a high and low trust society as follows: A *high-trust* society is a society in which the fitness (average payoffs) of altruistic people (altruists and reciprocal altruists) with high general trust increases over time. On the other hand, a *low-trust* society is a society in which the fitness (average payoffs) of egoistic people (egoists and reciprocal altruists) with low general trust increases over time.

We define *social intelligence* as the cognitive capability to judge another person's trustworthiness based on the information (memory) about that person. According to this definition, reciprocal altruists differ from altruists by the possession of social intelligence. An altruist is a person with low social intelligence because he lacks cognitive capability either to memorize his past

9) See Berg, et al. (1995), Burks, et al. (2003) and Yamagishi (2011) for general trust, social intelligence, and their coevolution. Zak (2011) shows that *oxytocin* is associated with human empathy, moral sentiments, and general trust.

experience or to make the best use of the memory. The same argument applies to the difference between egoists and reciprocal egoists. In short, altruists and egoists have low social intelligence while reciprocal altruists and reciprocal egoists have high social intelligence.

Consequently the four types of individuals can be characterized by different combinations of two *basic phenotypes* (general trust and social intelligence) as follows: An *altruist* is a person with high general trust and low social intelligence. A *reciprocal altruist* is a person with high general trust and high social intelligence. An *egoist* is a person with low general trust and low social intelligence. A *reciprocal egoist* is a person with low general trust and high social intelligence.

Finally we define a *high-growth* society as an economy in which the total or average payoffs (output) of members of the society increases faster through the interactions over time. In other words, the economy will grow if all members of society can achieve more cooperation and less defection in the multi-person repeated SD game. In contrast, the economy will decline and the society will evolve into extinction if the total or average payoffs (output) become minus and eventually exhaust some initial resources.

Ⅲ. The Agent-Based Model

The society evolves over a succession of time steps. Each time step consists of three consecutive sub-steps: the first sub-step involves the decision of the individuals about how to act (cooperation or defect), the second sub-step involves interactions between individuals (executing the decision, updating memory and payoffs), and the third sub-step involves the movement of the individuals (moving onto one of the so-called vonNeumann neighborhoods subject to the excluded volume constraint).

On the first sub-step, each individual decides how to behave in a face-to-face interaction with another person. Each individual faces a vonNeumann neighborhood consisting of north, east, south, and west. The individual who meets another person face-to-face chooses either cooperation or defection according to the strategy of his type (altruist, reciprocal altruist, egoist, or reciprocal egoist), which is based on his personal memory of the history of the other person. The individual may or may not continue his interaction with the same person in the next time step, depending on the movement outcome of the third sub-step.

On the second sub-step, each individual executes his decision in the interaction with the other person. After the action, the individual receives a payoff based on the outcome of the SD game. He updates his payoffs and memorizes how the other person has behaved. Each of reciprocal altruists and reciprocal egoists keeps a record of the past behavior of every individual with whom he has interacted.

On the third sub-step, we allow each individual on the lattice society to move to the nearest neighbor site he is facing and choose a new random direction to face, with the following exceptions: (1) if the nearest neighbor site is occupied by another individual, the individual remains in place and chooses a new random direction to face, and (2) if the site is empty but is faced by one or more other individuals on its nearest neighbor sites, the individual remains in place and chooses a new random direction to face.

The above process is repeated t time steps. It determines the evolutionary process and the aggregate outcome of the society which consists of the four different types of individuals: altruists, reciprocal altruists, egoists, and reciprocal egoists.

The simulation parameters of the agent-based model are as follows (see Appendix):

[n, p, {A, RA, E, RE}, {P, R, S, T}, t] = [50, 0.7, {A, RA, E, RE}, {−1, 1, −2, 2}, 1500]

where n = the lattice size of the society
p = the population density of the (n x n) lattice society
A = the initial share of altruists randomly distributed in the lattice society
RA = the initial share of reciprocal altruists
E = the initial share of egoists
RE = the initial share of reciprocal egoists
t = the time steps of simulation

I have chosen the payoff matrix {P, R, S, T} = {−1, 1, −2, 2} so that payoffs are symmetric and their average is zero. In this way, in an evenly and randomly mixed population, the expected value of total payoffs of society is zero. This gives the yardstick to which the performance of societies with different population compositions should be compared.

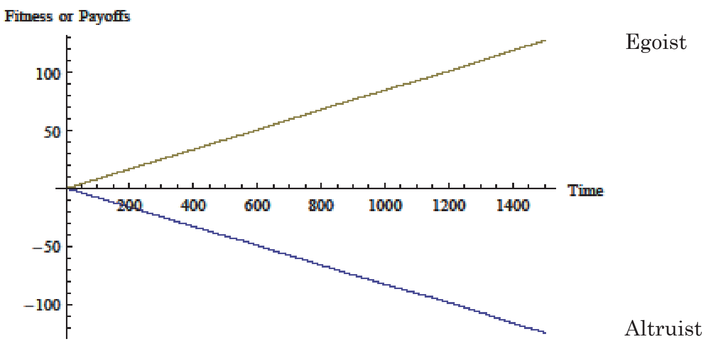
Ⅳ. Simulation Results

This section lists main simulation results. It turns out that simulation results are sensitive to the initial share of altruists in the population. The main message of the agent-based simulation model is the following: If the initial share of altruists is large enough, society will evolve into a high-trust and high-growth society. However, if the initial share of altruists is small, society will evolve into a low-trust society and it fails to grow. Thus society needs altruists. Listed below are general propositions that have emerged from the simulation model.

1. Altruists Cannot Survive Exploitation by Egoists in the Society of Altruists and Egoists

The proposition that altruists cannot survive exploitation by egoists is true if altruists and egoists are the only individuals in the population (Chart 1). In this special case the fitness (payoffs) of altruists is minus; they will be eliminated through natural selection. Thus social scientists may be able to justifiably assume that altruists do not exist in society and that all human beings are self-interest maximizing agents.

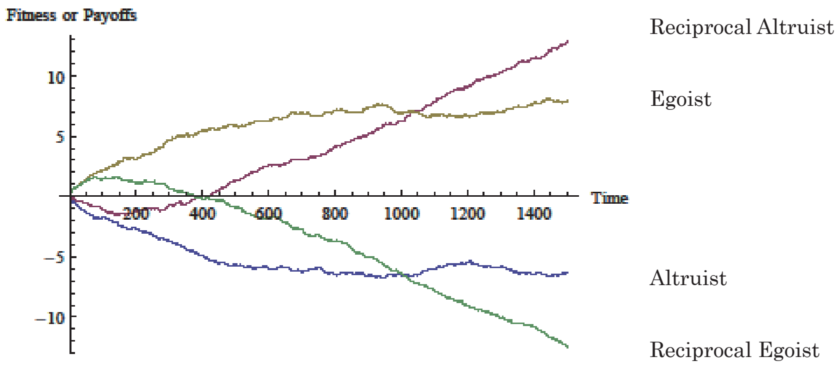
Chart 1 Altruists Cannot Survive: {A, RA, E, RE} = {0.50, 0.00, 0.50, 0.00}



2. Altruists May Be Able to Survive in a Diverse Society with Different Types of Individuals

With the equal shares of four types of individuals in the population, egoistic people (egoists and reciprocal egoists) will gain initially from exploiting altruistic people (altruists and reciprocal altruists). After the early stages, however, the combined payoffs (outputs) of altruistic people start to rise while those of egoistic people start to fall (Chart 2). Altruists will still be exploited by egoists. The losses of altruists are limited, however, so that they may be able to survive over time. That is, in a diverse society with different types of individuals, social scientists can no longer simply assume that all

Chart 2 Altruists Can Survive: {A, RA, E, RE} = {0.25, 0.25, 0.25, 0.25}

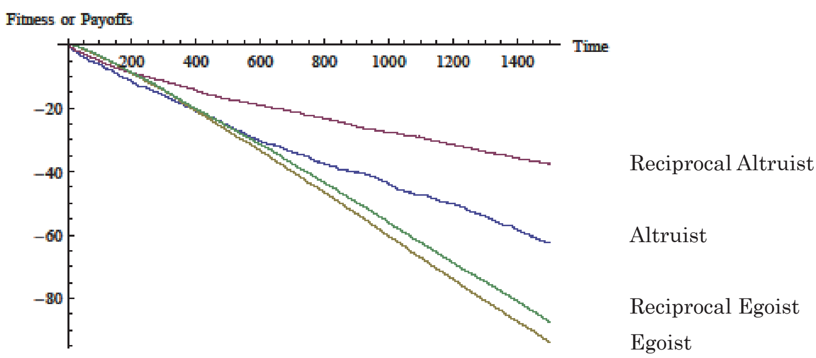


human beings are selfish, and that altruists do not exist. To study social phenomena, social scientists must take into account the possible effects of altruists on the workings and performance of society.

3. Society Cannot Survive without Enough Altruists

With a smaller share of altruists in the population, the society performs very poorly and its economy (total output or payoffs) continues to decline (Chart 3). The society cannot sustain itself and will evolve into extinction.

Chart 3 Society Cannot Survive: {A, RA, E, RE} = {0.1, 0.3, 0.3, 0.3}

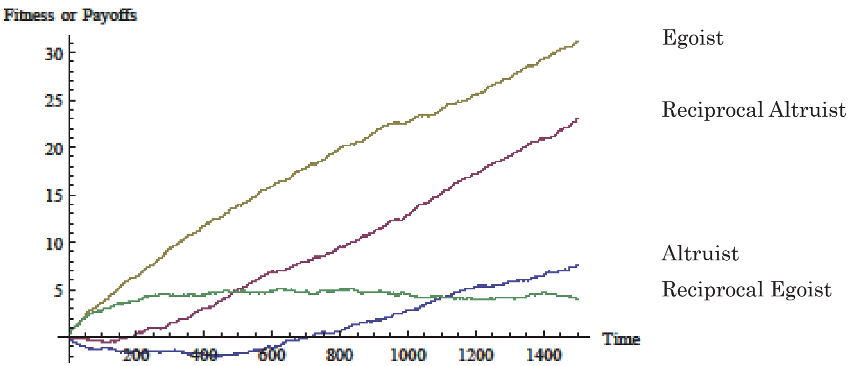


In this case the society needs more altruists in order to survive. This proposition may be compared with the first fundamental theorem of welfare economics which assumes no externality. The externality associated with social interactions can lead to a completely different macro-outcome from the optimal state that the first fundamental theorem predicts.

4. With a Large Share of Altruists, Coevolution of Altruists and Reciprocal Altruists Begins to Emerge

If the share of altruists is slightly larger than others in the population, both egoists and reciprocal altruists will gain the most (Chart 4). Altruists will not become extinct, however, as their fitness (payoffs) starts rising after an initial fall. Altruists will increasingly benefit from interactions with reciprocal altruists after the initial fall. The coevolution of altruists and reciprocal altruists starts to emerge. In this case, society will grow as the total outputs (payoffs) of its members rise.

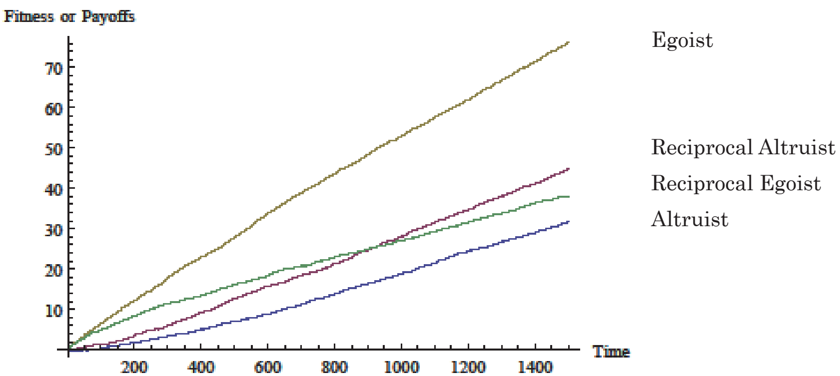
Chart 4 Emergence of Coevolution: {A, RA, E, RE} = {0.28, 0.24, 0.24, 0.24}



5. Altruists Help Everybody Coexist and Help Society Grow

A higher share of altruists in the population benefits everybody in the society (Chart 5). Egoists benefit from the exploitation of altruists while reciprocal altruists gain from mutually beneficial interactions with altruists. Society will grow as the total payoffs of its members rise. Altruists will survive and help society evolve into a prosperous society. Moreover all four types of individuals can coexist and their fitness (payoffs) will continue to rise. Society can sustain itself with all members benefiting on average from mutual interactions over time. Altruists, reciprocal altruists, egoists, and reciprocal egoists all coexist in a mixed society. This is a counter-intuitive case in that, although an egoist has the highest fitness and an altruist the lowest, the fitness (average payoffs) of all members of society, including altruists, continues to rise.

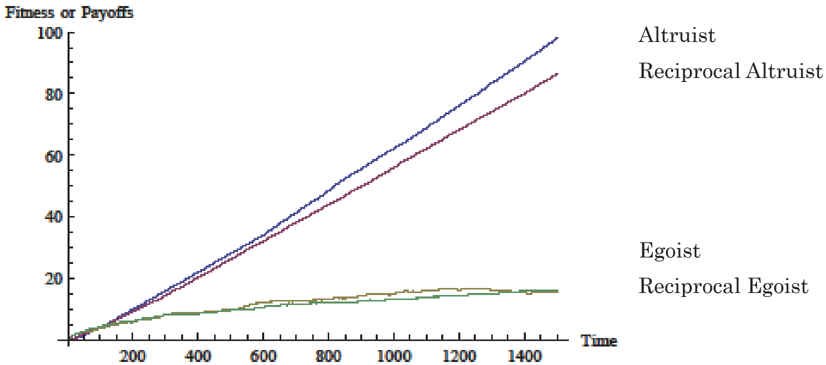
Chart 5 Altruists Help Society: {A, RA, E, RE}＝{0.34, 0.22, 0.22, 0.22}



6. Strong Coevolution Gives Rise to a High-Trust and High-Growth Society

If the initial share of altruistic people (altruists and reciprocal altruists) is larger than that of egoistic people (egoists and reciprocal egoists), the gains from the coevolution of altruists and reciprocal altruists start to dominate the loss due to the exploitation by egoistic people. Although altruistic people increasingly dominate egoistic people in fitness and payoffs, both coexist in society and the total output rises over time (Chart 6). In this case, coevolution helps society evolve into a high-trust and high-growth society.

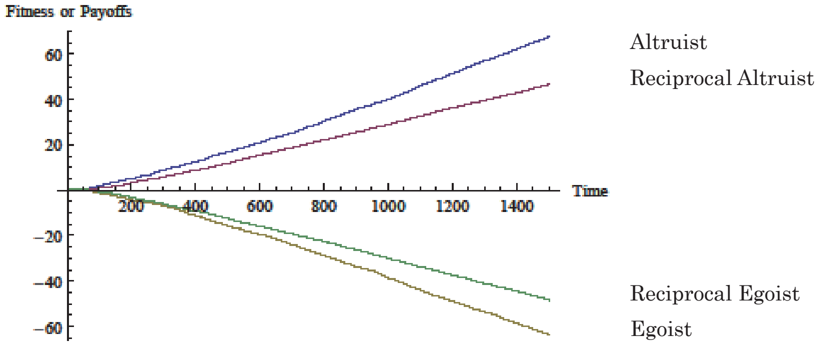
Chart 6 A High-Trust and High-Growth Society: {A, RA, E, RE} = {0.2, 0.4, 0.1, 0.3}



7. Social Intelligence Differentiates between Altruists and Egoists, But Does Not Help Society Prosper Unless Combined with General Trust

With the same share of altruistic and egoistic people, a higher share of individuals with social intelligence leads to a divergence in fitness between altruistic and egoistic people (Chart 7). Strong coevolution of altruists and reciprocal altruists emerges. However, social intelligence by itself does not make society grow (unless it is combined with high general trust); the total output of society remains approximately zero over time. This is a case of social evolution leading to a high-trust and low-growth society. It indicates the critical importance of general trust for achieving the prosperity of society.

Chart 7 Social Intelligence Differentiates: {A, RA, E, RE} = {0.1, 0.4, 0.1, 0.4}



8. Social Intelligence Reverses the Fitness of Altruists and Egoists

Now compare Chart 7 with Chart 1. They show a striking contrast: that is, social intelligence reverses the fitness of altruists and egoists. In the society of altruists and egoists, egoists will have a positive fitness whereas altruists a negative fitness (Chart 1). In contrast, in the society of four types of individuals, altruists will have a positive fitness whereas egoists a negative fitness (Chart 7). They demonstrate that an introduction of a large share of individuals with social intelligence will make the signs of fitness of altruists and egoists completely reversed. This is an excellent example of the general proposition that the fitness of an individual depends on the social environment, in particular, the existence of other types of individuals and their frequencies in the population.

9. Further Implications

The simulation results contain further implications. First, reciprocal egoists generally perform poorly while reciprocal altruists perform better.[10] In most

10) This result is analogous to the finding of Axelrod (1984) who reported that the

cases, reciprocal egoists keep losing potential payoffs; they suffer from lost opportunities because they start with a non-cooperative behavior in social interactions. They are too cautious and less trusting of other people. The initial non-cooperative behavior that results from low general trust incurs large opportunities costs, from which reciprocal egoists can never recover. Thus the combination of low general trust and high social intelligence seems to have a low adaptive value. Reciprocal egoists tend to be worse off in a society that consists of altruists, reciprocal altruists, egoists, and reciprocal egoists. In short, social intelligence may become detrimental to fitness if it is combined with low general trust.

Second, both general trust and social intelligence play a critical role for the evolution of society into a high-trust and high-growth society. General trust helps society grow while social intelligence helps society differentiate between altruistic and egoistic people. Entering general trust and social intelligence into the multi-person repeated SD game radically changes its internal workings and macro-outcomes over time. Without social intelligence (reciprocal altruists), altruists cannot survive and are thus unable to generate cooperation and contribute to the prosperity of society. Without general trust (altruists), social intelligence cannot make society grow; it can only help society distinguish between altruistic and egoistic people. In short, the coevolution of general trust and social intelligence is the key to the survival of altruists and the prosperity of society.

Third, the agent-based simulation model demonstrates that "altruistic punishment" is not a necessary condition for cooperation.[11] Cooperation will

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Tit-for-Tat strategy (reciprocal altruist) had performed better than any other strategies.

11) "Altruistic punishment" is a behavior in which individuals punish others (defectors, free-riders, non-cooperators) at a cost to themselves in order to

emerge and sustain itself if strong coevolution emerges between altruists and reciprocal altruists. Most debates over the "weak" versus "strong" reciprocity has centered on the question of whether "altruistic punishment" actually exists or is necessary for the emergence and sustainment of cooperation.[12] Simulation results have shown, however, that what is needed for cooperation is not punishment, but the coevolution of general trust and social intelligence. It is only when the strength of coevolution is lacking that some mechanism of punishment (social institutions) may become necessary for maintaining cooperation.

Ⅴ. Conclusion

This paper has demonstrated that altruists can exist and will critically affect the workings and performance of society. Therefore social scientists can no longer ignore altruists and simply assume that all human beings are self-interest maximizing agents. They will derive wrong conclusions from the mistaken assumption. The agent-based model has identified a set of sufficient micro-specifications for the emergence of cooperation in society. Cooperation has emerged from the coevolution between different types of individuals, which constitutes a new mechanism of cooperation. The agent-based model has demonstrated that the coevolution of altruists and reciprocal altruists can help altruists survive, and generate a social evolution that gives rise to a high-trust and high-growth society.

The main reason altruists can survive in spite of exploitation by egoists

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advance the fitness of a larger group. See Fehr and Gächter (2002) and Pederson, Kurzban, and McCullough (2013) for evidence for and against the existence of "altruistic punishment" in humans. It was called "spite" by Hamilton (1970).

12) See, for example, Guala (2012), Bowles and Gintis (2011) and Trivers (2007).

is that they interact with different types of individuals other than egoists. Some interactions such as those with egoists and reciprocal egoists may be harmful to altruists, but others such as those with reciprocal altruists may be beneficial. If beneficial interactions dominate harmful ones, altruists can survive and increase their fitness (payoffs or outputs) over time. The gains from coevolution of altruistic people can overcome the losses due to exploitation by egoistic people. In short, the adaptive value of an altruist depends on the social environment, in particular, the existence of other types of individuals and their frequencies in the population.

In falsifying the proposition that altruists cannot survive the test of natural selection, this paper has simultaneously resolved another related controversy over the "weak" versus "strong" reciprocity. Advocates of "strong" reciprocity argue that altruists with a strong innate disposition to cooperate even at a net cost do exist. Advocates of "weak" reciprocity argue that only reciprocal altruists with a rational tit-for-tat strategy can exist. The controversy is resolved because both altruists and reciprocal altruists can coexist if the power of coevolution is strong enough to overcome exploitations by egoistic people. In fact, society needs *both* altruists and reciprocal altruists to generate strong coevolution so that it can sustain itself and prosper.

The coevolution of altruists and reciprocal altruists can be explained at a deeper level by the coevolution of two phenotypes: general trust and social intelligence. An altruist is a person with high general trust while a reciprocal altruist is a person with high general trust and high social intelligence. Therefore the coevolution of altruists and reciprocal altruists is essentially equivalent to that of general trust and social intelligence. The two expressions, one at the level of strategies and the other at the level of phenotypes, are therefore interchangeable. We have explained the emergence of a high-trust and high-growth society through the coevolution of altruists and reciprocal altruists. Equally, at the deeper level of phenotypes, we can explain the emergence of a cooperative and prosperous society through the coevolution of general trust and social intelligence.

This paper has emphasized that *coevolution* between different types of individuals is fundamentally different from the five mechanisms of cooperation (direct reciprocity, indirect reciprocity, spatial selection, group selection and kin selection) that depend on assortative interactions. Because assortative interactions arise from the *same* type of individuals, they are likely to produce inward cooperation and outward hostility, which will be strengthened by such *social institutions* as morality, gossip, shame, ostracism, shunning, bullying, punishment, expulsion, territoriality, nepotism, xenophobia, and ethnocentrism. Because cooperation is the basic organizing principle of human society, I have conjectured that coevolution will be the mechanism of cooperation for the *open society* and assortative interactions for the *closed society*. This conjecture points to a new direction for future research by linking two basic mechanisms of cooperation to the two basic forms of society.

To sum up, coevolution represents a new mechanism of the emergence of cooperation. Under the coevolution of altruists and reciprocal altruists, altruists can survive the test of natural selection and help society evolve into a cooperative and prosperous society. More generally, under the coevolution of general trust and social intelligence, human cooperation will naturally emerge. Coevolution between different types of individuals may offer the best mechanism of cooperation through which our society can transform itself into an open society.

Appendix

This appendix provides the simulation program so that the reader can repeat the simulations presented in the paper. The reader can also check the robustness of simulation results and extend the program in order to discover new results. All the simulations are programed and executed using Mathematica 9. See Gaylord and D'Andria (1998) and Wellin (2013) for technical details. The program is as follows:

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doesSocietyNeedAltruists[n_, p_, {s_, t_, u_, v_}, {P_, R_, S_, T_}, q_]:= Module
[{RND, k = 0, society, behave, decide, payoff, act, walk, vonNeumann, GN}, RND :
= Random[Integer, {1, 4}];
   society = Table[Floor[p + Random[]], {n}, {n}] /. 1 :> {++k, Floor[1 + v + u +
Random[]]} /. {{m_, 1} :> {RND, m, Table[{}, {k}], 0, Floor[1 + t/(s + t) + Random[]]},
{m_, 2} :> {RND, m, Table[{}, {k}], 0, Floor[3 + v/(v + u) + Random[]]}};
   behave[1, _] = 1;
   behave[2, {___, 0}] = 0;
   behave[2, _] = 1;
   behave[3, _] = 0;
   behave[4, {___, 1}] = 1;
   behave[4, _] = 0;
   decide[{1, name1_, lis1_, res1_, strat1_}, {3, name3_, _, _, _}, _, _, _]:= {1, name1, lis1,
res1, behave[strat1, lis1[[name3]]], strat1};
   decide[{3, name3_, lis3_, res3_, strat3_}, _, _, {1, name1_, _, _, _}, _]:= {3, name3, lis3,
res3, behave[strat3, lis3[[name1]]], strat3};
   decide[{2, name2_, lis2_, res2_, strat2_}, _, {4, name4_, _, _, _}, _, _]:= {2, name2, lis2,
res2, behave[strat2, lis2[[name4]]], strat2};
   decide[{4, name4_, lis4_, res4_, strat4_}, _, _, _, {2, name2_, _, _, _}]:= {4, name4, lis4,
```

```
res4, behave[strat4, lis4[[name2]]], strat4};
  decide[z_, _, _, _, _]:= z;
  payoff[1, 1] = R;
  payoff[0, 1] = T;
  payoff[1, 0] = S;
  payoff[0, 0] = P;
  act[{1, name1_, lis1_, res1_, behave1_, strat1_}, {3, name3_, _, _, behave3_, _}, _,
_, _]:= {1, name1, ReplacePart[lis1, Join[lis1[[name3]], {behave3}], name3], res1 +
payoff[behave1, behave3], strat1};
  act[{3, name3_, lis3_, res3_, behave3_, strat3_}, _, _, {1, name1_, _, _, behave1_, _},
_]:= {3, name3, ReplacePart[lis3, Join[lis3[[name1]], {behave1}], name1], res3 +
payoff[behave3, behave1], strat3};
  act[{2, name2_, lis2_, res2_, behave2_, strat2_}, _, {4, name4_, _, _, behave4_, _}, _,
_]:= {2, name2, ReplacePart[lis2, Join[lis2[[name4]], {behave4}], name4], res2 +
payoff[behave2, behave4], strat2};
  act[{4, name4_, lis4_, res4_, behave4_, strat4_}, _, _, _, {2, name2_, _, _, behave2_,
_}]:= {4, name4, ReplacePart[lis4, Join[lis4[[name2]], {behave2}], name2], res4 +
payoff[behave4, behave2], strat4};
  act[z_, _, _, _, _]:= z;
  walk[{1, a___}, 0, _, _, _, {4, ___}, _, _, _, _, _, _, _]:= {RND, a};
  walk[{1, a___}, 0, _, _, _, _, _, _, {2, ___}, _, _, _, _]:= {RND, a};
  walk[{1, a___}, 0, _, _, _, _, _, _, _, {3, ___}, _, _, _]:= {RND, a};
  walk[{1, a___}, 0, _, _, _, _, _, _, _, _, _, _, _]:= 0;
  walk[{2, a___}, _, 0, _, _, {3, ___}, _, _, _, _, _, _, _]:= {RND, a};
  walk[{2, a___}, _, 0, _, _, _, {1, ___}, _, _, _, _, _, _]:= {RND, a};
  walk[{2, a___}, _, 0, _, _, _, _, _, _, _, {4, ___}, _, _]:= {RND, a};
  walk[{2, a___}, _, 0, _, _, _, _, _, _, _, _, _, _]:= 0;
  walk[{3, a___}, _, _, 0, _, _, {4, ___}, _, _, _, _, _, _]:= {RND, a};
```

```
walk[{3, a___}, _, _, 0, _, _, _, {2, ___}, _, _, _, _, _]:= {RND, a};
walk[{3, a___}, _, _, 0, _, _, _, _, _, _, _, {1, ___}, _]:= {RND, a};
walk[{3, a___}, _, _, 0, _, _, _, _, _, _, _, _, _]:= 0;
walk[{4, a___}, _, _, _, 0, _, _, {1, ___}, _, _, _, _, _]:= {RND, a};
walk[{4, a___}, _, _, _, 0, _, _, _, {3, ___}, _, _, _, _]:= {RND, a};
walk[{4, a___}, _, _, _, 0, _, _, _, _, _, _, _, {2, ___}]:= {RND, a};
walk[{4, a___}, _, _, _, 0, _, _, _, _, _, _, _, _]:= 0;
walk[{_, a___}, _, _, _, _, _, _, _, _, _, _, _, _]:= {RND, a};
walk[0, {3, ___}, {4, ___}, _, _, _, _, _, _, _, _, _, _]:= 0;
walk[0, {3, ___}, _, {1, ___}, _, _, _, _, _, _, _, _, _]:= 0;
walk[0, {3, ___}, _, _, {2, ___}, _, _, _, _, _, _, _, _]:= 0;
walk[0, _, {4, ___}, {1, ___}, _, _, _, _, _, _, _, _, _]:= 0;
walk[0, _, {4, ___}, _, {2, ___}, _, _, _, _, _, _, _, _]:= 0;
walk[0, _, _, {1, ___}, {2, ___}, _, _, _, _, _, _, _, _]:= 0;
walk[0, {3, a___}, _, _, _, _, _, _, _, _, _, _, _]:= {RND, a};
walk[0, _, {4, a___}, _, _, _, _, _, _, _, _, _, _]:= {RND, a};
walk[0, _, _, {1, a___}, _, _, _, _, _, _, _, _, _]:= {RND, a};
walk[0, _, _, _, {2, a___}, _, _, _, _, _, _, _, _]:= {RND, a};
walk[0, _, _, _, _, _, _, _, _, _, _, _, _]:= 0;
vonNeumann[func_, lat_]:= MapThread[func, Map[RotateRight[lat, #] &, {{0,
0}, {1, 0}, {0, -1}, {-1, 0}, {0, 1}}], 2];
GN[func_, lat_]:= MapThread[func, Map[RotateRight[lat, #] &, {{0, 0}, {1, 0},
{0, -1}, {-1, 0}, {0, 1}, {1, -1}, {-1, -1}, {-1, 1}, {1, 1}, {2, 0}, {0, -2}, {-2, 0}, {0, 2}}], 2];
NestList[GN[walk, vonNeumann[act, vonNeumann[decide, #]]] &, society, q]]
SeedRandom[17]
results = doesSocietyNeedAltruists[50, 0.7, {A, RA, E, RE}, {-1, 1, -2, 2}, 1500];
avgPayoff[lat_, strat_]:=
 (Apply[Plus, #]/Length[#]) &[
```

```
  Cases[lat, {_, _, _, x_, strat} :> x, 2] /. {} -> {0}]
fitness =
  Table[Map[avgPayoff[#, i] &, results], {i, 1, 4}];
ListPlot[{Sequence @@ fitness},
 Joined -> True,
 PlotLegends -> {"Altruist", "Reciprocal Altruist", "Egoist", "Reciprocal Egoist"},
 AxesLabel -> {"Time", " Fitness or Payoffs "}]
```

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