

**Social Cognitive Learning
and the Evolutionary Mechanisms in Institutions**

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I. Introduction

The idea that many institutions in human societies have emerged unintentionally through a spontaneous coordination of the individuals' behavior on some common patterns or rules of conduct is as old as Scottish Enlightenment. It was clearly spelled out in Mandeville, Hume, Ferguson, and Adam Smith (cf. Hayek 1967a). On the continent the idea was later associated with the newly upcoming notion of evolution.¹ On the basis of his "causal-genetic" method, Menger (1883) merged both ideas to explain institutions like money, language, custom, and law as unintended collective outcomes of social interactions. In recent times, a wave contributions has taken up the issue again from a game theoretic point of view. Institutions are conceived in an abstract way as behavioral regularities shown by the members of a population or group in their social interactions (cf., e.g., Ulmann-Margalit 1977, Schotter 1981, Sugden 1986, Witt 1989, Binmore 1994, Vromen 1995). Where, initially, focus was on the equilibrium properties of the underlying games, later contributions have emphasized the evolutionary process from which those equilibria, i.e. institutions, emerge (see Young 1998 for a survey).

This literature has helped to make impressive progress in understanding the formal properties of the evolutionary institutional process -- not least by making use of modeling tools transferred from evolutionary biology. What is still under scrutiny, however, is the material question of what the evolutionary mechanisms in human populations or groups are which produce the conjectured dynamics (and which would be the analogue to genetic mechanisms of variation and selective retention). Basically, there seem to be two lines of

¹ Though the notion of evolution is often identified with the neo-Darwinian theory of biological evolution, it is in fact older than Darwin's theory. It had already been formulated, and even terms like 'genetic' been created, by the beginning of the 19th century with the school of thought in the humanities and social sciences associated with names like Herder, Savigny and Wilhelm von Humboldt; cf. Hayek (1967b).

arguments. Some scholars favor a more or less direct recourse to genetic mechanisms.² Other scholars focus on mechanisms residing in human behavior, particular learning and cognition.³

The present paper contributes to the second line of argument. It will be argued that institutions (of the spontaneously emerging kind) result from evolutionary mechanisms established, on the one hand, by social cognitive learning processes taking place in groups of interacting humans and, on the other hand, by competition between such groups. The behavioral regularities considered to constitute institutions in the game-theoretic perspective are thus claimed to “evolve”, though evolution is not understood here in the sense of the Darwinian theory of natural selection (or any analogy to it) -- which means that institutions are not taken as an expression of our genes. However, the two suggested evolutionary mechanisms jointly produce effects which are similar to those described as “speciation effect” and “group selection” in the Darwinian literature.

The paper proceeds as follows. The theory of social cognitive learning on which the substance of present argument rests is briefly outlined in section II. To illustrate how behavioral regularities can be conjectured to emerge from social cognitive learning a game-theoretic setting is introduced in section III. Assuming that the true challenge for explaining the spontaneous emergence of institutions is the case in which they help overcoming social dilemmas, a simple extension of the prisoners’ dilemma game will be used. Section IV

² Cf., e.g., Güth and Yaari (1992), Hansson and Stuart (1992), Binmore (1997), (1998, chap.2). These contributions have a good deal in common with sociobiology where the game-theoretic approach to evolution originated (with the intention to explain altruism as a rule of conduct among animals, see Trivers (1971)).

³ Cf., e.g., Witt (1996), Schlicht (1998), Rizello and Truvani (1998). Which of the two lines of research will be more fruitful heavily depends not least on how important phylogenetic influences (as suggested by sociobiology) relative to ontogenetic influences (as suggested by cognitive behavioral theory) are in determining human behavior in social interactions -- a question that is still open.

discusses the implications of social cognitive learning in that context, including the repercussions of institutions on the further fate of the groups or populations in which they emerge. Section V offers some conclusions.

II. Social Cognitive Learning and Its Behavioral Underpinnings

The working hypothesis in this paper is that the spontaneous emergence and change of institutions, defined here as behavioral regularities in social interactions, is based on learning. This implies an individualistic approach but, as will be explained, a non-reductionist one because of the (tacitly) socially shared behavioral elements which result from, and subsequently frame, learning within groups of intensely interacting individuals. The point of departure in the present argumentation is an ontological premise: human perception, information processing capacity, and thought are far from being perfect and of unconstrained power.⁴ Already in conceiving the choices that can be made, the individual agent is therefore unable to grasp the actual multitude of alternatives and their consequences. What is being considered in every moment of time is only a fraction of what could, in principle, be imagined to be possible series of choices that unfold into the future. Because of the very same limitations, even learning takes place selectively and results in partial, provisional, and highly idiosyncratic knowledge of what is relevant for evaluating the alternatives of action in a

⁴ This premise relates to, but is not identical with, the notion of “bounded rationality” going back to Simon (1956). The latter notion portrays human perception and information processing as adaptive. Like in the standard decision theoretic framework, the state of the world and the decision alternatives it offers are supposed to be given, but the non-olympic faculties of the human cognitive apparatus prevent the decision maker from more than recognizing the alternatives and their consequences in an approximate, imperfect and/or myopic fashion. What is ignored in such an interpretation is the imaginative capacity of our brain which enables humans to (selectively) think up and pursue new alternatives of action rather than merely to adapt more or less well to given ones. Indicative of this difference, a preferred example in the early explications of “bounded rationality” has been the game of chess (see Simon 1967). This game poses decision problems in which, because of the nature of its rules, the set of alternatives, though already quite complex, is indeed given. In the present context, the difference between adaptation to, and creative expansion of, the state of the world matters, because man-made evolution is not fully intelligible in terms of merely adaptive human faculties.

given, historical place and time. Given that choices are made between alternatives that have been perceived, it seems only natural, therefore, to ask to what extent, and in which way, individual choice may be biased by selective knowledge acquisition and recall.

According to cognitive theory (see, e.g., Anderson 1990, chap. 3) a key role is played here by selective attention processes which, in turn, depend on three features of information offered to the mental system: first, sensory strength and frequency of that information; second, recognition of similarities or an identity with already known elements/patterns (for this purpose relevant patterns stored in the memory must be activated by appropriate cues on an associative basis); third the 'validity' of recognized similarities/identities in the sense of an association with earlier rewarding, neutral, or aversive experience. The cues instrumental for memorizing patterns and identifying incoming information also occur in larger and more complex systems called frames. These are employed in classificatory and associative activities and allow knowledge to be represented in a meaningful way (Anderson 1990, ch.5). Indeed, the huge associative capacity of human long term memory is able to create, from a limited number of probably genetically coded cues, longer and longer associative chains with increasingly more complex sets of frames. The development starts in individual socialization, in the learning of language, and in the identification of meaning, and may well extend far beyond these early phases into a life-long process.

As a result, the human mind always 'frames' information with already existing interpretation patterns (knowledge representations) even on the level of deliberate reasoning and thus produces mental attitudes of a sometimes fairly rigid nature. The necessarily selective cognitive development, although entirely internal to the individual and in this sense subjective, is molded in social processes of communication with other agents (Bandura 1986, ch.2). In the communication process individuals tend to develop similarities in interpretation patterns and frames. Communication circles have an 'agenda setting' effect which modifies,

in a self-reinforcing way which is similar for all, the frequency with which particular information is (at the expense of potentially rivaling information) exchanged and attracts attention. In addition, people who belong to the same social environment are exposed to the same symbolic representation of knowledge which often suggests similar mental attitudes. Among other things they therefore tend to agree more closely as to what are rewarding or aversive experiences.

The subjectivity of the individuals' unique cognitive history notwithstanding, these common features mean that a tacit, collectively shared bias can occur within groups of intensely interacting individuals, a bias which influences what actions are selectively perceived, and what disregarded, as alternatives. This bias thus shapes the actually perceived choice set. Common beliefs and interpretations emerge tacitly and similarly for the agents in the population. The agents do not normally recognize the fact that, due to their selective information processing, potential choices go unnoticed, because the cognitive system that processes some information cannot at the same time reflect on how that information is processed. As a consequence, the tacit commonalities in perceiving and framing information are neither consciously chosen nor at disposition for deliberate design. Although a precondition of reasoning, they cannot in their entirety themselves be subject to reason. They originate from innate limitations of the human cognitive system, but, as they develop in a process of social cognitive learning, they are not in themselves genetically determined, that is, a matter of instinct, but a basic element of (population-specific) culture.

As already mentioned, the hypothesis of a population-specific, tacit influence on individual behavior on the cognitive level renders the individualistic perspective non-reductionist. Social cognitive theory of course focuses on the level of the individual. But, the individual is not viewed as an entirely autonomously acting agent as in the reductionist interpretation (sometimes implicitly adopted by arguing on the basis of the representative

individual). The autonomy assumption may, or may not, be justified as far as the act of choosing from a feasible choice set - as perceived - is concerned. It is untenable, it is claimed here, once it comes to the question of how people arrive at what they perceive. Tacit commonalities in perceiving alternatives, and disregarding others, emerge as a matter of fact in groups of intensely communicating individuals -- despite all otherwise undeniable subjective diversity. Tacitly socially shared constraints in the perception of alternatives can be expected to result in some similarities of individual behavior. There is little motivation to deviate from such similarities as long as the individually experienced consequences of similar behavior do not systematically diverge (what is unlikely to happen given the coherence also of response patterns implied by the similarities in the framing of information and in mental attitudes). For this reason, individual learning from experience should not in principle cancel out the effects of tacit cognitive commonalities.

In fact, in the form of observational learning the process of learning from behavioral feed back has itself a social dimension that reinforces, and creates further, cognitive commonalities (cf. Bandura 1986, chap. 2 for the following). The actions chosen by the agents and the consequences they experience can usually be observed by others. Those others can thus expand their knowledge about actions and consequences without bearing the risks and costs of experimenting themselves. Inferences with respect to success or failure of certain actions may appear the more meaningful to those agents, the more significant the respective actions of others qualify as models of behavior -- which they do when occurring in a sufficiently stereotypical and persistent manner. Because of their vicarious character, models of behavior displayed by some agent(s) and the associated consequences are likely to attract significant attention within a communicating population. This, in turn, ensures that they become an important part of collectively shared knowledge, i.e. develop into "social models" which, as commonplace patterns of behavior are abstracted from the particular historical contingencies of their emergence.

Since, in a given population, observational learning focuses on much the same social models, it tends to produce correlated results. New and old members of a population identify the behavioral regularity of a social model and its contingencies and consequences more easily than the underlying cognitive commonalities in the subjective sphere (and so does the scientific observer). For this reason, generalizations tend to be made on the phenomenological level: the more frequently some social model occurs in a population, the more convincingly it may be inferred to represent a “rule of conduct” Hayek (1967), even where no such rule has ever been stated, let alone the actual causation been understood. Once stated as a rule, people may feel confirmed in their biased, selective views that have led to the emergence of the social model. Serving as a basis for deliberate instruction and learning within the population, rules of conduct thus reinforce, in their easily grasped form, the cognitive commonalities from which they have originated.

Despite the emergence of tacit cognitive commonalities there is, of course, room for significant subjective variety of knowledge and interpretations even among members of groups with intense internal communication. This variety results from the particularities of the individual learning histories, from ambiguities in associating meaning with one and the same information, or simply from misconceptions. Variety is increased further by the imaginative capacity which people have in varying degrees, allowing for systematic reflection and inventive thinking. These faculties can change decision problems with a given set of alternatives into situations in which the agents not only make decisions but -- probably much more momentous -- create choices and actions not perceived earlier and widen their knowledge experimentally. Accordingly, with shifting constraints on the actions perceived, the individual gains the potential to innovate, i.e. to deviate from earlier patterns of behavior. Once new actions are indeed tried out, subjective variety triggers a crucial step in the evolution of institutions. Even if individually discovered new knowledge does not

disseminate through direct communication, the differences in behavior, which have been induced by the new ideas, will convey the information indirectly: new ways of behaving created by someone are likely to be noticed by others as a deviation from previous models and rules.

The attention which this event arouses is likely to focus on the consequences experienced by the innovator. The observed vicarious success or failure on the part of the innovator allows the individuals to assess their current behavior in the light of the new opportunities without themselves having to experiment. As long as the population members at least roughly agree in their appraisal of which outcomes are more or less preferable, the innovator's vicarious reward or loss tends to, respectively, induce or inhibit corresponding behavior adjustments by imitation (Bandura 1986, ch. 7). There is, thus, a tendency for variance in behavior to erode through observational learning and imitation where the variety of behavior really matters, i.e. where it implies outcomes rewarded differently. Both tendencies, that of increasing and of decreasing behavioral variety, taken together can well stabilize the actual degree of variance within narrow bounds. At the same time, cognitive commonalities as well as behavioral regularities in the social interactions within the population -- the population-specific institutions -- may be subject to continuing change.

III. A Simple Modeling Framework

Learning within groups of intensely communicating agents induces collectively shared attitudes, it has been argued in the previous section, with respect to how, at some point of time, the agents perceive their choice sets. Depending on whether behavior which deviates from the social models of conduct implied by these attitudes is observed to lead to rewarding or penalizing consequences, these constraints tend to be strengthened or weakened, respectively, in the further process. Since the members of the populations usually determine

those consequences in their mutual interactions, the vicarious outcomes themselves hinge on what the presently prevailing social models imply as a response to deviant behavior. A mutual dependency like this lends itself to a game-theoretic modeling. In the abstract terms of game theory, a collectively shared model of conduct can be given the meaning of a stable pattern of strategies repeatedly chosen rationally -- under the existing cognitive constraints and the effects of observational learning -- i.e. of a behavioral regularity that satisfies the definition of an "institution". The question of whether an institution emerges, persists, or changes within groups, can therefore be translated into a problem of convergence of a game to a stable pattern of strategies, given the hypotheses about how the players' knowledge changes through social cognitive learning.

To strengthen the point to be made, consider a social dilemma or rationality trap situation, more precisely, a prisoners' dilemma game. The crucial question here is under what conditions 'favorable' institutions, which allow for the dilemma to be overcome, can be expected to emerge, i.e. a stable cooperative solution of the game? ⁵ Before this question can be discussed in more detail, the precise structure of the game needs to be specified. As is well known, non-cooperation or defection is the dominant strategy in the one-shot, two-person prisoners' dilemma game. A continued cooperative behavior over a sequence of one shot games would therefore incur heavy (opportunity) costs upon an agent. Under certain conditions there may, however, be a chance that those costs pay off in terms of future cooperation gains, if other players can be educated to adopt the cooperative behavior. One way of education is punishing someone's non-cooperative response to one's own offering of cooperation.

⁵ The point is easier to make for a coordination game in which the resulting institution is a "convention" (Lewis 1967), because there is no comparable rationality trap phenomenon. Different from a dilemma game, in a coordination game the 'opportunity costs' of sticking to the social model of conduct are low, if not zero, so that the emergence of institutions is compatible with standard rational choice assumptions, cf. Wärneryd (1990), Boyer and Orlean (1993), Ellison (1993), Witt (1993), Young (1993).

A simple way of modeling the punishment option ⁶ is to extend the two-person one-shot prisoners' dilemma game into a specific two-stage game as follows. For the (simultaneous) opening moves, the players can choose c (cooperation) or d (defection) as usual. As second (closing) moves, the opponents involved may or may not react to the result of their first moves. Thus, there is a kind of second stage with simultaneous moves which reflect the players' simultaneous responses to information not available to them when their choices in the opening stage had to be made. The two randomly picked players' interaction ends after the pay-offs for the second stage have been revealed to them. To keep things as simple as possible let there be just two closing moves: a (accepting the first round outcome without further action) and p (punishing the opponent). Hence, for each of the players there are altogether two choices in the opening stage and four *contingent* choices in the closing stage, i.e. eight contingent strategies per player and sixteen outcomes or combinations of moves of both players in total (see Figure 1). However, not all of them are relevant or make sense. Consider a player i who uses move c in the first stage. Then, it would appear that no opponent j has a reason to choose move p in the second stage, independent of what j 's own move in the first stage has been. ⁷

 Figure 1 about here

⁶ An alternative would be to assume a repeated game (cf. Binmore 1998, chap. 3.3) with a pair of strategies c (cooperation) and d (defection) as stage game strategies is played sequentially a large number of times, or even indefinitely, in a specific (retaliatory or non-retaliatory) sequence in the interactions of two agents i and j in the population. However, such a construction presupposes either the same two players being involved in perpetuated interactions or, for all players involved, a very substantial capacity to recognize earlier opponents and to recall their earlier choices.

⁷ This should be inferred from the very meaning of the word "punishment". However, figure 1 shows that, under these conditions, move p is also always dominated by move a for both players in the closing stage. Accordingly, the possibility of "punishing" cooperation will not be considered further here.

Table 1 summarizes all contingent strategies which may be considered relevant.⁸ Since a symmetric game has been assumed it suffices to denote them for one player. By assumption, moves are chosen simultaneously. Thus, the opponent's move in the closing stage is not yet known when the own move at that stage has to be made. The latter is therefore contingent only on the opponent's move in the opening stage. (It may also be influenced by what the opponent is expected to do, but this will be ignored for the moment.) The *outcomes* accruing to the players from the various contingent strategies are given by the sum of the *pay-offs* of the first stage and the second stage of the game. For the first stage, in familiar notation, we have the order relation $T > R > P > S$ on the pay offs of the one-shot prisoners' dilemma game, where T ("temptation") denotes the pay off for defection while opponent cooperates, R ("reward") that for mutual cooperation, P ("punishment") that for mutual defection, and S ("sucker's pay-off") that for cooperation while opponent defects.

 Table 1 about here

For the pay-offs in the second stage, the following may be assumed. While move *a* does not seem to cause additional costs, the problem with move *p* is that, as a rule, punishment incurs costs on both sides, i.e. on those who take punishing measures as well as on those being punished. To assume the least favorable case, let the costs C_p which a punishing player incurs be larger than the cost C_o which the punished opponent has to incur. Moreover, to push the argument to its limits assume that punishment causes such heavy costs that in addition to the standard order relation above the following holds:

⁸ The move in the first stage is denoted before the semicolon and the second-stage move, which is contingent on the observed first-stage move of the opponent, after the semicolon.

$$P > T - C_0 \text{ and } S > R - C_p, \text{ where } C_p > C_0. \quad (1)$$

If, for simplicity, the additional assumption $C_0 > T - S$ will be made, a complete outcome ranking is induced as given in the bottom row of Figure 1.

Another extension that seems important for discussing cultural evolution in general and the emergence of institutions in particular is to add geographical space as structuring interactions, allowing to distinguish within and between group interactions. Space as a dimension and geographical proximity as a variable may matter in several respects. First, groups often form by the very fact that, in a given neighborhood, they adopt the same institutions. Second, geographically isolated populations are likely to develop different institutions or change them along different routes -- a true analogy to the speciation effect in natural evolution -- as the immense geographical variety of languages, customs, mores, religious practices, and other cultural particularities shows. Finally, competition between human populations with, and on the basis of, different institutions has geographical connotations: in the context of human society “group selection” (differential growth of group size), if there is any, is more likely a matter of differential migration rates between groups than of differential reproductive success. Migration presupposes a spatial dimension in which separate groups can be located and some minimal form of interconnectedness between the competing groups both on the level of physical migration and on the level of information flows (which precede the individual motivation to migrate or not).

For these reasons it seems useful, to introduce geographical space and some proximity measure, at least in a rudimentary form, into the game-theoretic setup just discussed. This means to think of a set S of n agents, indexed $i = 1, \dots, n$, who are distributed over a spatial dimension. For expository convenience let n be a large but constant number. As a minimal representation assume a one-dimensional space so that the individuals can be identified by n

points on a line which, for simplicity, are assumed equidistant. To exclude bordering cases, let the line form a closed circle. Accordingly, each agent i has more or less close neighbors to the left and to the right, and the proximity of any two individuals i and j can be measured by the number of points between them. At any point of time let each member of S belong to one and only one group, and let all groups form a spatial partition of S into disjunct segments (a closed set of neighboring points) of the circle. In the limiting case, the partition comprises just one group. In fact, since the formation of competing groups is itself an essential part of societal evolution, that limiting case of a still undifferentiated population S will be invoked here as the initial condition -- a kind of hypothetical state of nature of society.

Thus, all members of S are assumed to initially be involved in a prisoners' dilemma game which is repeatedly played in pair-wise interactions with randomly matched players without recall. However, for these interactions proximity matters, in fact, it is a crucial factor for spatially separable groups to form. The probability of any two individuals i and j being matched in an interaction should therefore reasonably be assumed to decrease with the distance between i and j , and to be zero beyond an equal interaction range r to the left and to the right of each individual. Let r , $(n-1)/2 \geq r \geq 1$, be identical for all individuals (assuming n is an odd number). To strengthen the argument assume that the individuals are unable to discriminate in their interactions between members of the population -- the least favorable case for the emergence of cooperation. This means that an interaction in which individual i is involved has an equal chance of $1/2$ of occurring on either side of i . Then the probability $p_{i,j}$ of an interaction between agent i and agent j on *one* side depends on r as given by

$$p_{i,j}(r) = (r - j + 1) / r (r + 1), \quad 1 \leq j \leq r, \quad (2)$$

where for any given r , $\sum_j p_{i,j}(r) = 1/2$. Now define a neighborhood N adjacent to agent i on

one side by a segment of k points on the circle. By summing over (2) one gets

$$\Phi_k = \sum_{j=1}^k p_{i,j} = (2rk - k^2 + k) / (2r(r+1)) \quad \text{for } 1 \leq k \leq r. \quad (3)$$

with $0 < \Phi_k < 1/2$ for $1 \leq k < r$.

IV. Emergence of Institutions, Speciation Effect, and “Group Selection”

Given the modeling framework developed in the previous section we can now turn to a discussion of the emergence and change of institutions and of their repercussions on the fate of the respective groups. As has been explained, this may be considered a phenomenon of cultural evolution, i.e. a result of social cognitive learning within intensely interacting groups. Two problems may be distinguished. A first one deals with the question of what social model of behavior, or kind of behavioral regularity, or institution will emerge and survive the learning process with innovations within groups or within the entire population. The second problem concerns the formation of groups with differing institutions analogously to the speciation effect and potential differential growth processes between groups with more or less favorable institutions (“group selection”). To start with the first problem, recall the conditions of the social learning process. As the initial condition, the agents’ perception -- or common knowledge -- of contingent strategies is confined to the social models of how to behave in pair-wise interactions so far practiced in the population. Collectively shared cognitive constraints can only give rise to, and observational learning can only operate on, behavioral regularities -- social models represented by some of the contingent strategies in Table 1 -- to the extent to which they are practiced in the population.

To simplify the analysis, in the initial, homogenous state of nature of society -- no

groups having formed yet -- this strategy may be assumed the same for all members of the population, be it for genetic or cultural reasons. However, some strategy innovation may sometimes be tried somewhere by a member of the population, the 'innovator'. Since people are inclined to settle on the strategy which they can recognize as most successful among those they perceive in the population, the innovator's experiment is likely to become an object of observational learning. This means that the outcome realized with the deviant strategy becomes common knowledge and, if it is superior, the deviant strategy is recognized as a successful social model to be adopted. The outcome which the innovator realizes thus either induces or inhibits imitation of the new strategy. Accordingly, the social learning process can result in three different cases. The innovative strategy

- (i) gains a foothold in the population,
- (ii) disseminates through imitation,
- (iii) disappear because even the innovator abandons it.

With reference to Table 2, the first of the above problems can then be specified in two ways. If an initially all defectionist population is faced with some of the cooperative contingent strategies as innovation, which of the alternatives (i), (ii), or (iii) will hold? Alternatively, if an initially all cooperative population is faced with some of the defectionist contingent strategies as innovation, which of the alternatives (i), (ii), or (iii) will hold?

Through the spreading of common knowledge about a new strategy by observational learning any member of the population may, or may not, be motivated to adopt the new social model when being involved in an interaction next time.⁹ Let us assume a probabilistic version of rational adoption behavior as follows:

⁹ However, the analysis of the adoption behavior is complicated by the fact that, with the possible dissemination of a new contingent strategy, the expected outcomes of the contingent strategies of all members of the population tend to change, but do so differently depending on their proximity to the innovator.

Assumption 1

The members of the population who learn about a new contingent strategy switch to that new strategy

- with a positive probability monotonously increasing with the positive difference between the outcomes of the innovative and the prevailing contingent strategy,
- with a probability of zero otherwise.

To complete the list of possible behaviors, an assumption about the innovator's response to her own experiment with a new contingent strategy is necessary:

Assumption 2

The player who tries a new contingent strategy keeps to it as long as it does not result in a lower outcome than the contingent strategy previously played. In case of a lower outcome, the innovator switches back to the formerly played contingent strategy after a limited number of interactions (subjective test interval).

Taken together assumptions 1 and 2 induce a selective replication device which, in turn, allows to analyze whether some particular contingent strategy persists in the population, if an innovative strategy turns up or, more precisely, whether it is evolutionary stable. The result is

Proposition 1

Depending on what contingent strategy is newly tried by an innovator against what prevailing contingent strategy, the cases (i), (ii), or (iii) result as given in Table 2.

A sketch of the proof based on an adaptation of the evolutionary stable strategy criterion (Maynard Smith 1982, pp.10-20) to the present model is given in the Appendix.

Table 2 shows a remarkable, though not very much surprising, asymmetry with respect to the chances of a cooperative social model of behavior to emerge on the one hand and to survive where it already exists on the other hand. Neither of the cooperative variants can even gain a foothold, not to speak of successful dissemination, in an all defectionist population. The reasons for this differ (see the appendix). By contrast, defection has much better chances as an innovative strategy not only to gain a foothold in a population in which a cooperative social model prevails, but also to disseminate and to make cooperative behavior disappear. There are, however, some differences. Despite the high costs incurred by punishing an opponent, the combination of offering cooperation in the first stage and punishing attempted exploitation in the second stage (contingent strategy $\{c; p \mid d\}$) is much less vulnerable than is the permissive combination of offering cooperation and accepting exploitation (contingent strategy $\{c; a \mid d\}$). In fact, permissive moralism has no chance to survive.

The results in Table 2 seem to raise some doubts as to whether a cooperative social model of behavior could ever emerge from cultural evolution as portrayed here, at least in undifferentiated populations. This leads over to the second problem mentioned above, relating to the speciation effect and to group selection. Indeed, the situation changes significantly, if groups of agents with *identically* deviating behavior can form within the population. Such a group formation may be due to specific, geographically limited challenges like natural disasters or the settlement of virgin areas, or to narrowing genetic ties --

conditions which come close to those of geographical isolation which favor the evolution of new species in nature. In the present modeling framework, groups are formally represented by a closed set of neighbors (a segment of points on the circle). Once one such group of identically deviating individuals (a segment of innovators) occurs, the previously homogeneous structure of the population is broken. The collective innovators on the one hand and the rest of the population on the other can be interpreted as two groups basing their interactions on different social models of behavior or institutions. A dissemination of the new contingent strategy in the population (neighboring the original group) could then be interpreted as a differential growth process in which ever more population members, by adopting the innovation, ‘migrate’ into the innovating group.

Of particular interest here is the question of whether a group of individuals adopting one of the cooperative contingent strategies collectively has a chance to grow (perhaps to the size of the entire population). On the basis of the model suggested so far the following answer can be provided.

Proposition 2

In an all defectionist population a group of players adopting the contingent strategy $\{c; p \mid d\}$, i.e. a cooperative social model of behavior, can survive and grow, if the group size exceeds a critical mass m^* , $(n-1)/2 < m^* \leq n-1$.

For the sketch of the proof see the Appendix.

Proposition 2 states nothing less than that an institution which is favorable in terms of the individual pay offs it yields can not only emerge spontaneously, but can also furnish the group with a differential growth advantage. However, as the analysis suggests, there is a prerequisite for this to happen: the association of cooperativeness and aggressiveness against

attempts of exploiting cooperation on the one hand which implies, on the other hand, a willingness to bear the extra costs of punishing defectionist behavior. There is no equivalent result for the permissive contingent strategy $\{c; a \mid d\}$ which offers cooperation in the first stage and accepts being exploited in the second stage nothing equivalent holds. A social model of that kind is doomed to disappear under all circumstances except the trivial case of a group of adopters of size n .

V. Conclusions

In the present paper an attempt has been made to shed some light on the evolutionary mechanisms from which institutions, defined as behavioral regularities shown by the members of a group in their social interactions, emerge and under which they continue to change. The behavioral regularities are considered the result of “evolution”, where evolution has been interpreted as the outcome of a complex collective learning process, i.e. a cultural phenomenon rather than one of natural selection. To explain in more detail what happens in those collective learning processes, the theory of social cognitive learning has been introduced for which considerable experimental evidence has been gathered in social psychology. In a simple version of the prisoners’ dilemma game the implications of that theory for cultural evolution in general and the evolution of institutions in particular have been exemplarily discussed.

The crucial implication of social cognitive learning theory in the abstract framework of the prisoners’ dilemma game are collectively shared cognitive constraints on the perception of the feasible set of strategies. The state of these constraints determines the selective mechanisms of the emergence and transmission of group specific institutions. Due to their bounded rationality, the agents in a group or population do not consider all imaginable ways of behaving in social interactions, but rely on a limited number of

observable social models of behavior. However, the prevailing social models are occasionally challenged by the (experimental) introduction of an innovative move. Depending on the pay offs which an innovator can realize, the new form of behavior can gain a foothold in a group, can disseminate, or can disappear.

As always in evolutionary processes, the specific historical contingencies of time and space as, e.g., the so-called ‘occupancy effect’ (what kinds of behavior are challenged by the innovation) or features of spatial proximity and isolation (the analogue to the speciation effect in natural evolution), have been shown to play a crucial role for what precisely will happen to a behavioral innovation. Yet, there are also systematic effects related to the features of the newly introduced strategy. For instance, in the case of the specific prisoners’ dilemma game discussed, a crucial feature for the emergence of cooperation and reciprocity as prevailing behavioral regularities turned out to be its combination with ‘aggressiveness’ or, more precisely, the willingness to individually bear the costs of punishing all attempts to exploit the offered cooperation. Taken together, systematic features and historical contingencies determine what institutions emerge in groups and how institutions continue to change spontaneously. As is quite obvious, the properties of the different institutions prevailing in different localities in geographical space may entail relative advantages or disadvantages for the single group member in terms of her realized pay offs. The differences can induce migration processes and, accordingly, a differential growth or decline of groups with differing institutions -- the equivalent in cultural evolution to “group selection”.

Proof of proposition 1

Consider the new contingent strategies entering a population with prevailing contingent strategy as given in Table 2 in the order of the columns from left to right and in each column from top to bottom.

- Defectionist strategy entering a population of ‘permissive’ cooperative players, i.e. $\{d; a|c\}$ or $\{d; a|d\}$ entering $\{c; a|d\}$:

initially, the innovator realizes an undiminished outcome $T > R$ with certainty. The more the defection as a behavior disseminates, however, the more often another defecting player is encountered and $\{d; a|d\}$ played against $\{d; a|d\}$ by assumption. The innovator’s expected outcome then gradually converges to $P < R$. Since returning to the contingent strategy $\{c; a|d\}$ would entail R when encountering a player using the same contingent strategy and S when playing against defectionists the innovator never switches back to $\{c; a|d\}$. Players playing the originally prevailing contingent strategy among themselves obtain an outcome R while, as the innovator’s opponent, they get S . If they switch to the defection strategies $\{d; a|c\}$ or $\{d; a|d\}$, they realize $T > R$ against cooperative players and $P > S$ against the innovator (and, later, other defectionist). This means that $\{c; a|d\}$ is an inferior strategy under all circumstances. Hence, by assumption 1, there is a finite waiting time for all player to switch to defection. $\{d; a|c\}$ and $\{d; a|d\}$ disseminate, i.e. (ii) holds (which means that $\{c; a|d\}$ is driven to extinction).

- Defectionist strategy entering a population of ‘aggressive’ cooperative players, i.e. $\{d; a|c\}$ or $\{d; a|d\}$ entering $\{c; p|d\}$:

initially, the innovator realizes with certainty an outcome $T - C_0$ which, by the assumed order relations, particularly relation (1), is smaller than R . Should the defectionist strategies disseminate, the innovator's expected outcome gradually increases to $P > T - C_0$. Since returning to $\{c; p| d\}$ would entail R when playing against $\{c; p| d\}$ and $S - C_p$ when playing against defecting players, the innovator's future behavior according to assumption 2 crucially hinges on whether defectionists can ever gain a significant share among the player. Consider therefore the players playing $\{c; p| d\}$ and obtaining an outcome R among themselves while, as the innovator's opponent, they get $S - C_p$. If they switch to a defection, they realize $T - C_0$ against $\{c; p| d\}$ players and $P > T - C_0$ against the innovator (and, later, other defectionists). If any player is likely to switch, it will be the innovator's neighbor. Let $E(\pi_{ac})$ denote the expected outcome of a player playing the aggressive cooperative strategy $\{c; p| d\}$ and $E(\pi_d)$ the expected outcome of a player choosing d in the first stage. According to the geographical structure of interactions we then have for the immediate neighbor player of the innovating player

$$E(\pi_{ac}) = \frac{1}{2} R + \Phi_1 (S - C_p) + (\frac{1}{2} - \Phi_1) R.$$

In case of switching the neighbor gets

$$E(\pi_d) = \frac{1}{2} (T - C_0) + \Phi_1 P + (\frac{1}{2} - \Phi_1) (T - C_0).$$

Equating both expected values and solving yields

$$\Phi_1^* = [T - C_0 - R] / [T - C_0 - R + S - C_p - P] < \frac{1}{2},$$

because $0 > T - C_0 - R > S - C_p - P$. Hence, it cannot be excluded that the probability Φ_1 happens to satisfy the condition $\Phi_1^* < \Phi_1 \leq \frac{1}{2}$. (Note, however, that since $\Phi_1 = 2/(n+1)$, the condition is the less likely to be satisfied, the larger n .) If this is the case, there is a finite waiting time for the neighbor player to switch to defection according to assumption 1. If the innovator maintains the new strategy for long enough, incurring the opportunity loss $R - (T - C_0)$, the expected outcome may grow to P in the

best case (through the neighbors' switching). P is better than T-C₀ but still inferior to R so that the innovator may eventually be inclined to return to playing the old strategy according to assumption 2. However, if a neighbor has already switched such a move would amount simply to changing places with the neighbor. Thus, while it cannot be excluded that the defection strategy disseminates, i.e. (ii) holds, if this happens at all it may be a matter of cyclical convergence, probably even infinite cycling, i.e. case (ii) would hold. (In case $0 < \Phi_1 \leq \Phi_1^*$, by contrast, switching is excluded so that for the corresponding parameter values defection as an innovation is certainly unable to survive, i.e. (iii) holds).

- 'Permissive' cooperative strategy entering a population of defectors, i.e. $\{c; a|d\}$ entering $\{d; a|c\}$ or $\{d; a|d\}$:

here the order relation on the pay offs of the original one-shot game is decisive; initially, the innovator is certain of realizing an outcome $S < P$. However, should $\{c; a|d\}$ disseminate, the innovator's expected outcome gradually increases to $R > P$. Since returning to defection would entail P when playing against defecting player and T when playing against a player using strategy $\{c; a|d\}$, by assumption 2 the innovator is to return to defection after playing a number of times $\{c; a|d\}$. As far as the defecting players are concerned, they obtain an outcome P in playing $\{d; a|d\}$ among themselves while, as the innovator's opponent, they get T playing $\{d; a|c\}$. If they switch to $\{c; a|d\}$, they realize S against defecting player and R against the innovator. Since $T > R$ and $P > S$ no switching will occur by assumption 1 and $\{c; a|d\}$ cannot survive, i.e. (iii) holds.

- 'Permissive' cooperative strategy entering a population of 'aggressive' cooperative players, i.e. $\{c; a|d\}$ entering $\{c; p|d\}$:
when playing against $\{c; p|d\}$, an innovator playing $\{c; a|d\}$ cannot be distinguished.

The innovator may maintain its ‘innovative’ contingent strategy forever (without any practical relevance), but the contingent strategy will not disseminate by being imitated, i.e. (i) holds.

- ‘Aggressive’ cooperative strategy entering a population of defectors, i.e. $\{c; p|d\}$ entering $\{d; a|c\}$ or $\{d; a|d\}$:

initially, the innovator can be sure of realizing an outcome $S - C_p < P$. However, should the aggressive cooperative strategy disseminate, the innovator’s expected outcome gradually increases to $R > P$. Since returning to defection would entail P when playing against defecting player and $T - C_o$ when playing against players using strategy $\{c; p|d\}$, the innovator’s future behavior according to assumption 2 crucially hinges on whether $\{c; p|d\}$ can ever gain a significant share among the player. Consider therefore the players playing $\{d; a|d\}$ and obtaining an outcome P among themselves while, playing $\{d; a|c\}$ as the innovator’s opponent, they get $T - C_o$. If they switch to $\{c; p|d\}$, they realize $S - C_p$ against defecting player and $R > T - C_o$ against the innovator. By reasoning analogously to the case where defection invades $\{c; p|d\}$ a critical value

$$\Phi_1^{**} = [S - C_p - P] / [S - C_p - P + T - C_o - R] > 1/2$$

can now be derived. Hence, there is no value of Φ_1 in the admissible interval $(0, 1/2]$ such that a switch may occur. Since the innovator is to return to playing defection according to assumption 2, $\{c; p|d\}$ cannot survive, i.e. (iii) holds.

- ‘Aggressive’ cooperative strategy entering a population of ‘permissive’ cooperative players, i.e. $\{c; p|d\}$ entering $\{c; a|d\}$:

when playing against $\{c; a|d\}$, an innovator using strategy $\{c; p|d\}$ cannot be distinguished. The innovator may maintain its ‘innovative’ contingent strategy forever, but the strategy will not disseminate by being imitated, i.e. (i) holds.

Proof of proposition 2

If all members of a segment N of the circle (the group) simultaneously adopt the contingent strategy $\{c; p | d\}$ while defection continues to prevail outside N , these member can realize crucially differing outcomes depending on whether they interact among each other or with agents outside N . The members at the edge of N profit least from the cooperation gain since, by the non-discrimination assumption they interact equally likely on the side with N as their neighborhood as on the opposite side. The members at the edge are therefore most likely to switch back to defection. The expected outcome of such a member of a group of k innovators is

$$E(\pi_{ac}) = \frac{1}{2} (S - C_p) + \Phi_k R + (\frac{1}{2} - \Phi_k) (S - C_p).$$

Should that member switch back to defection the expected outcome would be

$$E(\pi_d) = \frac{1}{2} P + \Phi_k (T - C_o) + (\frac{1}{2} - \Phi_k) P.$$

Equating both values and solving yields

$$\Phi_k^{**} = [S - C_p - P] / [S - C_p - P + T - C_o - R] > \frac{1}{2}.$$

Hence, by eq. (3) no number of group members $k \leq s$ exists so that $E(\pi_d) \leq E(\pi_{ac})$. By assumption 1, the member at the edge of N is to switch back in finite time to defection, while none of its neighbors outside N (and a fortiori no other player outside N) is likely to imitate the innovation. The situation changes, however, if N is allowed to have more than s members.

In that case, the respective expected outcomes are

$$E(\pi_{ac}) = \frac{1}{2} R + \Phi_k (S - C_p) + (\frac{1}{2} - \Phi_k) R \text{ and}$$

$$E(\pi_d) = \frac{1}{2} (T - C_o) + \Phi_k P + (\frac{1}{2} - \Phi_k) (T - C_o).$$

Equating both values and solving yields

$$\Phi_k^* = [T - C_o - R] / [T - C_o - R + S - C_p - P] < \frac{1}{2}.$$

In view of eq. (3), this means that a critical number of group members m^* exists such that, once m^* has been exceeded, defectionist strategies in the population will be driven to extinction. All player will eventually switch to $\{c; p| d\}$. Depending on the size of the variables T , R , P , S , C_p , and C_o , m^* varies in the interval $((n-1)/2, n-1]$. This means that a group using strategy $\{c; p| d\}$ can survive and grow if its size exceeds the critical mass m^* .

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TABLE 1 Contingent strategies available to the players

strategies with mutual cooperation in the first stage	<ul style="list-style-type: none"> - $\{c; a \mid c\}$ -- accept the favorable outcome R in the second stage - $\{c; p \mid c\}$ -- a “punishing cooperation” case (not considered further)
<hr/>	
limits strategies with mutual defection in the first stage	<ul style="list-style-type: none"> - $\{d; a \mid d\}$ -- accept P in the second stage to keep damage within - $\{d; p \mid d\}$ -- punish opponent in the second stage for jointly causing P
<hr/>	
strategies with unlike choices in the first stage	<ul style="list-style-type: none"> - $\{d; a \mid c\}$ -- accept the advantageous outcome T in the second stage - $\{d; p \mid c\}$ -- a “punishing cooperation” case (not considered further) - $\{c; a \mid d\}$ -- accept being exploited (outcome S) in the second stage - $\{c; p \mid d\}$ -- punish opponent in second stage for attempting exploitation

TABLE 2 Survival and Dissemination of Deviating Contingent Strategies

prevailing strategy	new strategy entering the population		
	$\{d; a \mid c\}$ or $\{d; a \mid d\}$	$\{c; a \mid d\}$	$\{c; p \mid d\}$
$\{d; a \mid c\}$ or $\{d; a \mid d\}$	-----	(iii)	(iii)
$\{c; a \mid d\}$	(ii)	-----	(i)
$\{c; p \mid d\}$	(i), (ii) or (iii)	(i)	-----

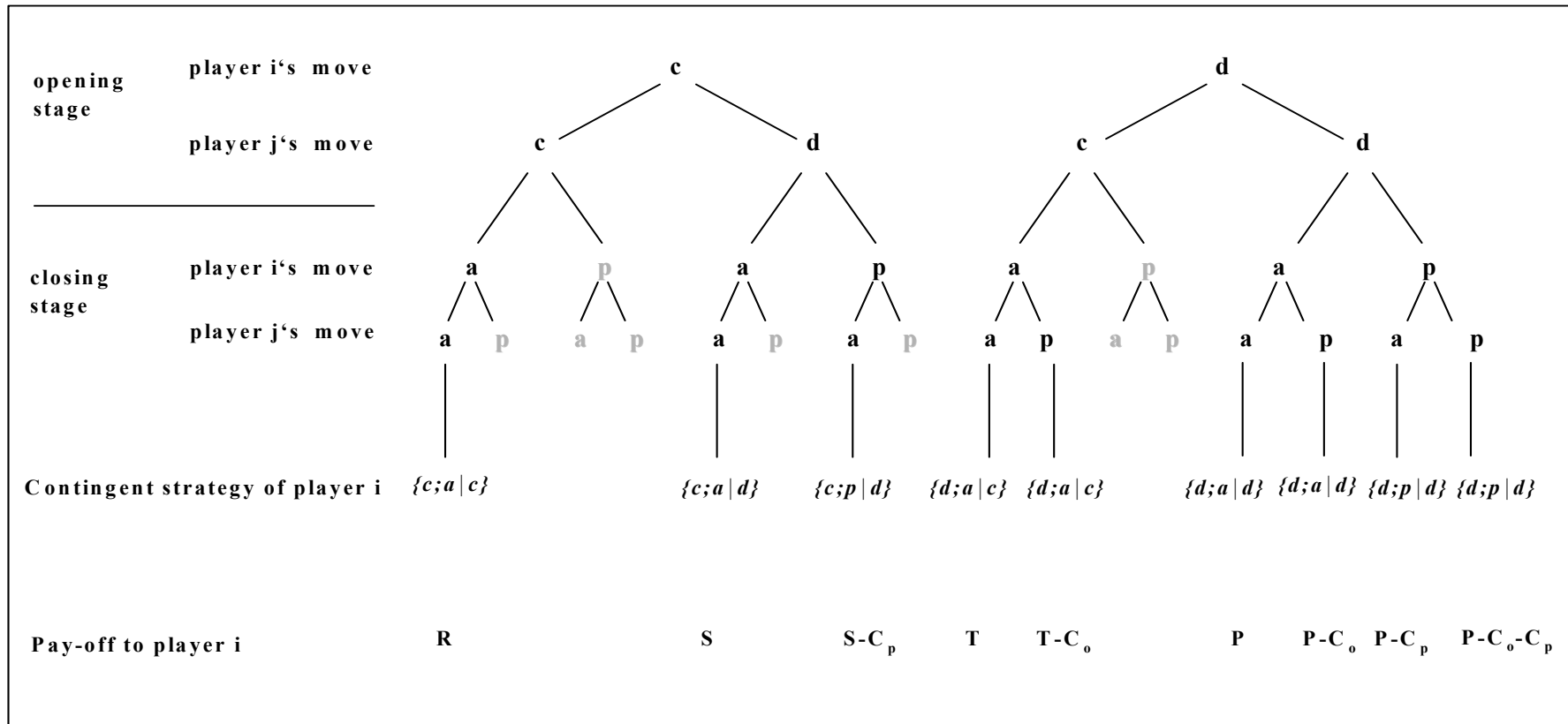


Figure 1 Prisoners' Dilemma with Punishment Option in Extensive Form
(for omitted contingent strategies see fn. 7)