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REGULAR ARTICLE

The concept of choice: why and how innovative behaviour is not just stochastic

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Abstract The goal of this paper is to highlight the importance of the concept of choice. To do so, a synopsis of the most important contributions to this topic—featuring an eclectic set of scholars across disciplines—is provided. As central to the argument, John von Neumann's contributions, game theory and simulation techniques on von Neumann machines, are identified. Innovation (economic and theoretic) as the driving force behind human evolution seems to head for a new scientific paradigm based on von Neumann's ideas.

Keywords Game theory · John von Neumann · Innovation · Concept of choice · Innovative behaviour

JEL Classification B41 · B50 · B20

1 Choice—back to the roots

The concept of choice has played an extremely important role in the history of thought. Appearing in many scientific disciplines, it is not surprising that it was used in different, often ambiguous meanings at different times. This paper will concentrate on the role this concept plays for evolutionary political economy, but it proves to be important to start with a wider view on the emergence of this notion.

The best device to structure the field seems to be a simple question: Whose choice? It immediately leads to the observation that, historically, the emergence of the concept of choice is tightly linked to the tasks of the French enlightenment. Indeed in any religious world—such as the Middle Ages—the fatalism involved in

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the belief in superior beings makes an investigation into the decision behaviour of this being a heresy. At best, the elite of priests might use some pretended special access to its decision logic to impress the public. But this type of religious exegesis is not important for the current argument. When in the seventeenth century René Descartes did not dare to publish his works on scientific methods[1] for years, it was mainly due to the fear that they would ascribe too much decision power to the mind of human individuals—and thus imply a loss of omnipotence of God and a consequent revenge on his earthly representatives. The interesting point is that, with this move to the possibility of a secular science, the one entity's invisible choice was substituted for a scientifically oriented ratio dispersed over a set of single human individuals—the set of learned scholars. A *concept of choice thus emerged as a method*, a rule set, which was thought to be *common to a set of physically independent human individuals*. With this brave methodological strike against religious fatalism, choice suddenly was a feature closely connected to physical human individuals.

But there is a second interesting twist to be found in these early days of enlightenment. As Baruch de Espinoza[2]—opposing Descartes in this important aspect—made clear, it is not particularly helpful to consider the mental material on which the decision algorithm works to be separated from the observing individual. Even if one accepts the reduction of choice to choices made by individual humans, it still is not possible to postulate a strict borderline between the choosing individual and an objectively given set of alternatives. In contemporary research, the experimental psychologist Daniel Gilbert has dubbed this Spinoza's challenge to Descartes warehouse metaphor: Ideas (the material of choice) are not like things in a warehouse from which an individual—using its ratio—chooses. As overwhelming recently available empirical evidence shows, it is more adequate to consider the decision process as a state transition of the individual; more precisely, a transition which—depending on the effort the individual is able to spend on the issue—lets the person simply accept incoming perceptions (observation and communication) up to a certain degree. Only if this threshold is passed will a process of '*unbelieving*' set in.[3] This type of *individual choice therefore works on partly produced and partly selected inputs*—there is no way to give an adequate description as a set of the three clear-cut ingredients of standard microeconomics: the utility function, a set of given alternatives, and an optimization algorithm. But note that the Spinoza view on individual choice does not imply that adequate formalization is necessarily impossible; it only is the distorted manner of mainstream microeconomics which fails. Indeed, recent advances in agent-based modelling promise much more fruitful formalization possibilities.

Deriving some of the consequences of Spinoza's perspective leads back to the initial question concerning the choosing entity: If inputs to the choice process are not only perceptions of natural phenomena by individual members of a species, but also include intra-species communication, then a whole new universe of strategic interaction comes into play. Certain inputs into the decision process—*ideas* as Spinoza named them—are not just "out there" in nature waiting to be perceived, but

[1] See (Descartes 1990 (1637)).

[2] See Spinoza (1982 (1677)).

[3] See Gilbert (1993) and McFadden (2000).

are purposefully produced by other entities. Not only do entities act as producers of communicated inputs to influence the choice of others, but the acquisition of ideas includes a (self-) communicative element. The entity acquires only those inputs towards which it turns its attention, i.e. there exists an alter ego which governs the focus of perception. The dialogue between the two egos constitutes what currently is considered to be the hottest topic in this research area: consciousness. But brain research can only explore some inner dynamics on the level of the human individual. The extremely complicated interactions which constitute larger social entities—families, tribes, nation states and the like—are beyond its reach. This process of the emergence of larger social entities in human society is still little understood, despite its evidently growing importance. With each large social entity which evolution enables, a certain degree of consciousness and a certain capacity to choose is involved. One consequence of Spinoza's perspective thus is the emergence of larger social entities, and their dominance over human individuals: As anthropology shows, the first social forms of humans did not have any important role for the concept of the single human individual. The historical record appears to be a blunt reversal of what currently is taught in microeconomic courses—there never has been this mysterious set of individuals who strategically cooperate to constitute a new, larger social entity. It rather has been the case that large social entities had to develop up to a certain point in history until they were able to introduce the concept of the human individual, which opposes the other new concept, the concept of nature. So while the human species evolved into ever larger social entities (tribes, nation states, continental units, world society), the conceptualizations used by these entities worked rather in the opposite direction (families, individual humans). The question 'whose choice?' in such a complicated network of interwoven social entities can only be answered if the involved multiple egos are analytically disentangled. In a sense, this extends Spinoza's original intent: not only should the distinction between free will and an objectively given choice set of an entity be abandoned, *the entity itself should be understood as consisting of multiple social egos*. In this framework, choices are action plans formulated in the language of the respective ego, partly coinciding with and partly contradicting other choices proposed by egos inhabiting the same social carrier entity.

This was the state of affairs when merchant capital conquered the globe. Choices of merchants coincided with the choices of their feudal sovereigns, and the only limit to the power of such a coalition was the power of a similar coalition in a rivalling nation. In the eighteenth century, social consciousness featured Daniel Defoe and Jean-Jacques Rousseau, both emphasizing the human individual struggling with nature. But while Defoe's isolated Robinson[4] gradually learns to make the *right individual choices only*, Rousseau's œuvre[5] introduces the idea that individuals should agree on a *social contract* to form a *new social entity*. But Rousseau, in contradiction to Hobbes, does not insist on the positive role of the individual's ratio to support the choice of a social contract. Rather he romantically prefers to trust in the basic instincts of human nature. The influence of Rousseau on the French

[4] See Defoe (1719).

[5] See Rousseau (1762).

Revolution and European Enlightenment in general was enormous—the topic *individual choice versus social choice* was on the agenda.

At that point in history classical political economy entered the arena of scientific disciplines: *Adam Smith's An Inquiry into the Nature and Causes of the Wealth of Nations*[6] can be interpreted as an attempt to reconcile a 'choice' of welfare on the national level with the choices of profit maximizing smaller decision units, the entrepreneurs. The scientific progress of Smith's contribution with respect to the concept of choice was twofold. First, he identified a class of decision-making entities with empirically observable impact, and thus disburdened theory from the vague construct of a natural human individual. Second, he realized the positive influence of the heterogeneity of this class of entities on the overall welfare; it is the division of labor distributed over specialized heterogeneous production units, which enables the overall growth of welfare. Note that both of Smith's advances—*historical specification of economic agents* instead of use of anonymous agents and the *explicit endogenous role of heterogeneity* instead of the assumption of a representative entity—have been reversed by the current microeconomic mainstream.

Classical economic theorists explored several dimensions of the new terrain opened up by Adam Smith. *Thomas Robert Malthus* introduced the perspective that the choice of workers to have many children will undermine any harmonizing social transfer policy—only ideological intervention at the household decision level, inculcating the lower classes with middle-class virtues, could perhaps stop the overshooting population growth, which kept the working class at subsistence level[7]. He thus introduced a new class of agents, the workers, and, contrary to Smith's result that the optima for his entities (the nation and the entrepreneurs) coincide, Malthus found that the incomes of these new entities will be fixed at the lowest possible level. This perspective not only paved the way for the inclusion of heterogeneous sets of classes as important *entities at a meso-economic level*, it also pointed at the necessity to investigate *disequilibrium processes* emerging from the heterogeneous choices.

Seen from this vantage point, *Karl Marx's class analysis* is just the culmination of classical political economy.[8] His social classes form historically without class consciousness and only later achieve it gradually. Nevertheless, there is always a feedback from some institutionalized organizers of class consciousness on the minds of ordinary class members. According to Marx, pivotal choices are made on the meso-level, while the state is only the vehicle that transports and executes the prevailing power relations between classes. A major methodological innovation to choice theory is that Marx insists on the *necessary and positive role played by contradictions*. As a critical disciple of Hegel, Marx upended Hegelian dialectics; instead of postulating German idealisms famous dictum that freedom is insight into necessity, he rather saw novelty as new dimension provoked by the processing of contradicting forces. Using the terminology introduced above: With multiple egos

[6] See Smith (1776).

[7] See Malthus (1803).

[8] See Marx (1969).

pointing at contradictory choices, the social entity is forced to produce a new ego—this indeed is the core of conscious development and the development of consciousness.[9] Needless to say, a formalization of these ideas still remains a desideratum.

The time after classical political economy, the last decades of the nineteenth century, was characterized by impressive successes in the natural sciences—and an intellectual recession in economic theory. Most exciting for the concept of choice remains *Charles Darwin's work*. His remarkable argument in *The Origin of Species* can be considered as the final scientific deathblow to the Christian religious credo which held that God had chosen the set of species existing on earth. Darwin substituted this choice of a superior being by assuming a succession of two-stage processes—variety generation and selection—which continuously transform the set of existing species. Under this perspective, mankind was just the latest result of this evolutionary process and not the effigy of God.

But how can Darwin, who worked mainly on biological species with a low level of consciousness, contribute to the clarification of a concept that presupposes sophisticated human minds? Indeed Darwin's starting point still was close to the eighteenth century's guiding topic of nature versus individual, though it now read as *environment versus species*. In the sequel, the direction of causality is reversed: it is not the entity choosing actions to survive in nature, now it is the environment which selects traits of the entity. Species thus evolve as adaptations to their environment, which appear as if the environment were selecting them. Of course, Darwin was rejecting the idea that there really was a purposefully selecting nature and instead favored the idea of contingency: Only a close look at the particular historical record of a phenomenon can reveal what ex post appears as the working of a natural law.[10] As a consequence, the biological sphere really would not need a concept of choice; the evolution of species could be seen as an unguided drift through time. Only recent advances in evolutionary game theory revived the idea that some early forms of consciousness play an important role in biology.[11] But though these early forms of consciousness do not enable choice—which remains a notion only useful for the description of the human species—they cast some light on the emergence of the special capacities of humans. Why and how these findings of evolutionary game theory can enhance our understanding of choice will be explained below.

2 Probability—taming the unknown

While Darwin[12]—similar to Descartes more than 200 years earlier—hesitated to publish his research, fearing not without reason the strong influence of the church on scientific careers, another eminent scientist successfully applied a new method called probability theory to a most intriguing problem of physics. In 1872, *Ludwig*

[9] Compare Schumpeter (1911).

[10] See (Gould 2002, pp.1339–1343).

[11] See (Smith 1982).

[12] See (Darwin 1859).

Boltzmann[13], building on the work of *James Clerk Maxwell*[14], formulated his famous Boltzmann equation that was able to describe the behavior of molecules of a perfect gas out of equilibrium. His major innovation was to postulate a probability distribution function, which specifies the density (and the change of density) of particles in a given energy range. The feature relevant for the concept of choice is that the elaboration of this theory (the 2nd law of thermodynamics) lead to the surprising result that nature seems to be described more adequately in probabilistic terms, i.e. statistical mechanics, than in classical Newtonian terms. There definitely was a deep scientific revolution of the natural sciences in the air, which blossomed in the early twentieth century with Einstein's contributions. This became visible due to a scrutinizing formalization of the smallest elements of the physical world with a method that assigned numbers in the closed interval of zero and one to states of the natural world—probability theory.

Boltzmann was well aware of the far-reaching consequences of his findings, and in a paper in 1897 gave birth to an often cited argument: non-equilibrium is essential for the existence of a sentient creature. Therefore, a sentient creature could not find itself existing in an equilibrium region, probable as this may be, for in such regions no sentience exists.[15] Maxwell's illustrative invention of a little demon, which due to the probabilistic nature of the 2nd law of thermodynamics should temporarily be able to reverse the increase of entropy, makes the same point.[16] So the introduction of basic randomness at the microscopic level of physical phenomena opened up the possibility, indeed the need, to understand living systems as builders of negentropic episodes.

Probability as a basic feature of matter in the way physicists have identified it, of course, is not what currently is understood by this name in economic theory. Since gas particles do not possess consciousness, they cannot act strategically, and therefore the essence of the source of the unknown in negentropy building human societies is completely absent there. In other words, for human societies, 'not knowing' simply means that there is a blind spot in the social entity's knowledge stock, and that it therefore assigns a probability measure to its guesses. The intriguing point is that the *two different notions of probability*—the *basic physical probability* (call it bp-probability) and the *entity oriented probability* (call it eo-probability)—are eventually physically linked in human brains, and are conceptually linked by the concept of time. The currently dominating economic mainstream propagates an 'Expected Utility Hypothesis' which makes extensive use of the assumption that social entities maintain expectations of events in the future, which govern their current behavior. Time—and its irreversibility that also was brought into focus by physicists—thus does play a crucial role for eo-probability, but only as an exogenously given scale. The differences clearly can only be resolved by a proper use of terminology. The disentangling of the complicated processes involved spans over several scientific disciplines and only modest advances are in sight.[17]

[13] See (Boltzmann 2000).

[14] See Maxwell (1860).

[15] See Sclar (1993, pp. 28–48).

[16] See Hanappi (2003a, b).

[17] See (Farjoun and Machover 1983).

Nevertheless, the widely acclaimed success of the natural sciences in the late nineteenth and early twentieth century did inspire mathematically inclined economists to dare some imitating exercises.

Léon Walras and his followers produced an analogue to the static version of Newtonian mechanics, which they thought could mimic equilibrium of exchange actions between owners of resources.[18] Owners are only linked by markets with fully flexible market prices adjusting to the exogenously given preferences of the owners. The original proposition only saw exchange after all the prices and quantities had been set to their equilibrium. The world was described as a simple sequence of static equilibriums between resource owners, all interesting dynamics shifting equilibrium positions remaining exogenous to the model. Though countless refinements of this general equilibrium theory (GET) have been proposed since its original formulation, the fundamental vision has remained the same.

It is evident that, after the shocking disequilibrium experience of World War 1, several economists, who were inclined to consider their science as descriptive of what really was going on in political economy, started to doubt the importance of the simple static equilibrium framework. In 1911 *Schumpeter* propagated his *theory of development*, which set the entrepreneur as the bold decision maker pushing the economy out of equilibrium. Unfortunately, the theory remained on a purely descriptive level. *John Maynard Keynes* set out for a bold argument to resurrect probability theory (logical relationist probability, or eo-probability in the terminology of this article,) in his treatise on probability.[19] As did *Frank Knight*, he considered the source of the unknown to be missing knowledge,[20] but unlike *Frank Ramsey*[21], he insisted that the relevant social entity is not the human individual, but rather a larger entity adding to the gradually more objective status of eo-probability. If more recent results of experimental psychology—compare the first part of this paper—are taken as facts that could shed some light on these old debates, then a version of Keynes perspective seems to be most appropriate. It seems that, with a sophisticated formulation of communication processes in a simulation environment, many of these old controversies could be represented and opposing opinions could be reconciled.

But apart from the brave scholars who set forth to save the concept of eo-probability the pivotal step forward in economic theory came from a mathematician, *John von Neumann*. As Philip Mirowski recently emphasized, John von Neumann's introduction of *game theory* was based on his *and Oskar Morgenstern*'s view that stochastic behavior in economic settings assumes a form radically different from the probabilistic descriptions of non-living systems.[22] Contemporary mathematically oriented game theorists usually do not grasp what a radical break in economic theory production von Neumann and Morgenstern originally had in mind. As Chapter 1 of

[18] See (Smith and Foley 2002).

[19] See Keynes (1973 (1921)).

[20] Compare Knight (1933 (1921)).

[21] See (Ramsey 1931 (1926)).

[22] Compare (Mirowski 2002, pp. 94–152).

their classic book shows, they really set out to produce a new formal language for the social sciences.[23]

The theory of strategic behavior, game theory, in its most general form provides some formal tools to grasp the idea that choices of heterogeneous entities lead to actions the interdependent singular outcome of which can be evaluated by each player, but can only be ascribed to whole sets of individual actions. Technical details of how this formalization can be achieved are less important than the central idea itself—as a matter of fact, overemphasizing the formal instrument can lead research astray. The great advantage of the new approach is that it forces the model-builder to be explicit with the assumptions made about information and communication as well as with the assumptions about the differences between the heterogeneous players and—finally—the rules of the game. With the pandemonium of possibilities, built along the actual lines of parlor games played by ordinary people, for game-theoretic models, the assumptions of GET are just a trivial and inadequate special case.

John von Neumann, the mathematician, of course imported his extraordinary formal skills to make his proposal at the same time a proposal for a new branch of mathematics.[24] In the two decades after publication, the rigidity of his more specific approach made it rather difficult for other economists to follow his lead—contrary to the excitement stirred by its general goals immediately after publication. The moment a wider group finally came back to game theory, it was the mathematically working group. As Mirowski reports, von Neumann was not too happy to see his approach further developed only by mathematicians like John Nash—he was turning towards the invention of general symbol manipulating machines, i.e. computers, possible devices for simulating social entities' model building.

Mathematical formalisms sometimes develop a life of their own, leading researchers to a dead end. They forget that primal inspiration regularly comes from the world outside of mathematics—at least this is what history of science teaches. Nowadays, and in particular for the problem at hand—modelling choices of social entities—computational methods work hand in hand with mathematical developments tailored to the needs of the project.[25] The built-in tendency of mathematical evolution towards ever looser connections to empirically observable phenomena thus is supplemented by down-to-earth simulation.

In the simplest case, eo-probability enters a game-theoretic model as a vector of probabilities of the pure strategies an entity can choose from. This pair of vectors, actions and their respective eo-probabilities, is called a mixed strategy. Mixed strategies are the outcome of the internal model entertained by the respective social entity. This internal model building thus can—and should—incorporate all the necessary ingredients spelled out in the retrospective survey in the first part of this article. To see the dramatic difference between the interaction of particles and strategically acting social entities, a brief glance at one of the simplest games can help.

[23] Compare Neumann and Morgenstern (1944).

[24] Compare (Selten 2001)).

[25] Compare the theory of minority games (Coolen 2005).

Consider the following payoff matrix of a simultaneous move game specified in strategic form.

Entity B

Entity A

0	-1	1
1	0	-1
-1	1	0

In this game, both players should have a strong incentive not to be outguessed by their opponent. But in a one shot game, this is not really a problem, since there exists no game history from which players can learn. So without communication with the opponent, the only way to take into account its strategic behavior is to assume via introspection that the other entity resembles oneself. This is the step towards the assumption of a representative agent, and it does not lead very far. To see this, note that this assumption consists of two assumptions:

1. Every entity has the same internal model
2. Every entity knows that this is the case and therefore knows that everybody arrives at the same choice.

From (2) it follows that only payoffs on the diagonal will occur, and since these are all equal, it does not matter which one is chosen. Under these circumstances, the use of the internal model leads to the advice 'choose whatever you want'. Knowledge about the opponent and strategic possibilities (due to the entries on the diagonal of the payoff matrix) are too scarce to allow for interesting dynamics. Contrary to GET game theories, strengths are displayed if heterogeneity is allowed for and repetition with memory produces dynamics. All these latter ingredients of course are characteristic of the human species.

Using again this simple game and allowing for repetition and heterogeneity of the simplest form gives a completely different picture. Assume that seven different types of entities are playing this game for 500 rounds. Each type consists of 100 agents and each of these 700 agents each round meets one opponent (drawn with uniform bp-probability!). Agents don't have memory, so there still is not much choice injected in this setting. The types are rather dull: type 1, 2, and 3 always choose row 1, 2, and 3, respectively; type 4 chooses row 1 or 2 with equal probability; type 5 does so with rows 1 and 3; type 6 does so with rows 2 and 3; finally, type 7 chooses any of the three rows with a probability of one third. Since this is now a repeated game, one might expect that some tendency favoring the mixed Nash equilibrium (type 7) could occur. Figure 1 shows the average payoffs of the respective types.

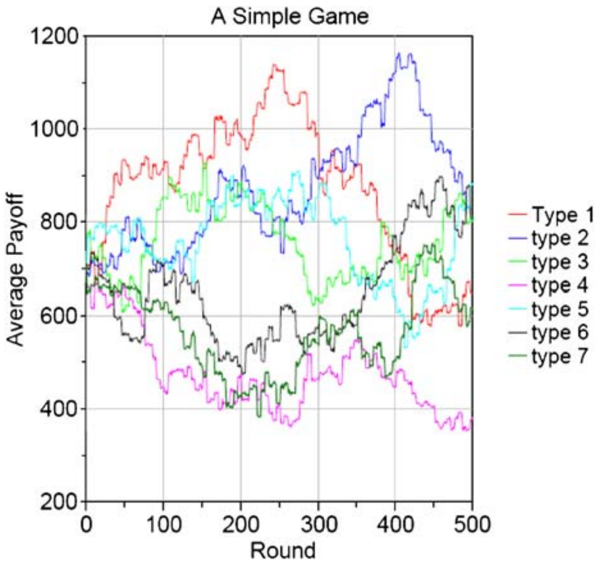

Fig. 1 Average payoff of the seven different entities

As this simulation run (which is typical) shows there is no tendency that favors type 7—simply because conscious choice would need at least some memory that could be used to build expectations about encounters, locate and spot known partners of the past, and the like.

In a next exercise, one can make (heterogeneous) internal model building more sophisticated and check which types are favored. This will not be carried out in this article; this example should only give the flavor of this type of research.

As a general rule, it seems to be wise to substitute the assumption of a representative agent with a structure of heterogeneous types with homogeneous agents. Indeed, the next goal must then be to explain the emergence of these types endogenously: meso-economic social entities as temporarily prevailing solutions to contradictory forces.

A most interesting point of time in the life of meso-economic social institutions is their birth, in other words *social innovation*.

3 Innovation—pulsation of environments

In the last chapter it was argued that during the twentieth century the most important innovation in theory building in the social sciences was John von Neumann's and Oskar Morgenstern's new language of game theory. An interesting question thus is if and how this tool might help to investigate the process of innovation. Many contemporary mainstream economists using game theory would react on this question with a negative answer. They consider only those parts of game theory, which help them to determine equilibrium states, i.e. states, where the time derivatives of all endogenous variables are zero, and therefore exclude all dynamics that go beyond the study of equilibrium paths. But innovation by its very definition is a departure from an equilibrium path. Despite John von Neumann's theoretical roots in equilibrium dynamics of systems in theoretical physics such a narrowing down of the scope of game theory is not only superfluous, it is even misleading and runs counter Neumann's own intention to develop a formal language that *replaces* the theoretical tools which economics had inherited from the theoretical physics. And as his colleague at Princeton University at the time, Josef Schumpeter, emphasized economic development of the human species is all about innovation—technical innovation as well as social innovation.

Only with the advent of evolutionary game theory the equilibrium-oriented squad of game theorists in economics started to lose some of its finest scholars.[26] Even a champion in this field, Ariel Rubinstein, recently published a paper that attested the standard (mainstream) interpretation of game theory its impotence with respect to its ability to mimic the actual communication process, see (Salant and Rubinstein 2007). As argued above an indispensable part of modelling strategic interaction consists of formulating the communication process adequately. In other words, perception, transformation into a ('bounded but rational') model, and exchange with other models including eventual modification have to be distinguished and made explicit. One aspect of actually observed communication is the fact that there usually exist features of a decision problem that do influence the choice of the decision maker although closer inspection of the influence they exert on the outcome of the choice to be taken shows that it does not exist. To incorporate this possibility the standard framework typically is extended by the concept of *frames*: A frame includes observable information that is irrelevant in the rational assessment of the alternatives, but nonetheless affects choice. As Salant and Rubinstein prove even this small extension towards a model of communication would not leave the results of the standard approach unchanged.

Going one step further to model under which conditions and in which ways *entities strategically produce frames and use frames of others* goes beyond currently available mathematical skills – though simulation of well specified cases are straight forward and simple. At that point of the argument it is important to see that an entities ability to produce and to communicate visions of possible—but not actually observed—worlds is not just a dispensable additional feature that can be added to the standard model used in mainstream microeconomics. As argued in the last chapter this feature constitutes a core capacity of the human species. Instead of representing human individuals as a set of simple atomic entities each one just expressing an innate preference order by a degenerate kind of choice in exchange relations, the change of perspective initiated by John von Neumann conceptualizes choice as s creative process emerging in the interplay in between social entities as well as in between real processes and visions. Choice thus is not simply derived from innate properties; *choice rather is part of an innovative process that enables an entity to build an internal model to guide its actions*. Decoupling model building somewhat from immediate perception[27] provides certain degrees of freedom for possible models and thus enables the necessary variety, which evolutionary processes need

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[26] Compare (Fudenberg and Levine 1998, 2007) and (Roemer 1981, 2006).

[27] For an alternative see (Simon 1956).

for their processing. It is obvious that innovation—*social innovation* in the just mentioned sense—is the *driving force of evolution*.

The primal social innovation evidently has been the emergence of the first social forms of the human species itself. As hinted at in the last paragraph of "Section 1", evolutionary game theory was able to identify a forerunner of human individuals are characterized by heterogeneous behavioral traits, then the overall population can be said to play a mixed strategy. If, furthermore, this mixed strategy has evolved long enough in an environment that was stable enough to assure the improvement of the population's fitness, then the vector of these population shares carries this population's knowledge. Note that an animal of another species which might encounter an animal of the former species experiences a kind of eo-probability: all members of the other species might look alike, but the eo-probability of a certain behavioral trait, e.g. being aggressive, is equal to the share of the carriers of this trait in the total population.

Since each individual member carries exactly one trait all of its life, the change of shares is rather slow. What gave the human species the decisive advantage over the rest of the animal kingdom—at least this is the speculation—was *the possibility to internalize mixed strategies in the brains of each single individual*, *a capacity that was experienced by the emerging consciousness as choice*. This new capacity not only meant greater flexibility if environments started to change more rapidly, but it also meant enhanced stability if sudden disasters killed greater parts of the population—with the internalized probabilities, the overall mixed strategy could always remain constant, while, without that feature there always was the danger that certain features might become wiped out completely. Unfortunately it seems that we do not have the slightest historical evidence yet whether and how this primal social innovation took place.

Note that social innovation as core process of the human species has to be understood at least at two game-theoretic levels. On a *first level* the *choice of a mixed strategy* provided some evolutionary advantage with respect to flexibility and social memory—as just described. Since the different trajectories, which entities choose to traverse environments (starting from different starting positions), lead to different experiences, and hence to different internal models, it is obvious that communication is essential to provide a counterforce against diverging views. Heterogeneity versus the repeated effort to reconcile partly contradictory experiences via communication into knowledge, this process of creation out of contradiction constitutes a *second game-theoretic level*. At this level it is *not* a mixed strategy in a given internal model, which emerges; this level rather focuses on the emergence of new models out of parts of the proposed set of given (heterogeneous) internal models. As far as this creation succeeds, it contributes to the emergence of a new social entity. At this level the task of game-theoretic description is not to cast choice behaviour for a given extensive form game (first level), instead it has to *throw light on the emergence of newly emerging game trees* involving the essential interplay of communication and experiences. To expand the scope of traditional game theory to cover the part of the emergence of its central ingredients is straight forward—at least from an evolutionary perspective.

This second level, innovative choice is currently mainly investigated by Schumpeterian economics—and with different terminology by brain researchers investigating the neurological basis for model building by analogy. Both streams of research today still remain mostly within their descriptive realms of possibility; prevailing newer mathematical methods of game theory carry the birth-mark of theoretical physics, von Neumann's vision to overcome this deficiency has not been followed. Perhaps a more algorithmically inclined information science can help to point a way out of this impasse.[28]

Fortunately enough the deficiencies on the side of the development of formal languages are somewhat balanced by empirical research. There is ample evidence of how social innovations worked in the last 2,000 years. An old idea of Martin Shubik (1980) was to take a closer look at the categorization of environments as they are represented in payoff matrices. Some structures of payoff matrices support and even necessitate certain evolutions (and co-evolutions) that eventually lead to internalized knowledge, i.e. choice. This is not only a statement about animal populations, but also can be understood as an argument concerning industries. Environments, represented by these payoff matrices, used to change slowly, but they changed. More precisely, to an increasing degree they were changed by the populations which inhabited them. In other words, there is one overall system containing the slow dynamics of environments as well as the still somewhat faster dynamics of the populations living in them. It is thus important to understand the newly emerging payoff matrices, in principle, as knowledge enabling states—global environmental problems hopefully will produce new social entities which gain knowledge to make the right choices to cope with the involved dangers. Of course, this is a big issue that goes beyond the scope of this article.

Innovations arrive in swarms. This fact has received a lot of attention and explanations abound. It is not that surprising. Even from a purely formal point of view, it can be said that large systems tend to be oscillating systems[29]—and the global production system gains speed and extension in a breath-taking manner. On the other, hand all life on earth has experienced oscillations of the natural environment in the time domain (days, years). It might not be too far-fetched to link the emergence of memory of living systems to the pulsating character of the perceived environment. As argued above, the experience of time simply reflects the rise of entropy in the natural world. One of the most exciting research areas in mathematical biology concerns the detailed features of how temporal pulsations are translated into the spatial domain (compare (Strogatz 2003)). Still, most formal treatments allow only for a parsimonious consideration of the time domain; the formal tool set still is too restricted in that area. It seems reasonable to try to formalize the emergence of social entities as ascending pulsations passing a certain threshold of strength. The most important ingredient to understand their temporary existence is what is called the ratchet effect. Ratchets keep activity levels from falling back to lower levels. In economics, they typically are linked either to meso-economic institutions or to knowledge effects. The really difficult part to explain comes when the social entity with the help of a ratchet has reached the new plateau and looks around to find the new direction to which it should address its efforts.

[28] Compare for example Roughgarden et al. (2007).

[29] In an influential article Larry Samuelson (2002) writes that 'evolutionary game theory thus provides little reason to believe that equilibrium behavior should characterize all games in all circumstances.'

Recent technologies have increased the importance of waves of communication, of fashions in techniques and management styles. But the extremely low interest rates of the last three decades signal that globally there is an excess supply of capital—and really profound investment into innovative areas is stagnating. Perhaps it is again the question of the social entity that has to be solved first: Whose choice should it be to choose the next large scale innovation?

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