Annals of Public and Cooperative Economics 71:2 2000 *pp. 229–259*

NETWORK INTERACTION WITH MATERIAL AND RELATIONAL GOODS: AN EXPLORATORY SIMULATION

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ABSTRACT:** *We model interaction within the members of a work group, who carry on different projects and can choose to cooperate with each other or to exploit the work of the others. We focus our attention on the dynamic interdependence between their material performance and the structure of the relations among them. In particular, we assume that their satisfaction depends both upon the material outcome of their projects and upon the quality of their reciprocal relations (so that these two aspects are seen, to a certain extent, as psychological substitutes). As dissatisfaction may generate the disruption of social links, the consequent failure of the projects is a possible outcome. In turn, satisfactory relations and stable cooperation may loop positively together. Our model merges game theory and network representation of the relations among actors, thus opening a route of research that, to our knowledge, has not yet been explored.*

* We are grateful to Luigi Vanin for his essential help in the production of the computer simulations and for fruitful discussion of a lot of details. We thank Giacomo Corneo, the seminar audience at University of Osnabrück and especially Benedetto Gui for insightful comments on earlier drafts, with the usual disclaimer.

** *Résumé en fin d'article; Zusammenfassung am Ende des Artikels; resúmen al fin del artículo.*

1 Introduction

Economic processes essentially deal with the interaction among human actors, but the provision of satisfactory analytical models of such interaction has proved to be one of the most difficult tasks faced by economists and, more generally, by social scientists. Economic historians and methodologists of economics (e.g. Donzelli (1983) and Boland (1982)) have been advising us for a long time of the pitfalls that hide behind rigidly individualistic or holistic settings. These difficulties are basically due to one main issue: if, on one hand, it is true that aggregate economic results appear as the complex combination of several individual behaviours[1], it is also true on the other hand that individuals are never isolated. The socio-economic context that frames individual action shouldn't be seen as given once for all, since it is modified in turn by all the interactions which take place within it (Puggioni and Sacco (1998)). Indeed, one of the most complex problems in modelling interaction comes right from the co-evolutionary dynamics of individual actions and social structure (Granovetter (1985)).

In this paper we try to provide a first step toward the study of such a co-evolutionary social dynamics by means of a simple game-theoretic model that should be seen as a contribution to the vast literature that in the last decades has tried to establish a bridge between the micro and the macro dimensions of economic analysis (Weintraub (1979)). Our approach is to avoid the micro–macro contraposition, focusing instead on the 'mesoeconomic' structure of the relations among economic agents, and thinking of such a structure as a particular kind of economic good (a relational good) or as a peculiar form of capital (relational capital). The recent literature in both economics and social sciences has convincingly stressed the relevance of such concepts (see e.g. Uhlaner (1989), Coleman (1988) and (1990), Donati (1991)).

In a short synthesis, relational goods (henceforth RGs) can be defined as a class of local public goods (non rivalry and non excludability hold just for those who find themselves in a certain context of relations), such that they cannot be enjoyed alone, but only jointly, through the relations shared with other people. This makes them different both from private goods and from traditional public goods,

1 Throughout the paper we refer to the behaviour of individual actors, who can also stand for firms or institutions.

which, at least in principle, can be enjoyed alone. A consequence is that, the specific identity of the people sharing a RG may be crucial, and, besides, their number may increase individual satisfaction (think e.g. of a party). One of the most salient aspects of RGs is that the research of such goods prompts individual behaviours towards reciprocity and solidarity (the existence of which, in many cases, is hardly accounted for by the rational action paradigm). Examples of RGs include social approval, friendship, sharing life with another person, creating or reinforcing group identity, having high quality relations in work environment.

RGs have not only intrinsic value, but also instrumental value, in that they can be pursued as means for some further purpose (everyday experience offers many instances of 'convenient' relations). Moreover, independently from an individual's subjective intention in building a social link, the structure of social relations among actors may work as an objective constraint, which raises the costs of reaching one's goals[2], or, conversely, may work as a sort of capital, which increases the possibilities that are available to an individual and, over time, to an economy as a whole (think e.g. of industrial districts). This general idea is usually captured by the concept of social capital. Examples are the amount of trust and the information potential incorporated in relations, the existence of certain norms with effective sanctions, structured authority relations, the presence of social organizations[3] (see Coleman (1988) and (1990)). Here we shall focus on the fact that, since RGs may turn out to be instrumentally useful, it will not be inappropriate to consider their aggregate level in a social network as a particular endowment of the network itself, thus being able to study its possible influence on aggregate result over time. We shall consequently consider this initial level as a form of capital, namely a relational capital (henceforth RC).

The above remarks, although brief, call for the close consideration of two fundamental points:

- On one side, we need good formal models of individual action and interaction;

2 In some developing countries, for example, it is likely to observe such obstacles due to an inadequate social structure.

3 Notice that the latter can be built either for economic purposes (e.g. private firms), or for non-economic ones (e.g. voluntary cultural or mutual help associations).

- On the other side, we need an analytical formulation of the structure of social relations in which actors are embedded.

These two aspects are evidently distinct, but a good model should be able to account for their reciprocal influence, that is, as we mentioned, of their co-evolutionary dynamics (Macy (1996)). A major, very promising research direction of development in this respect can in our opinion be found in the combination of social network analysis and evolutionary game theory.

Evolutionary game theory has commanded extensive attention and research effort from economists in the past few years[4]. Much less attention has however been paid to date to social network analysis, at least in the economic literature. On the contrary, it has been extensively studied and developed among sociologists (see Wasserman and Faust (1994) and Scott (1997)). This is however a major weakness of the economic approach, which tends to focus on rather artificial and mechanic characterizations of interaction contexts in terms of random pairings or local interaction among actors living on a rigidly symmetric lattice (see e.g. Fudenberg and Levine (1999) for an overview). Social network analysis has on the contrary developed articulated characterizations of the subtleties of human interaction in terms of reciprocity, intensity, duration and content of relationships, and the network characteristics of density and permeability (defined, respectively, as the ratio between the active social links and the possible ones, and as a measure of the 'ease' of interaction among actors). Moreover, starting from these concepts, and using suitable techniques of multidimensional scaling, it is possible to translate relational differences into social distances, thus elaborating a social metrics.

These are only a few hints of the potential benefits in terms of analytical richness that can be expected from a substantial combination of these two different streams of research.

If we concede that actors are not only interested in their own material gains when interacting with others, but also in the relations they can establish with them (i.e. they attach value to RGs), we can

4 For a critical nontechnical introduction, see e.g. Hargreaves Heap and Varoufakis (1995). Weibull (1995) provides a rigorous and systematic treatment.

reach a double result: on one hand, we can explain behaviours that remain poorly elucidated by traditional rational choice models: think e.g. of high levels of participation in the provision of public goods, or to the creation and diffusion of trust and reciprocity; on the other hand, we point out how individual and social welfare builds on satisfactory ways of 'being-with-others', as it is clearly established in the social sciences literature (e.g. Donati (1991)). Both points are elaborated in the present model.

In the game theoretic literature, the prisoner's dilemma game has become a simple paradigm of the structure of the possible conflict between a cooperative behaviour and a defectionist one, which is relevant to many economic interactions. The prisoner's dilemma is characterized by the fact that, even if mutual cooperation represents the optimum social outcome and is Pareto-superior to mutual defection, it is not reached, because each player, individually, finds it more rewarding to defect. This scenario, as we shall see, can be significantly modified by the introduction of relational aspects, both because they can lead individuals to reason in a non strictly self-interested way (see e.g. Sugden (1993)), and because they add a new motivation to individual behaviours (see e.g. Uhlaner (1989) and Sacco and Zamagni (1996)).

As far as welfare aspects are concerned, one can legitimately assume that, on one hand, rewards from interactions with others depend upon both the relational and material dimensions[5]; and, on the other hand, such rewards induce players to modify their relational attitudes, thus acting as one of the most important leverages of socio-economic structural change.

The model presented here is meant as a preliminary step toward an effective merging of the evolutionary game-theoretic and of the social network approaches into a common framework. We therefore do not develop a full evolutionary model endowed with a selection mechanism acting over players and/or behaviours but rather a basic game-theoretic model which allows us to compare the material and relational performance of different adaptive strategies. We do this by

5 An interesting model, in which concern for socially provided goods in socially segmented environments fosters economic growth, is developed by Corneo and Jeanne (1999).

studying a particular class of games, which could be called 'relational–economic' or 'network' games. Since research in this direction is in its infancy, it will be useful to discuss in some detail the structure of our model. This will be done in the following section.

2 Simulation model: prisoner's dilemmas in a triangular social network

We focus upon the well known prisoner's dilemma game (henceforth PD)[6], and upon an extremely simple social network that involves only three actors (henceforth called A, B and C). Before considering more technical and formal aspects, we discuss the model in its general lines.

2.1 The game's general structure

We assume that each of the three players interacts with the other two for a predetermined length of time, during which she repeatedly faces the choice between defection or cooperation toward either of them. In other words, at each turn of the game, each couple of players plays a PD[7]. At the beginning, the relation linking each couple can be more or less intense, but its intensity evolves endogenously throughout the game. Relational intensities play a double role in the model: first, they are considered 'goods' in their own right, i.e. they directly

6 PD's fundamental characteristic consists notoriously in the fact that it presents defection as a dominant strategy, which, when adopted by both players, leads to a Pareto-inferior outcome than would be obtained through mutual cooperation. Individual rationality, i.e. rational pursuit of self-interest, then fails not only from a social point of view, in the sense that it yields socially inefficient outcomes, but even from a strictly individual one, in the sense that, if a compelling norm existed which causes players to cooperate, each one of them would individually be better off.

7 We keep the structure of the game fixed: at each turn, players always face the same PD. A somehow complementary research path is explored by Joireman et al. (1996), who let the game structure (technically, the payoff matrix) vary endogenously, but do not consider the specific relations among actors, i.e. the social structure.

contribute to individual satisfaction[8]; second, they are the specific channel through which interaction (and particularly cooperation) takes place. For the latter reason, they may indirectly cause the emergence of stable social patterns of cooperation through the reinforcement of the interaction between players who *successfully* aspire to the cooperative outcome[9]. To focus ideas, assume that players, as members of a work group, are carrying out a joint work, within which they are responsible for different projects. Assume moreover that each of them is paid according to the results of the project under her direct responsibility, which takes advantage of the help from the other members of the group (perhaps because of complementary skills)[10]. It will appear immediately convenient for anybody to try to exploit the cooperation of the others but not to cooperate herself (a very common situation in any corporate experience, which may well be described through a PD).

As we said, a distinctive feature of our game is that players are not just interested in their material gains (i.e. in the outcome of their projects), but also in the relations which occur among them. In particular, their satisfaction in the long run depends upon a combination of these two factors, material and relational. In the medium run[11] each couple of players intensifies or loosens the relation linking them according to the reciprocal satisfaction experienced in their previous interactions. For example, it is possible that a cooperative player may feel exploited by a defecting one and is thus induced, over time, to reduce her relational intensity with the 'unfair' partner. This makes defection a risky choice, because, even if it may be immediately rewarding, it can bring in the long run (through reciprocal dissatisfaction) to the disruption of the social link between the two

8 The representation of the 'quality' of a relation through its 'intensity' is admittedly rather crude and should be thought of just as a first approximation. For a definition of the concept of relational intensity see Mitchell (1969).

9 The effect of relational intensities in situations where the emergence of cooperation is problematic is analysed in detail below.

10 Kremer (1993) investigates such a technological complementarity among workers with different skills in the case in which it is not possible to substitute several low-skill workers for one high-skill worker. In particular, he tackles the question of how such workers are matched together and focuses his attention on the so-called O-ring production function.

11 We can think of the long run as of the whole length of interaction (100 turns). We moreover distinguish between a short run, corresponding to a single turn of play, and a medium run, corresponding to a horizon of two turns.

work partners, thus making both of them lose any possibility of successfully carrying out their joint work, i.e. the two projects they work jointly at[12].

We pay explicit attention to the fact that the same 'objective' results are not evaluated in the same way in any situation, but their evaluation (and consequently the satisfaction derived from them) may depend to a substantial degree upon the level of the 'aspirations' held 'subjectively' by players in any particular moment of their interaction. In the present model, we consider two alternative specifications of such aspirations: first, we keep them fixed at a predetermined level, then we let them vary adaptively, assuming that players learn from experience and adjust aspirations according to their actual performance[13].

We assume that players decide at each turn how to behave toward each of the other ones. Relational intensities, however, change more gradually and slowly. The meaning of this assumption lies in the recognition of the inertial character of social structures, which, from a short run point of view, makes them look somewhat stable; on the other hand, behaviours are updated more frequently, possibly according to some form of rationality[14]. In particular, we consider three kinds of adaptive strategies that have been extensively studied in the literature on PDs and correspond to different instances of adaptive rationality (see e.g. Sigmund (1993) for an overview): *Win/stay lose/shift* (henceforth WSLS), *Best reply* (henceforth BR) and *Tit for tat* (henceforth TFT). We shall present them later in more detail. We

12 The scenario we depicted may be applied to several possible situations: think e.g. of the case of two scholars with complementary skills (e.g. a theorist and an econometrician) who are simultaneously carrying out two papers which will appear under one name, but still require the specialized contribution of the other scholar to be successfully completed in some detail; or think of the case of two workers (either independent or dependent) with different skills, who are matched for a certain time in a work group, whose task consists in developing an articulated proposal (of whatever kind it may be), a part of which is realized through their cooperation and another part of which is due to each individual's autonomous work, but such that if the group breaks up, no joint proposal will be presented and the work of both (autonomous and cooperative) will be lost (think e.g. of a joint society of an architect and of a lawyer who work together on the architectonic and legal aspects of some building projects).

13 A change in a player's aspiration level directly implies a different degree of satisfaction. Whether (and how) it may also influence strategic choices of action depends on the particular assumption made about players' rationality.

14 It is worth noting that, if behaviours were interpreted as obeying to social norms rather than to rationality, their changes would also be very slow.

Table 1

	Cooperate	Defect
Cooperate	2	0
Defect	3	1

concentrate for the sake of simplicity on 'homogeneous populations' of players adopting the same behavioural option. We are thus able to draw well defined conclusions about the performance of a strategy when every member of a population adopts it[15]. However, at the end of the paper we will have something to say about 'mixed populations' as well.

Our analysis is based on simulation results. We simulate 756 finitely repeated games, each lasting 100 turns, each corresponding to slightly different treatments of initial conditions and parameters of the model.

2.2 Analytic structure of the simulation model

We now present in technical detail the distinctive features of the model.

Material payoffs matrix

The (symmetric) payoffs matrix, which never changes over the game, is of a traditional PD type (see Table 1, where payoffs are those of the row player).

This structure is entirely standard. An additional complication comes however from taking into account the relation among players (RGs). Consequently, in the future we will refer to the present matrix as to the material goods matrix (henceforth MGs), i.e., the one reporting material payoffs. We shall call $M_n(A,B)$ the material payoff gained by A playing against B at the n^{th} turn (an analogous notation extends to the other players).

15 This way, the analysis takes a somewhat Kantian flavour.

Players' strategies

Each player's strategy consists of two parts: her behaviour at each turn, and how to modify her relations with other players at any two turns[16]. We keep these two components separated at the logical level: while the dynamics of relational change is assumed to be the same for everybody, we shall henceforth speak of 'strategy' just to denote the rule that players follow to determine how to play next (which can be WSLS, BR or TFT). As we said, we only simulate interactions within strategically homogeneous populations (i.e. those in which all players adopt the same strategy) and assume that strategies remain unchanged throughout the whole game[17]. We now present an analytical description of such strategies:

- WSLS is a player who keeps behaving in the same way if her performance is satisfactory, while shifting to another behaviour at random when not satisfied[18]. Her satisfaction is evaluated at each turn through the comparison between her actual performance and her aspiration of performance over that turn. We shall refer to such aspirations as the 'immediate aspiration level'. It represents the total (material and relational) desired payoff[19] at that turn: she will 'stay' at the next turn if she gets more, and will instead 'shift' action if she gets less[20]. Due to the lack of any strong reference for WSLS immediate aspiration levels (and also for her choice of action at the first turn), we simulate different possible calibrations of such strategy, which will be presented later. The pragmatic, experimental nature of the WSLS rule may make it seem somewhat

16 This way we distinguish between slow social dynamics and fast rational response dynamics.

17 Both restrictions will have to be abandoned in future research. Anyway, in the present setting one can think of players as either genetically or (deeply) behaviourally programmed; in the latter case, one can think that the order of magnitude of the amount of time needed to modify the programming in the face of bad performance is larger than the duration of the interaction process and that behaviour can thus be thought of as stable. Some of the most interesting developments arise from abandoning this limitation (see e.g. Antoci, Sacco and Zamagni (1997)).

18 In our simulations she does not randomize: if unsatisfied of cooperation, she will defect, and vice versa.

19 Total payoff will be analytically defined later.

20 Notice that such immediate aspiration is defined just for WSLS and concerns a short run horizon. We shall later introduce for all strategies aspirations over the medium run, that should not be confused with the present ones.

unsophisticated and 'irreflexive', if not entirely naive[21]. However, as we shall see later, it is also a quite flexible strategy that guarantees on average 'good' results in 'complex' situations.

- BR chooses the best behaviour from the point of view of her personal interest narrowly defined, that is to say, she always defects (as in PD this is a dominant strategy)[22]. It is worth noting that BR qualifies as the most 'rational' strategy in the traditional sense, because of its exclusive focus upon self-interested maximization. Nevertheless, in complex social contexts, this strategy does not always turn out to be as rewarding as one might think.
- TFT cooperates at the first turn with any other player and then gives tit for tat, that is to say, she imitates her opponent's behaviour at the previous turn[23]. As a result, whenever TFT players face each other, they keep cooperating throughout the whole game. This strategy can be interpreted as a strict obedience to a norm of retributive justice[24].

The analysis of the network made of three WSLS is particularly complex, in that one has to specify, besides the other variables, the players' immediate aspirations and actions at the first turn. The analysis of the BR and TFT populations is easier, because, playing among themselves, they constitute two paradigmatic cases: universal defection, which is the paradigm of narrowly self-interested rationality, and universal cooperation, which in the traditional PD leads to the Pareto-dominating solution. In mixed population settings,

21 For example, when facing a BR, who always defects, a defecting but unsatisfied WSLS could be prompted to cooperate at the next turn to look for more rewarding payoffs, thereby ending up worse off.

22 Notice that it is completely irrelevant whether she cares only about material payoffs or about RGs as well, in that the latter case merely amounts to a monotonic transformation of the material payoffs matrix (whose entries go through sum or product with a given set of relational intensities), and thus defection remains a dominant strategy.

23 In other words, she starts playing conceding her trust to any player and keeps cooperating throughout insofar as no one defects; but she is not willing to let others exploit her and does not forgive even a single detection: she immediately punishes it with her own defection. If the opponent shifts later back to cooperation, she follows after one turn and forgets about the past, otherwise she goes on defecting.

24 In homogeneous population settings, such norm is equivalent to a strict ethical code prescribing cooperation.

things obviously change: we simulated a few such cases, to give some intuitive idea of the results that could emerge.

Initial relational intensities

The social structure that frames the interaction among the three actors is captured by the relational intensities. Some theoretical issues are in order: for example, should we think of relational intensity as an objective or a subjective magnitude? And furthermore, how to measure it?

About the first problem, it should be observed that social relations are a bridge between the objective and the subjective dimension and that they should be dealt with consequently. In our model, we think of intensity values in objective terms. Intensities are then modified in an inter-subjective way: if both players share a common attitude as to the intensification or to the weakening of their link, the latter is modified in the suitable direction, whereas if they disagree, the tie is weakened, but less than in the consensual case. Anyway, the choice of a single player is not enough to determine how a relation will evolve, because this is the product of the intentions of both. Finally, the subjective aspect finds its place too, as a player's decision to intensify or weaken a relation depends entirely on her subjective satisfaction, i.e. on her aspiration level. Thus, subjective and objective aspects interact and influence each other, as it ought to happen in a co-evolutionary model.

As far as the measure of relational intensity is concerned, it must clearly capture several aspects in a synthetic way. It is of course unrealistic to condense all the information regarding RGs in only one value, but it is nevertheless useful to highlight the logic and the mechanics of the model[25].

Another feature highlighted by our model is the influence of initial levels of relational capital on long run outcomes of the interaction. The

25 Were this kind of analysis to be applied to real situations, a vector of values, representing the relevant characters of a relation on more dimensions, should be associated to every interaction that builds the social network. How such a vector could and should be built is a problem that cannot be addressed in general terms.

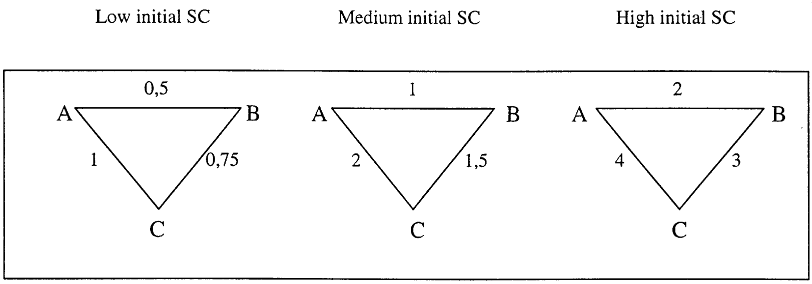

Figure 1

amount of RC available to the three subjects at the beginning is here simply calculated as the sum of the initial relational intensities (initial level of RGs)[26]. We simulate three initial situations, in which RC is respectively 'low', 'medium' or 'high'[27]. The graphs of these triadic social networks look at the beginning of the game like in Figure 1 (where the numbers aside the lines denote the intensity of the various relations).

We suppose that at the end of even turns players evaluate their satisfaction toward each of the other ones on the base of their total results in the two previous interactions: a relation is intensified by +0,2 (or weakened by −0,2) if both players are reciprocally satisfied (or reciprocally unsatisfied), while its intensity diminishes just by −0,1 if one is satisfied but the other is not. This relational dynamics can be seen as driven by individual behavioural rules that are part of the specification of the individual strategy (e.g. 'cooperate/weaken', 'cooperate/intensify', 'defect/weaken', 'defect/intensify'), whose outcome is an intensified relationship only if both players choose strategies that contain the 'intensify' option.

26 When relations are seen as goods, their subjective dimension becomes most apparent, whereas when they are seen as capital, their objective, aggregate dimension dominates.

27 We measure relational intensities on a scale running from a minimum of zero to a maximum of 4. At the beginning, we suppose without loss of generality that the link between A and B is less intense than that between B and C, which is in turn less intense than that between A and C.

Let us consider the relation A/B as an example, keeping in mind that the same holds for the other two relations. We call $R_n(A,B)=R_n(B,A)$ the (symmetric) relational intensity between A and B at the n^{th} turn (the numbers in Figure 1 show these values when n=1). Let $P_n(A,B)$ be the 'total payoff' (both material and relational) earned by A playing against B at the n^{th} turn (whose analytical definition will be discussed later). Similarly $P_n(B,A)$ is defined as B's 'total payoff' against A at the same turn. Let n be an even turn of the game (since relations are only modified every two turns). We then set $T_n(A,B)=P_{n-1}(A,B)+P_n(A,B)$: it is the 'total payoff' of A vs. B in the two turns $n-1$ and n. Likewise we define $T_n(B,A)$. Let $H_n(A,B)$ and $H_n(B,A)$ be the 'aspiration levels over the medium run' (again, the discussion of such concept will follow later), held at turn n respectively by A vs. B and vice versa. If $T_n(A,B) > H_n(A,B)$, then A is 'satisfied' of her relation with B, otherwise she is unsatisfied. In turn, B is satisfied of her relation with A if $T_n(B,A) > H_n(B,A)$, and otherwise unsatisfied[28].

To sum up, if both are satisfied, we postulate that $R_{n+1}(A,B)=R_{n+1}(B,A)=R_{n-1}(A,B)+0.2$; if both are unsatisfied, then $R_{n+1}(A,B)=R_{n+1}(B,A)=R_{n-1}(A,B)-0.2$; if only one is satisfied, then $R_{n+1}(A,B)=R_{n+1}(B,A)=R_{n-1}(A,B)-0.1$.

Aspirations over the medium run and evaluation of satisfaction

We admittedly model the dynamics of relational intensities as driven by individual aspiration levels in a rather crude way. Although simple, this modelling choice allows us to make some considerations of interest as to the medium-long run properties of the model, as we consider aggregate players' satisfaction levels over the 100 turns of the game.

There are potentially several possible ways of defining total payoffs – i.e. of aggregating MGs and RGs – and, correspondingly, aspiration levels (that is of constructing the two matrices P_n and H_n). In this paper, we specify for each turn of play total payoffs as the product of MGs and RGs: $P_n(A,B)=M_n(A,B)*R_n(A,B)$. Players' satisfaction, then, is computed at the end of even turns as the difference between the sum the total payoffs got in the two previous turns of interactions and the level of aspiration carried over the same two turns. Analytically, let n be an even turn of play and $S_n(A,B)$ be the

28 Notice that, as this comparison takes place any two turns, $T_n(A,B)$ and $H_n(A,B)$ are defined just for even values of n. As a consequence, for all even n $R_n(A,B)=R_{n-1}(A,B)$.

degree of satisfaction of A vs. B after turn n (which involves her performance against B in the interactions in the two turns $n-1$ and n); we have $S_n(A,B)=T_n(A,B)-H_n(A,B)$.

Such definition of total payoffs through multiplication requires some comments. First of all, it corresponds to the idea that, to a certain degree, MGs and RGs can be substitutes. In particular, it means that, for a given level of aspiration, a player might be either satisfied by virtue of a good relational situation (even if her material results are not exalting) or because of good material results, which may compensate the lack of meaningful ties. We recognize that a direct multiplication gives just a rough idea of how this substitution may look like in reality (we refer the reader to Antoci, Sacco and Vanin (1999) where we develop a model in which substitution between RGs and MGs is explicitly taken into account). However, we choose it because its simplicity lets us address in a very general way the issue of the interdependent dynamics of these two different sources of individual welfare. Moreover, it is evident that we cannot aggregate MGs and RGs by simply summing them, unless we find a monetary equivalent for the latter[29]: in its absence, our choice is not only meaningful, but also analytically convenient. Finally, since in our simulations aspiration levels over the medium run are never negative, while relational intensities can fall down to zero, whenever this last case occurs both players are since then till the end of the game always unsatisfied[30]: this is coherent with the idea that they are carrying over a joint work, which becomes impossible if they completely separate from one another.

As to the definition of players' aspiration, we distinguish two basic cases: fixed and adaptive aspirations (the latter allows for learning from experience). For both cases, we simulate three possible initial situations of 'low', 'medium' or 'high' aspirations. We assume that, in the absence of information from past history of play, each player initially holds aspirations that are proportional (by a factor of 1, 2, 4, respectively) to the intensity of her relations with the opponents: formally, $H_2(A,B)=K_H*R_1(A,B)$, where $K_H\in\{1,2,4\}$ is

29 Some possible hints in this direction come from the analysis of substitution relationships between nonmarket and market goods (see e.g. Ebert (1998b)) and from the application of a methodology employed in the theory of cost of living indices (see e.g. Ebert (1998a)).

30 Therefore, they do not have any reason to intensify their relationship again. Giving players a chance to rebuilt a 'frozen' relationship might be an interesting extension of the model.

the proportionality constant and the initial aspiration value is called H_2 because it concerns the turns 1 and 2 (the extension of the definition is immediate).

In the adaptive case, we suppose that each player updates her aspirations by taking the arithmetic mean between her previous aspiration level and her actual cumulated payoff. Analytically, this amounts to write $H_{n+2}(A,B)=[H_n(A,B)+T_n(A,B)]/2$, where n is again an even turn of play. This specification clearly tends to stabilize satisfaction levels with respect to the fixed aspiration case.

We conclude with some remarks about satisfaction. We can indicate A's total satisfaction as $S(A)=\Sigma_{n\in[1,50]}[S_{2n}(A,B)+S_{2n}(A,C)]$, and accordingly for B and C. Measuring satisfaction in terms of subjective aspiration levels instead of utility functions has two relevant advantages: that of focusing directly and explicitly on the fact that each individual has different evaluation criteria, and that of allowing for the analysis of how preferences change over time. Last, but not least, aspiration levels can be defined in a cardinal way, as they are related to payoffs (they are nothing else than 'hoped' total payoffs for two turns), so that the difference between them, i.e. satisfaction, can be coherently measured as a (almost) completely objective variable[31]. With this specification, we can safely treat the difference between aspirations and payoffs as an objective quantity, which allows comparisons among different players.

Calibration of WSLS players

We have already discussed to some extent how to specify WSLS players' behaviour. It is time to tackle this point in more detail. Let us start with immediate aspirations. We assume that at the beginning they

31 We understand that the last conclusion may appear problematic, for at least three reasons; first, because it can well be the case that an individual does not actually know what her goals are, that is to say, what she exactly aspires to; second, because nothing assures that it is always possible to measure complex aggregate goals on a unique scale; last, because the researcher could not know the real levels of aspiration. Nevertheless, this last problem concerns empirical investigation, and we therefore do not consider it here; the second one, although valid in general, does not apply to our model in view of our definition of aggregate payoffs; the first one is resolved through an *ad hoc* assumption, that every player has well determined preferences.

are proportional to the intensity of relations[32]. If K_{PT} is the proportionality constant, then player A is satisfied with her first turn played against B if the following condition is met: $P_1(A,B)=R_1(A,B)*M_1(A,B)>K_{PT}*R_1(A,B)=IH_1(A,B)$ (where $IH_1(A,B)$ denotes A's initial immediate aspiration level toward B), that is to say, if $M_1(A,B)>K_{PT}$. In other words, satisfaction at the first turn depends entirely upon the material payoff, which is determined by strategic interaction. Hence, according to the values of K_{PT}, immediate aspirations can be interpreted as sets of preferences corresponding to different 'personality traits'[33]. We therefore define 5 possible personality traits for WSLS players, by assigning to K_{PT} the real integer values from -1 to 3[34]:

- Why Bother ($K_{PT}=-1$): this player's aspiration level is less than zero, which means that she is always satisfied. Whatever may happen, she will not be induced to change her chosen action, because she will be content with the outcome anyway.
- Lazy ($K_{PT}=0$): this player may be unsatisfied only if her material payoff equals zero, that is to say, only in the case in which she cooperates against a defecting opponent. In any other case, she will be happy with her course of action.
- Exacting ($K_{PT}=1$): this player's satisfaction strictly depends on the opponent's behaviour. If the other player cooperates, she is satisfied; if, instead, the opponent defects, she is unsatisfied. Although this player does not necessarily want to cooperate, she asks for cooperation on the opponent's side anyway!
- Opportunist ($K_{PT}=2$): this player is satisfied only if exploiting other people, that is, when she defects and the other one cooperates. In any other case, she keeps on shifting her actions until the above happens.

32 This assumption is somewhat analogous to the one we made about medium term aspirations for all strategies.

33 It is worth stressing that in the fixed aspiration case these personality traits characterize players throughout the whole history of play, whereas in the adaptive case they are modified according to one's own experience. In this last instance, the updating mechanism for immediate aspirations is the same used for medium term aspirations, that is, the arithmetic mean with actual payoffs. Formally, writing $IH_n(A,B)$ for A's immediate aspiration level towards B at the n^{th} turn, we have: $IH_{n+1}(A,B)=[IH_n(A,B)+P_n(A,B)]/2$. It can be observed that, as for the medium run, immediate aspirations are defined on aggregate results too, that is, on the product of MGs and RGs.

34 We stick to our choice of keeping populations strategically homogeneous. Therefore, we only consider cases in which all of the three WSLS share the same initial personality trait.

- Utopian (K_{PT}=3): this player's aspiration level can never be satisfied. For this reason, she will try to reach her goals by shifting her behaviour every time, without getting satisfaction until her aspirations are adaptively revised downward.

As to WSLS' initial choice of action, we assume that every player chooses the same initial action toward both opponents.

3 Analysis of simulation results

We now turn to the analysis of the effects of these different initial settings on the following dimensions of the final outcomes:

- Emergence of a stable network configuration;
- Emergence of stable cooperation;
- Material performance;
- Relational performance;
- Players' final satisfaction;

We summarize here the most relevant features of each parameter constellation.

3.1 Players' strategies

Players' strategies constitute a key variable for explaining outcomes under all of the dimensions of analysis.

Emergence of a stable network configuration

We have already stressed that one of the peculiar characteristics of our model is the fact that the relational network changes endogenously. One can wonder whether network dynamics settles down at a certain point to some sort of steady state configuration[35]. It turns out that frequency (and speed) of network stabilization of BR players is much higher than that of TFT and WSLS ones[36]. The most interesting

35 To check this, we define a network stability index, given by the number of turns (out of 100) in which the whole network has remained in its (stable) final configuration.

36 This happens because, trying to exploit each other, BR are easily reciprocally unsatisfied and consequently tend to loosen their links over time, often until their disruption. Since in our model social ties cannot be 'rebuilt', a network with disrupted links turns out to be particularly stable.

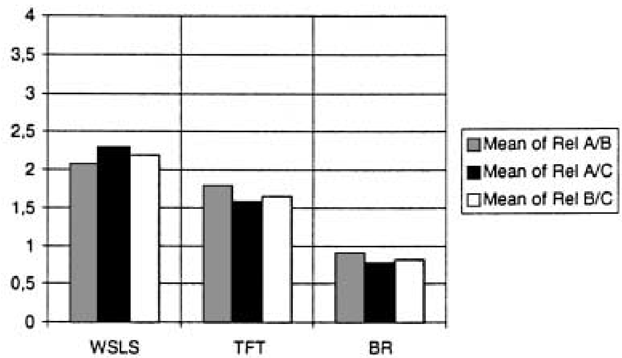

Figure 2 – Average final intensity of relations A/B, A/C, B/C (by strategy)

dynamic aspect concerns however the specific kind of relations that tend to become stable, i.e. what the stable social network looks like. Different strategies bring about very different consequences in this respect, as shown in Figure 2.

This result allows some understanding of the comparative social effects of the different forms of adaptive rationality. On one side, the individually most rational strategy (BR) is likely to lead to either solipsistic or at best scarcely social outcomes; on the other side, a norm of rigid reciprocity (TFT) does better: isolation is avoided, but social closeness is rare; finally, the pragmatic, impulsive and apparently less 'rational' strategy (WSLS) is on average the most conducive to intense social relationships. Such result is due to WSLS players' experimental attitude toward their opponents, which lets them behave in a more flexible way than the other two strategies. An intuition of why this behavioural pattern turns out to be socially rewarding can be grasped by observing that the possibilities of getting on reciprocally well may be reduced by a higher degree of rigidity.

Emergence of stable cooperation

As BR and TFT behave here as universal defectors and universal cooperators respectively, WSLS is the only strategy that needs closer inspection. The three couples of WSLS players tend on average to settle down to a stable pattern of action between the seventieth and the eightieth turn. In particular, they are more inclined to stable cooperation than to stable defection: it turns out that, when actions stabilize, it is four times more likely that cooperation emerges rather than defection[37].

If we discriminate among WSLS on the basis of players' initial personality traits, the results are the following. Lazy players are the least cooperative: because of their low reactivity to actual performance, they are not able to learn the way to cooperation. Together with Why Bother players, moreover, they are the only ones who are likely to end up as stable defectors, whereas Exacting, Opportunist and Utopian players never stick on stable defection, so they are able to reach a higher stability of cooperation. Such results can be rationalized in terms of the implicit sanctioning mechanism against defection that is produced by a relatively high tendency to change action as a response to poor performance.

As to the effect of the action chosen at the first turn, we find that initial cooperation is likely to bring about stable cooperative patterns, a result that reminds somewhat of the stability of trust in environments with an initial cooperative bias (see Fukuyama (1995)).

Material and relational performance

Let us start from the material payoffs[38]. Since the material part of our game is a PD, it is straightforward to understand that the

37 We study players' ability to stabilize their choice of action on cooperation or on defection through the introduction of two indexes (Coop and Def, respectively), defined in terms of how volatile are the cooperative/defective actions observed at the last turn of play. Analytically, take, say, the couple A/B and denote the defective action as 0 and the cooperative one as 1. If C(A,B) is the action chosen by A against B at the last turn – and likewise for C(B,A) – we can write:
Coop A/B={ASC A/B *[C(A,B)+C(B,A)]}/2
Def A/B={ASC A/B *[C(A,B)+C(B,A)−2]}/2
where ASC (Action Stability Counter) measures the number of previous turns in which the last action observed has been chosen without interruption. Averaging such indexes over the three interactions of a given simulation run and over the whole set of runs for any given strategy yields an aggregate measure of the cooperative/defectionist attitude of WSLS vs. TFT vs. BR.

38 Analytically, take player A as an example (analogous definitions hold for B and C). Remembering that $M_n(A,B)$ is the material payoff gained by A playing against B at the n^{th} turn, and defined $M(A)=\Sigma_{n\in[1,100]}[M_n(A,B)+M_n(A,C)]$, the aggregate production of our small economy is given by $M_{TOT}=M(A)+M(B)+M(C)$. Notice that, given the material payoffs matrix, $M(i)\in[0,600]$, i=A,B,C; $M_{TOT}\in[600,1200]$, the minimum and the maximum being obtained respectively in the cases of universal defection and of universal cooperation.

population of BR, always defecting, will reach the least efficient outcome (corresponding to the Nash equilibrium), whereas the Paretian optimum is reached by the population of TFT, who always cooperate. Interestingly, WSLS players end up very close to the Paretian optimum, thus proving to be a very efficient strategy from the material point of view[39]. Of course, this is not surprising, since we saw that WSLS tend more often to stabilize their reciprocal behaviour upon cooperation than upon defection.

As far as relational performance is concerned[40], TFT appears once again as the most rewarding strategy, WSLS obtains somewhat close results, whereas BR, unsurprisingly, performs poorly also on the relational side[41]. Such result is consistent with the previous ones: the elastic behaviour of WSLS turns out to be socially almost as efficient as a permanent cooperation[42].

Players' satisfaction

If we consider S_{TOT}=S(A)+S(B)+S(C) as a measure of aggregate final satisfaction, i.e. of social welfare, we can compare the different strategies by their welfare effect (see Figure 3, which reports average levels of S_{TOT}).

Not surprisingly, universal cooperation (TFT) brings about the highest satisfaction, WSLS obtains worse but somewhat close results, whereas BR attains a negative level of satisfaction, mainly due to the disruption of relational links caused by her defective logic of play: in the face of disrupted links, any outcome from the joint work becomes impossible, any dyadic group cannot solve its task and thus dissatisfaction unavoidably arises.

39 The average value of M_{TOT} for the population of WSLS is 1015.

40 The analytical setting is analogous: defined $R(A)=\Sigma_{n\in[1,100]}[R_n(A,B)+R_n(A,C)]$, the relative success of the various strategies is represented by the average values of R_{TOT}=R(A)+R(B)+R(C). Notice that $R(i)\in[0,800]$, i=A,B,C (the maximum being attained if all relations had always intensity 4); consequently, $R_{TOT}\in[0,2400]$ (remember that the relational intensity enjoyed by an individual and that enjoyed by her partner are the same).

41 The average values of R_{TOT} for the populations of TFT, WSLS and BR are respectively 1400, 1276 and 768.

42 Although we are aware that the values M_{TOT} and R_{TOT} are just 'aggregate production measures' (for this reason we speak of performance and not directly of efficiency), we would like to defend the possibility of interpreting them in terms of efficiency.

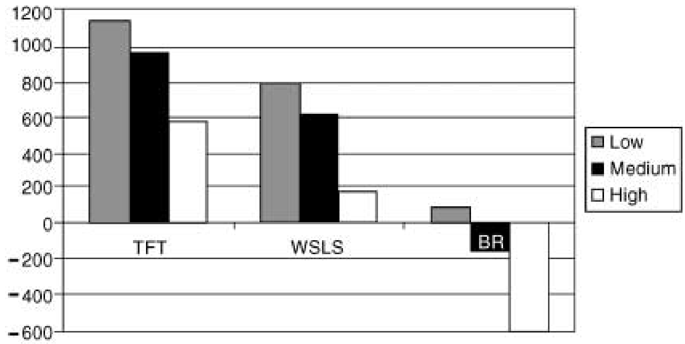

Figure 3 – Social welfare (by strategy and initial social capital)

3.2 Initial relational capital

Initial levels of RC are essential in the explanation of the following dimensions of the outcomes[43]:

- Relational performance;
- Players' satisfaction.

Interestingly, the dynamics of RC seems to be more important than its initial value[44].

Relational performance

As we saw, relational performance is largely determined by players' strategies, while all the other initial conditions have a small influence on it, but RC. When initial RC shifts from low to high, relational performance rises substantially[45], as one could well expect to be the case.

43 One might think of the initial level of RC as a sort of proxy of the past (i.e., extra-model) relational history of interaction among players.

44 This seems to support an interpretation of RC that stresses its importance more at the evolutionary level of social reproduction of relational–economic patterns than as a direct resource in some kind of production function. Although this is an interesting question, the present setting is too simple to tackle it adequately.

45 From little less than 1000 to little less than 1600.

Players' satisfaction

If we look again at Figure 3 above, an apparently paradoxical feature emerges: an inverse relationship between initial RC and final satisfaction. This result could be taken as a proof of the fact that satisfaction does not depend so much upon the starting level of RC as, instead, upon its dynamics throughout the interaction. In other words, good results obtained starting from difficult social situations produce much more satisfaction than those emerging from favourable social contexts[46].

3.3 Fixed vs. adaptive aspirations

The alternative between adaptive and fixed aspirations is relevant for the explanation of the following variables:

- Emergence of a stable network configuration;
- Emergence of stable cooperation;
- Final satisfaction.

Emergence of a stable network configuration

Fixed aspirations significantly increase the stability of the relational network: on average, the network reaches a stable configuration around the twentieth turn. This is not surprising, as the relational dynamics is driven by satisfaction, which in turn depends upon payoffs and aspirations. If the latter depend again upon payoffs, a more complex feedback loop emerges, which plays against quick stabilization.

As far as the final relational intensity is concerned, the social advantage of WSLS, that we observed in general in Figure 2, is mainly gained in the adaptive aspiration case. In fact, WSLS' major adaptive virtue is its flexibility, that works better in complex environment. A more linear logic of play tends instead to be more successful in more structured contexts. This is a hint that deserves further exploration in future research.

Emergence of stable cooperation

Learning from experience has a destabilizing effect not only on relations (as we have just seen), but on action patterns too; this is again hardly surprising. As a consequence, both cooperation and

46 Nevertheless, it could be the case that such a result does not hold in strategically mixed settings: this point mandates deeper investigation, without which any straightforward interpretation is somewhat unsure.

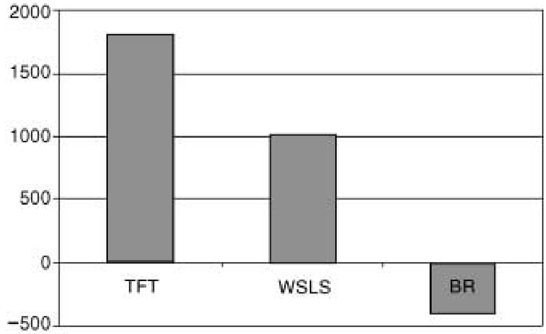

Figure 4a – Social welfare (by strategy, with fixed aspirations)

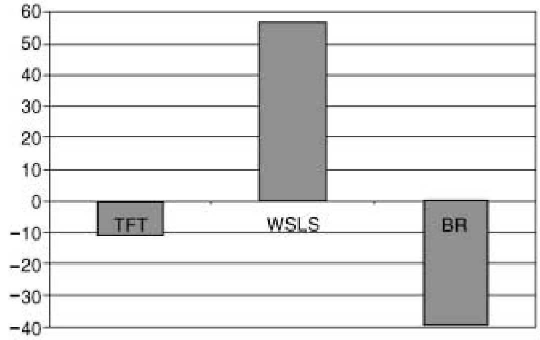

Figure 4b – Social welfare (by strategy, with adaptive aspirations)

defection are much more stable in the fixed aspirations context than in the adaptive one. In particular, in the latter case it never happens that WSLS players stabilize upon defection.

Final satisfaction

The graphs in Figure 4a and 4b show the relative satisfaction achieved by the three strategies respectively in the fixed and in the adaptive aspiration case[47].

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47 When players adjust aspirations to performance, the difference between the two, i.e. individual satisfaction, becomes obviously smaller (to give an idea, notice that average totals drop from 993 for the fixed aspirations case to 53 for the adaptive aspirations one!). As a consequence, one should consider satisfaction values as measured on two different scales for the fixed vs. adaptive aspirations cases, avoiding (misleading) straightforward quantitative comparisons between the two.

It is immediate to notice, again, the substantial increase of WSLS' performance in terms of comparative satisfaction in the adaptive aspirations vs. fixed setting. The 'experimental disposition' of WSLS players has substantial strategic value in that it avoids locking into inefficient outcomes and this implies crucial advantages upon more rigid strategic types, the more so the more 'rugged' the payoff landscape. Interestingly, thus, once allowed to react to experience, TFT players end up with a negative satisfaction, in spite of still excellent material and relational results: the more rigid the individual behavioural rule, the more likely it is that it stabilizes in a perverse way.

3.4 Initial levels of aspiration over the medium run

Our last level of analysis concerns the effects of the different initial levels of aspiration. They are relevant for the explanation of the following variables:

- Emergence of a stable network configuration;
- Emergence of stable cooperation;
- Relational performance;
- Final satisfaction.

Emergence of a stable network configuration

Players' aspirations influence network stability in the adaptive case only: the smaller the aspiration level, the more stable the network[48]. Their influence on final intensities of the relations is instead of primary importance (both in the fixed and in the adaptive aspirations case). In particular, too high initial aspirations have the effect of fostering players' mutual dissatisfaction, with the consequence of a gradual weakening of relations, often down to 'relational freezing' (0 intensity). This result is less spectacular in the adaptive aspiration case, but it still holds.

Emergence of stable cooperation

The stability of cooperation among WSLS is negatively related to their aspiration levels. Moreover, it turns out that, if excessive aspirations are an obstacle to cooperation, too low ones open the way to the emergence of stable defection. Therefore, stable cooperation is

48 In the fixed aspirations case, instead, initial levels of aspiration do not matter much: the network reaches anyway a stable configuration in twenty turns of play on average.

most likely, and at the same time stable defection is most unlikely, when medium term aspirations are initially at an 'intermediate' level.

Relational performance

The most striking outcome is that with high aspirations relational performance falls dramatically. Indeed, this is coherent with our discussion of the level of final relational intensities: high aspirations easily generate dissatisfaction, which induces the progressive weakening of relations (both in the fixed and in the adaptive aspirations case).

Final satisfaction

Finally, low initial aspirations are more likely to be met, while high initial aspirations always cause final dissatisfaction (i.e. negative values of satisfaction), both in the fixed and in the adaptive aspirations case.

4 Possible developments

We consider the present model as a contribution of mainly methodological value for the investigation of an extremely complex and wide field of analysis: the study of the reciprocal influence between the social context, on one side, and individual behaviour, on the other. The analytical tools we made use of, i.e. game theory and network representation of social relations, can be applied to a host of different situations. We present here some of the possible extensions, in order of increasing generality.

1. Within the limits of the model presented here, it is important to systematically develop the scope of the simulation analysis. In particular, it is necessary to tackle interaction within strategically non-homogeneous populations. To give an idea of the results that could emerge, we summarize the basic outcomes of some preliminary simulations. Notice that the insights below are quite provisional and need further scrutiny.

- BR obtains the best material results in interactions with other strategies, as opposed to her poor performance in homogeneous populations: this is not surprising, since the strategic strength of BR is indeed its robustness against alternative strategies;
- As to the relational performance, TFT confirms to be the best, compared to the other strategies, as it has already been found for

homogeneous populations; but this result could depend to a substantial degree on the composition of the mixed population;

- Finally, higher initial levels of RC increase final satisfaction, a result that is opposite to the one observed in homogeneous populations: as we said, this point mandates deeper investigation, to see whether the positive correlation found in this fragmentary investigation of the more general case receives further corroboration.

2. The set of alternative strategies should be expanded to allow for further instances of adaptive rationality. Moreover, strategies could be governed by relatively sophisticated cognitive mechanisms (see e.g. Fudenberg and Levine (1999)). Some interesting developments in this regard, come from the so called cognitive economics: in this field, economists and psychologists can find a significant ground for common work (see Viale (1997)), maybe exploiting the possibilities provided by the new generation of artificial adaptive agents such as artificial neural networks (see e.g. Buscema et al. (1998)) and genetic algorithms (see e.g. Macy (1996)).

3. The modelling of relations among actors is another hot field of research. In particular, one could study different types of social links, which are not characterized by a unique intensity value, but are irreducibly multi-dimensional. Besides, one could analyse structures of interaction in which relations are directional (think e.g. of flow of goods or information among players); moreover, we should tackle the problem of the endogenous establishment of new relationships (see e.g. Yamagishi and Hayashi (1996)) and thus of how players choose each other (see e.g. Stokman and Zeggelink (1996)). In this regard, the cooperation between economics and sociology could be very fruitful.

4. Finally, modifications could be introduced as to the shape and size of the social network, and the stage game itself. In particular, the payoffs matrix need not be of the PD type. One could even imagine that the players find themselves involved in different games over time, either for exogenous or for endogenous reasons, that could involve a complex interaction with the population dynamics of individual strategies and dispositions (see e.g. Joireman et al. (1996)).

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Interaction de réseau avec des biens matériels et relationnels. Un essai de simulation

Les auteurs modélisent l'interaction entre les membres d'un groupe de travail qui mènent divers projets et qui ont le choix entre coopérer (entre eux) ou exploiter le travail des autres. L'attention est portée sur l'interdépendance dynamique entre leur performance matérielle et la structure de leurs interrelations. Ils font en particulier l'hypothèse que leur satisfaction dépendra à la fois du résultat matériel de leurs projets et de la qualité des relations réciproques (ces deux aspects étant considérés jusqu'à un certain point comme des substituts psychologiques). Une insatisfaction peut conduire à la dissolution des liens sociaux, dont peut résulter l'échec des projets. En revanche, des relations satisfaisantes et une coopération stable peuvent se combiner positivement. Le modèle combine la théorie du jeu et la représentation en réseau des relations entre acteurs, et ouvre ainsi des pistes de recherche, qui selon les auteurs, sont encore inexplorées à ce jour.

Netzwerk-Interaktion mit materiellen Gütern und Beziehungsgütern: Eine exploratorische Simulation

Wir konstruieren ein Model mit Interaktion zwischen den Mitgliedern einer Arbeitsgruppe, die verschiedene Projekte durchführen und die Wahl haben, miteinander zu kooperieren oder aus der Arbeit der anderen Kapital zu schlagen. Wir richten unsere Aufmerksamkeit auf die dynamische Interdependenz zwischen ihrer materiellen Leistung und der Struktur der Beziehungen zwischen ihnen. Insbesondere unterstellen wir, dass ihre Zufriedenheit sowohl von dem materiellen Ergebnis ihrer Projekte als auch von der Qualität ihrer reziproken Beziehungen abhängt (sodass diese beiden Aspekte – zu einem gewissen Grad – als psychologische Substitute gesehen werden). Insoweit Unzufriedenheit das Zerreissen sozialer Bindungen bewirken kann, ist das folgerichtige Scheitern der Projekte ein mögliches Ergebnis. Umgekehrt können zufriedenstellende Beziehungen und stabile Kooperation positiv miteinander korrelieren. Unser Model führt Spieltheorie und Netzwerkrepräsentation der Beziehungen zwischen Akteuren zusammen und eröffnet somit einen Forschungsansatz, der unseres Wissens bischer noch nicht verfolgt worden ist.

Interacción de red con bienes materiales e interpersonales. Un ensayo de simulación

Los autores modelizan la interacción entre los miembros de un grupo de trabajo que llevan a cabo diversos proyectos y que pueden elegir entre

cooperar (entre ellos) o explotar el trabajo de los otros. La atención se centra en la interdependencia dinámica entre el resultado material y la estructura de sus interralaciones. La principal hipótesis es que la satisfacción dependerá simultáneamente del resultado material de los proyectos y de la calidad de las relaciones reciprocas (ambos aspectos están considerados hasta un cierto punto como sustitutos psicológicos). La insatisfacción puede conducir a disolver los vínculos sociales, de lo cual puede resultar el fracaso de los proyectos. En cambio, relaciones satisfactorias y una estable cooperación pueden combinarse positivamente. El modelo combina la teoría de juegos y la representación en red de las relaciones entre actores y abre así vías de investigación que, según los autores, todavía no están exploradas.