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Agenda-diffusion and innovation

A simulation model

H. Schnabl

Department of Microeconomics, Institute for Social Research, University of Stuttgart, Breitscheidstrasse 2c, W-7000 Stuttgart 1, Federal Republic of Germany

Abstract. The neoclassical approach to innnovation is based on its economic advantages and thus in a strict sense seems to be applicable only to incremental innovations with a low degree of novelty. It is contended in this paper that so-called generic innovations, which are more important to the evolutionary process because of their high degree of novelty, always bring about uncertainty which will be compensated by social contacts, i.e. by communication. The author shows that a communication model based on very simple assumptions and implemented as a simulation model is able not only to sketch significant features of the diffusion process but also to give additional clues to the process modelled.

Introduction

Two of the basic questions of evolutionary economics are how innovations come about and under what conditions they are successful, i.e. how they influence economic evolution.

Innovation research in the 60's and early 70's favored economic advantages as the main source of innovation success (Mansfield 1968) and thus described adoption as an *equilibrium process*. Modern innovation theory, however, distinguishes more sources and contexts (user vs. manufacturer defined innovations, cultural and organizational contexts etc., (cf. Clark 1987) and shows that even economically optimized choices may not be able to avoid adoption of inferior technologies (Arthur 1988, p. 593f.; Gerybadze 1982, p. 44).

There may be enough information for making rational decisions concerning incremental innovations, but for the so-called generic type of innovations, about which almost nothing can be known because it is entirely new, a rational evaluation would appear to be impossible. The latter is the most interesting type of innovation in the field of evolutionary economics because its future is completely open (Metcalfe 1988, p. 566f.). Whether a certain innovation will ultimately lock in depends on the evolutionary path it takes "on the razor's edge (Arthur 1988, p. 594f.).

"Innovations are sets of ideas with both technological and organizational dimensions which are embedded in distinct sociocultural settings" (Clark 1987, p. 169). Here, another dimension comes in: the *social embedding* of the diffusion process. Potential adopters are either firms or consumers. Firms can be the manufacturers or the users of an innovation, while consumers are usually almost exclusively users. No innovation can be "sold" to its prospective users if they cannot form a preference order because they do not know how to evaluate its advantages.

For the *consumption use* of an innovation, Rogers (1983) has shown that it is the *process of communication* which determines its success.

"Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. ... This definition implies that communication is a process of convergence (or divergence) as two or more individuals exchange information in order to move toward each other (or apart) in the meanings that they ascribe to certain events. We think of communication as a two-way process of convergence, rather than as a one-way, linear act in which one individual seeks to transfer a message to another" (Rogers 1983, p. 5).

For *firms* as users or as sources of innovations, the investigations of E. v. Hippel showed that the communication approach is also valid.

At this point, the neoclassically oriented student of innovation might question the possibility of communication *between* firms. However, even where firms were rivals, v. Hippel's research (1988, pp. 83 f.) and that of Th. J. Allen (1983) showed that, under normal conditions, there is extensive "information trading" between organizations at the expert level on the basis of an informal reciprocal "exchange-contract".

This rather surprising behavior is explained as a kind of prisoner's dilemma with regard to the principal uncertainty about the features and future prospects of innovations. Thus, the observed behavior seems to follow the well-known result of prisoner dilemma situations, that, in the long run, cooperation pays (v. Hippel 1988, pp. 85–88).

This raises the question of *how* communication about innovations can bring about their diffusion. Successful communication *synchronizes the contents of people's minds* and thus, to a certain degree, their *behavior* also. Hence, communication is a prerequisite for synchronized activities in every social system.

If on the other hand, communication becomes obsolete, the "reproduction ability" of the social system is disturbed or even destroyed. This is true for matrimony as well as firms or nations – a striking example being the story of the Tower of Babel in the Bible.

In the following sections, an attempt is made to analyse the process of diffusion and innovation transmission within a social system from the perspective of communication. This is done by first reviewing and criticizing some relevant models of diffusion. Then, we try to model the diffusion process by the construction of a simulation model that depicts, on a microanalytic level, communication sources in a social system, and also their interactions. As the social system is modelled at the level of individuals, there seems to be no alternative to the use of simulation techniques for obtaining some results, as Nelson and Winter have also argued (Nelson and Winter 1982). Moreover, a simulation model allows us to "experiment" with the influence of some determinants on the results of the social communication processes modelled.

Existing models of diffusion

In biological evolution the emergence of a new animal is ascribed to *mutation* and *selection*, while in economics or social life the evolution of new technologies or institutions is a consequence of *innovation and* the *successful diffusion* of this innovation.

In the literature, this process of diffusion is mostly described by the so called *logistic equation* (Bass 1969; Mansfield 1968; Kaas 1973; Schünemann, Bruns 1985). It is broadly applicable in many fields of evolution including population biology, especially for depicting the pace of an infectious disease. Assume a given population with n individuals, y of them infectious. The rest, $n-y$ are susceptible and will contract the disease when enough time has elapsed, the time-rate of infection being given by k. The share $a=y/n$ of individuals *with* disease can then be determined by Eqs. 1 and 2 for the continuous time case:

$$da/dt = k \cdot a \cdot (1-a). \tag{1}$$

Integration of Eq. 1 results in

$$a(t) = \frac{a(0)\, e^{kt}}{1 + a(0)\,(e^{kt}-1)}. \tag{2}$$

For the *discrete* time model we get

$$a_{t+1} = a_t + k \cdot a_t \cdot (1-a_t) \tag{3}$$

as a recursion formula which also yields the logistic curve [1].

The above models of diffusion have the advantage of giving clear cut and easy to control results if the model is adequate and parameters are known. However, their disadvantages are:

- they only work on a *macro*analytic level
- they only support a one-way progress of diffusion which results not from communication but from a kind of "contagion".

The first criticism shows that only a few features of interaction at the population level are directly taken into account. There are no differences in personality which could be of any importance. This of course supports the view of diffusion as a mere *effect* transferred from individual 1 to individual 2. But, as Rogers (1983, p. 7) emphasises, the diffusion of cultural traits, socially important knowledge or attitudes always occurs by way of a communication process, where *both sides* interact and both are affected.

Research in innovation diffusion has found that there are at least two steps – *awareness* and *adoption* – which can easily be distinguished in reality.[2] The first step of the innovation process – raising awareness of the novelty – depends on the semantic information content of communication. The second step is determined by a *decision process* which takes into account some *advantage* the novelty should have if it is to be adopted. This advantage may be a "real" economic one in the

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[1] The logistic curve has the potential of chaotic behavior for $k > 2.57$ in the given form (cf. May 1976; Schnabl 1989).

[2] A famous example of innovative processes was the adoption of a 2–4D weed spray, a kind of herbicide, introduced to Iowa farmers in the early fourties (Cavally-Sforza and Feldman 1981, p. 35).

case of economically relevant innovations, or may simply be ascribed to the innovation.

Traditional economics would probably try to develop a utility model at this point, but this would mean ignoring the fact that the usual premises of "givens" are not valid here. There is no starting point of "already existing preferences". These have first to be constructed. Preferences for things yet unknown can hardly be developed if there is no previous experience of them. Unless however, there are some preferences on which a choice can be based, such experience cannot be acquired. To break this vicious cycle, an attempt would be made to borrow experience or preferences from others. In the absence of own preferences, the preferences of peers can be taken over or advice asked of some expert, that is, preferences are acquired through communication (Rogers 1983, pp. 213ff.).

To model this diffusion process and to overcome the above limitations, an individualistic, i.e. microanalytic, simulation model of innovation diffusion based on *two-way communication* will be constructed. The danger of constructing an "ad hoc" model will be avoided by basing its elements on well known and reliable concepts from the *social sciences* and *communication theory*, as discussed in the next section.

The simulation model

Basics: social environment and communication

The literature on social groups emphasises the role of *affirmation* in the acquisition by two individuals of their common beliefs that form the basis for a successful diffusion process. In the area of economics particularly, social environment and its transmitted experience play an important role (Katona 1946).

The fact that the individual mostly is not sure whether he or she should believe that there are possible advantages of *something new* means that the person tends to adopt a *group belief* (Hofstätter 1957, p. 94). The individual assumes that there is a higher degree of *certainty* of information behind the seemingly uniform beliefs of others.

So, if we assume that, via *symmetrical* two-way communication, a transmission of beliefs takes place between individuals in a network, we have the basis for a *socially initiated* preference order. This essentially models the second step in the diffusion process, the *decision to adopt* – or not to adopt – the innovation.

Towards a theoretical foundation of communication-effects

For a valid foundation of modelling the communication process in question, we need to allude to the *theory of attitudes*. The concept of attitudes in social sciences has *three components*.

These are
- the cognitive
- the emotional (=affective, motivating) and
- the behavioral aspects (Triandis 1975, p. 11).

The cognitive aspect defines the *knowledge about the subject*. For the process of diffusion, this seems to apply to the first phase which goes with the *awareness* of the subject. The second aspect of attitude is *emotional*, i.e. it has to do with whether the subject is inclined to accept or reject the innovative item. Consistency is expected between *emotional reactions* to a given subject and *behavior* towards it. This relation is called the *A-B-relation* in the literature (Schuman and Johnson 1976, p. 198 f.) and means that *A*ttitude determines *B*ehavior. In certain circumstances this reaction can in reality show up in a weaker form than expected.

This short description of attitudes makes it clear that innovation diffusion via communication does not primarily concern the knowledge-awareness aspect but rather the second and third aspects where attitudes are changed. Although *all three aspects* of attitude are influenced by communication, here we want to simulate primarily the *change* in the *emotional/motivational aspects of attitudes which result from communication.*

Emphasizing the motivational bias of attitudes and behavior, we can better understand why information alone, the first aspect, "did not reduce their uncertainty about how the innovation would work ...". However, evaluation by peers, the second aspect, can "... persuade an individual to form or change a strongly held attitude." (Rogers 1983, p. 197 f.) and thus bring about behavior, the third aspect i.e. final adoption of an innovation. Thus, it is primarily the transmission of the *second aspect* of attitudes which exerts social influence, i.e. the building up of preferences on which orthodox economic analysis could then be based.

Specifications of the model

The *attitude* towards a *given subject*, we call it agendum, is sketched by a variable A_i for every individual i, $i=1, \dots, n$, being confined to the interval $[-100, 100]$. This corresponds well to the common practice of measuring attitudes on such scales in the social sciences. A *negative* A_i shows *refusal* of a given agendum, an A_i close to zero means indecision. To separate the area of indecision from the clear and pronounced attitude *pro* or *contra* a given topic, a threshold value was introduced which was fixed at $+40$ and -40 for all runs. Thus "innovations" are depicted by the "fact" that most people, being rather ignorant of the "innovation", have very low A_i's – indecision – and only a few have distinct attitudes.

A simple possibility for modelling the attitude change would be to let the individuals' attitude switch to that of the perceived majority. This type of model, which is also used in physics (cf. also Arthur 1988), certainly yields the desired outcome, but then we might just have put into the model the result we wanted to receive. Moreover, this assumption would be only a poor representation of the *process* of communication. A more basic approach which depicted the *single communication event* could possibly produce the same result but, if it did, would be providing a cumulative result of a variety of communication events and would therefore be less biased towards a "wanted" result.

There is no doubt that communication mostly brings about a convergence of opinions and attitudes. This could be modelled as an "averaging process" as in Eq. 4:

$$A_i^+ = (A_i + A_j)/2 \tag{4}$$

where the superscript " + " denotes the next time period as shorthand notation for "$t+1$" while the indices "t" on the right side are omitted.

However, this averaging would only bring about an alignment to low level attitudes. Unfortunately, as is known from diffusion processes this would result in a "thermal death" rather than in a spread of distinct positive (or negative) attitudes.

A better way to grasp the two-sided effect of communication is given by Eq. 5. This is a formula which biology uses to model *blending inheritance* of some trait X (e.g. hair color) stemming from the trait expression of father and mother, X_f and X_m (Cavalli-Sforza and Feldman 1981, p. 275)

$$X^+ = b_m X_m + b_f X_f \,. \tag{5}$$

We use it here simply as an analogue for what is going on in the "attitude-exchange"-model of communication developed above. By substituting A for X in Eq. 5 we obtain Eq. 5a

$$A_i^+ = b_i A_i + b_j A_j \tag{5a}$$

where the new attitude-value of individual i is the result of blending the previous attitude of i and the attitude of the other individual j with whom i is communicating.

From biology we know that, according to Eq. 5, the mean of the trait remains unchanged if $b_m + b_f = 1$ holds, especially in the form $b_m = b_f = 1/2$. While in biology the formal parameters b describe some hereditary potential of the parents, in the communication process the b's have two different meanings – *strength of conviction* and *credibility of the communicator.*

In reality both determinants have been shown to influence the success of communication. While credibility of the communicator is important for the recipient (Kroeber-Riel 1980, p. 462), the conviction of the communicator, that what he believes and is communicated is "true" is a prerequisite for his credibility. As we try to model a two-sided communication – and Eq. 5a should describe the two-sided result of it – the b's in Eq. 5a can be interpreted as cumulating the effects of the elements which are intermingled in the process. A high b_i then means that individual i has a strong belief that his attitude is "correct"; that he is *credible* to the recipient and thus in a position to *convince* him. In other words, he transfers a certain amount of his attitude to the recipient.

If we take β's instead of b's, thus indicating the differences from the biological model, we obtain *communication formula*

$$A_i^+ = A_i \beta_i + A_j \beta_j \tag{6}$$

with $0 < \beta_i, \beta_j < 1$. Because of the basic assumption of *symmetry* in the communication process, we can exchange j and i so that Eq. 6 gives also a valid description of the attitude change of the communication partner j[3].

[3] There are, of course, other ways to model the transmission process. One example is an approach of Osgood and Tannenbaum developed in order to model incongruity of attitudes *within* one person (Kroeber-Riel 1980, p. 220) which distributes the gap between two attitudes according to their values. Another example is Karlsson's simulation of diffusion processes (Karlsson 1976), which is similar to ours in that it also assumes a network of communicating persons, but works with transmission-*probabilities* of both communicator and recipient, which additionally are ordered in two classes of credibility. Kroeber-Riel argues that multiplying those particular probabilities, which is necessary for the modelling of the transmission, does not reflect the real process (Kroeber-Riel 1980, p. 467).

a

A_i \ A_j	−−	−	+	++
−−	>>	>>	><	<>
−	>>	>>	><	><
+	><	><	>>	>>
++	<>	><	>>	>>

b

A_i \ A_j	−60	−30	+30	+60
−60	−66 / −66	−55 / −55	−11 / −11	+66 / −66
−30	−55 / −55	−33 / −33	0 / 0	+11 / +11
+30	−11 / −11	0 / 0	+33 / +33	+55 / +55
+60	−66 / +66	+11 / +11	+55 / +55	+66 / +66

Fig. 1 a, b. Table of communication situations

In contrast to biology, in our model the *sum of the β's* can and even must *exceed 1*. It thus creates an "amplification effect" which tends to increase the values of attitudes A_i on average – this can be checked easily with an example (cf. Fig. 1). Additionally, A_i and β_i seem to be *positively correlated* by some intrinsic factors since a noncorrelation would lead to cognitive inconsistencies which the individual would try to avoid. Thus we used

$$\beta_i = \begin{cases} 0.5 & \text{if} \quad 0 < |A_i| < 40 \\ 0.5 \ldots 1 & \text{else} \end{cases}$$

where for values of $/A_i/ > 40$ the β_i's were a monotone linear function of $|A_i|$. It is clear that the β_i are important system variables.

As the attitude of an individual towards a given agendum can be situated in one of the following intervals,

Intervals:	$[-100, -40[$;	$[-40, 0[$;	$[0, 40[$;	$[40, 100]$
Symbols:	$(--)$ or $=$	$(-)$	$(+)$	$(++)$ or #

there are in principle 16 situations where two individuals are combined in a communication situation as Fig. 1 shows.

All 16 cases were analysed for plausibility of the result after the "modified averaging process" of Eq. 6. As an example the attitude mixing effect of communication is calculated in Fig. 1 b, with a homogeneous $\beta_i = 0.55$. If for example, a $+30$ attitude meets another $+30$ both end up with $+33$, while a $+30$ and a -30 result in a zero attitude for both.

Eight of the 16 situations, which occur around the main diagonal, yielded a *parallel amplification* of attitudes ($\gg$) which is very reasonable (affirmation by communication). Another 6 cases after Eq. 6, resulted in both attitudes *closing up* ($> <$), which, in contrast, means a lowering of $|A_i|$.

Only two situations were handled differently. There were cases where both individuals had a *distinct attitude* ($|A| > 40$) but *different* scale sign, e.g. $A_i = -60$ and $A_j = +70$. This strong *confrontation*, resulting in a *polarization* of attitudes, was shown in experiments of communication research (Schneider 1985). It was modelled by simply *inverting* the sign of the second right hand term in Eq. 6 from $+\beta_j A_j$ to $-\beta_j A_j$ if β_j exceeded a threshold value of 0.6.

This is not an "ad hoc" decision to alter the basic equation, but just contrary to this, shows that Eq. 6 is able to model the rule as well as the exception. While in the "normal" case, a *convergence* of different attitudes is observed which results in smoothing out differences in the perception of reality, for the extreme case of different attitudes coupled with *high confidence* in *own beliefs*, the dissonance might well be solved by cutting social influence and instead strengthening own viewpoints. This "inversion" of behavior is well reflected in the switch of the influence sign from plus to minus and may thus be taken as additional support for Eq. 6.

Summarizing the above results, the communication process modelled after Eq. 6 yields three possible results. Two of these involve a symmetrical *amplification* of attitude values and occur in 10 of 16 cases, and the third, in 6 of 16 cases, involves a *lowering of attitude values* towards zero. Under "favorable" conditions, the overall performance can be expected to deliver more amplification effects than lowering effects thus steering the system to a successful diffusion. This depends, however, both on initial conditions and on states already achieved (path dependence) because of the interaction of the pro's and contra's.

The model forms a system of n coupled difference equations, which may even be nonlinear for the standard case $\beta = f(A)$. It would be rather difficult to solve this analytically but it is open to simulation techniques which are more appropriate for mimicking the evolution of mutually dependent attitudes on the basis of a *cellular automaton.*

Simulations and results

Every simulation was based on a cellular "field" of 16×16 $(=256)$ individuals. Since in reality, the network structure of communications is mostly unknown, it was depicted by taking the row/column place of a communication *partner* from a random number generator. Random numbers where also used for all attitude-values A_i and credibility/conviction coefficients β_i. Depending on the goal of the simulation, in most runs the A_i were given a Gaussian distribution, with expected value $E(A_i) = 0$ and the "rims" just transgressing the threshold value of ± 40 in a few cases. This gives an adequate picture of attitudes towards the "novel" innovation.

For most runs the β's were Gaussian-distributed around 0.5 in an interval of [0.46, 0.54] or, for some alternative runs, *they were homogeneously fixed* for all individuals (all $\beta_i = 0.52$).

Two kinds of communication *distances* were used, one was a "neighborhood-type", where one of the neighbor cells was determined as the communication partner, which meant that only row/column differences of $+1$, 0 or -1 were allowed in order to take one out of the 8 possible neighbors of a considered cell of the cellular automaton. The other was a "far-distance-type" (with distances $> |1|$) which would reflect "telephone-communication". In both types, "isolation" could also occur if the row/column random values pointed towards the individual himself but, because of the algorithm, this should have occurred more frequently, if at all, with the neighborhood-type. After the communication pattern had been fixed it remained unchanged during an entire simulation run.

The simulation step of *one period* called up each of the 256 individuals, choosing the appropriate partner and appyling Eq. 6. Then certain "statistics" for the simulation reports were drawn out and the next period followed. Depending on the "speed" of the communication-processes, which was mainly a function of the amount of the β-values, 35 to 70 "periods" were done per simulation run.

It should be clear at this point that apart from the use of the random number generator for setting the *initial conditions* of the process, randomness is not involved in the simulation. Despite the fact that the process is totally deterministic, its outcome is nevertheless sensitive to the initial conditions in the

- communication network
- distribution of the A_i
- distribution of β_i.

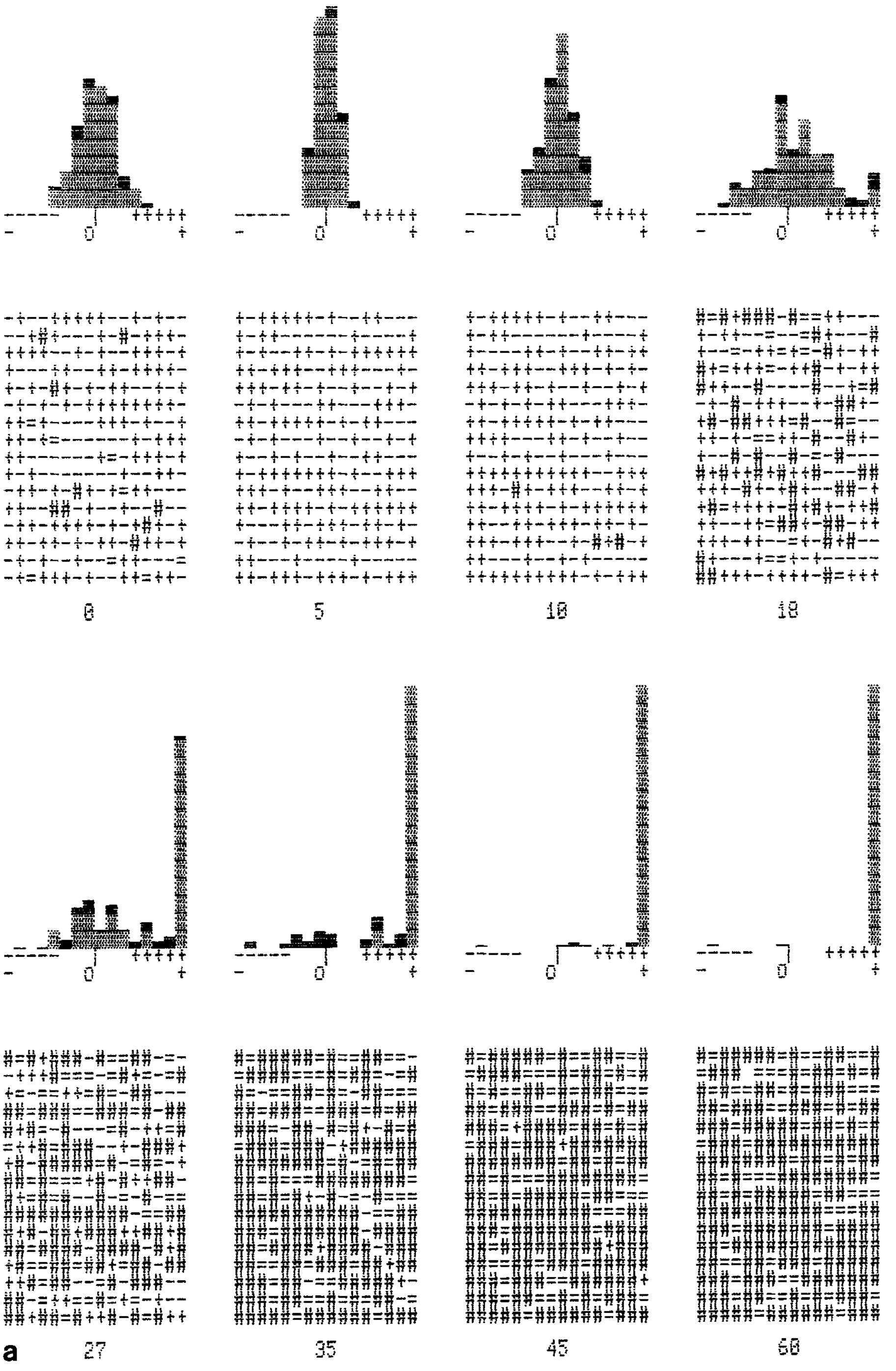
Figure 2 shows a typical simulation result for 60 periods, a Gaussian distribution of A_i with $E(A_i)=0$ and *homogeneous* $\beta=0.52$. Starting with the bulk of low-level attitudes (+ and −) and only a few distinct ones (− − and + +), as given by the rims of the Gaussian distribution, the process of transmission takes off, mainly as a result of the "parallel amplification" rendered by *all* $\beta_i > 0.5$. A comparison of the "topological" development and the corresponding histogram which depicts the whole spectrum of attitude-values helps to monitor the development. After a stage of latency the process gains momentum and shows the result of a logistic curve[4].

The second example (Fig. 3) shows that the process does not necessarily yield a symmetry between positive and negative attitudes, as was almost the case in Fig. 2. Because of a small imbalance at the starting point, one of them could be absolutely dominant but this might not become apparent until the indecision thresholds are transgressed. For the run of Fig. 3, the A_i again were Gaussian-distributed around zero but, as the random generator gives a random sample, this sample happened to be slightly asymmetric as the histogram of period 0 shows. All β_i were 0.52 and the communication pattern set to "telephone-communication" as it also had been for Fig. 2. A small preponderance of the positive attitudes at the start was enough basis for the "parallel amplification" process to absorb even the latent negative attitudes and to reach dominance without giving the contras even a chance to get into place. This evolution also shows up in the curves of average attitude values (∅).

In a third example, a pretty tight distribution of the A_i – no attitude higher than half the threshold value – and this time *Gaussian-distributed* β's ($E(\beta_i)=0.49$) were combined with *one* extremely convinced person ($A_i=99$, $\beta_i=0.99$), who was placed in the very center of the field. The communication pattern this time was "neighborhood"-type. The results show that, under these conditions, with even one half of the β's less than 0.5, a "leader character" can be successful. It is interesting to monitor the increase of the group in the "field-pattern" as well as in the stacked right hand column of the corresponding histograms. Figures 4 a and c show a segmentation of the population on the field graph into a high valued center and a low valued environment which did not take part in the process.

However, the fact that, in Fig. 2 to 4, an innovation was always successful could be falsely interpreted as taking it that the communication process modelled *always* leads to a successful diffusion. As only successful diffusions are important to evolutionary economic processes, we emphasized this type here, but, as we will see later, though successful diffusion is not a trivial result, it is only *one possible* outcome.

[4] Regression analysis showed evidence for the logistic with r^2 of 0.95 to 0.98 for all tested runs. Moreover this point is supported by arguments of diffusion research.



a

Fig. 2

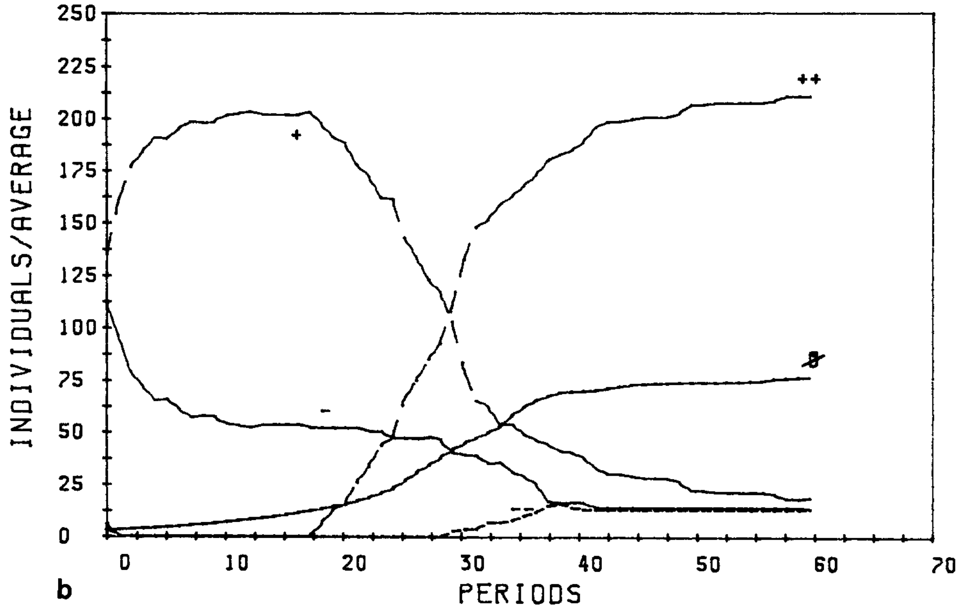


Fig. 2a, b. Standard simulation run

Discussion

Generalizations

As Figs. 2, 3 and 4 show, *successful* diffusion usually results in a course which is excellently sketched by the logistic curve. This pattern caused by *interactions* on the *microlevel* is rather similar to the *macroanalytic* curves known from population biology, such as the so-called Verhulst equation, (cf. Schnabl 1989) or from "contagious" diffusion processes (Bass 1969; Kaas 1973; Mansfield 1968).

The plotting of the logistic curve can be divided into the stages *latency, momentum* (= enforcement) and *saturation*. Only successful diffusion processes pass through all three stages and tend then to stay at the last. This can be derived from the dynamics of Eq. 6 which still work even at this point, although by definition the ultimate scale value of ± 100 is not transgressed.

If a diffusion process was successful, the innovation made its breakthrough. If it was not, then almost no one would have registered or paid any attention to it – innovation research literature reports success rates of about 2 out of 10. The word "diffusion" would normally not be used in this case. This shows that the meaning of the word "diffusion" encompasses a process as well as a positive, successful result.

Of course an innovation must also be embodied if it is to be real and to become obvious, but the process of transmission of positive attitudes remains an essential prerequisite for diffusion of innovations too [5].

[5] There are a lot of examples in innovation/diffusion research, including very unexpected secondary and tertiary economic effects which we will not discuss here, due to limitations of space, cf. the example of the tomato harvesting machine in Rogers (1983, p. 152). There are also examples of why prevailing negative attitudes (for example with family planning programs in developing countries (Rogers 1983, p. 68 f.)) can effectively impede diffusion. This may also be the case if attitudes are positive but insurmountable barriers, e.g. like costs, low income etc., hinder embodiment (cf. Rogers 1983, pp. 64–71, 149, 171, 195 f., 300 f.).

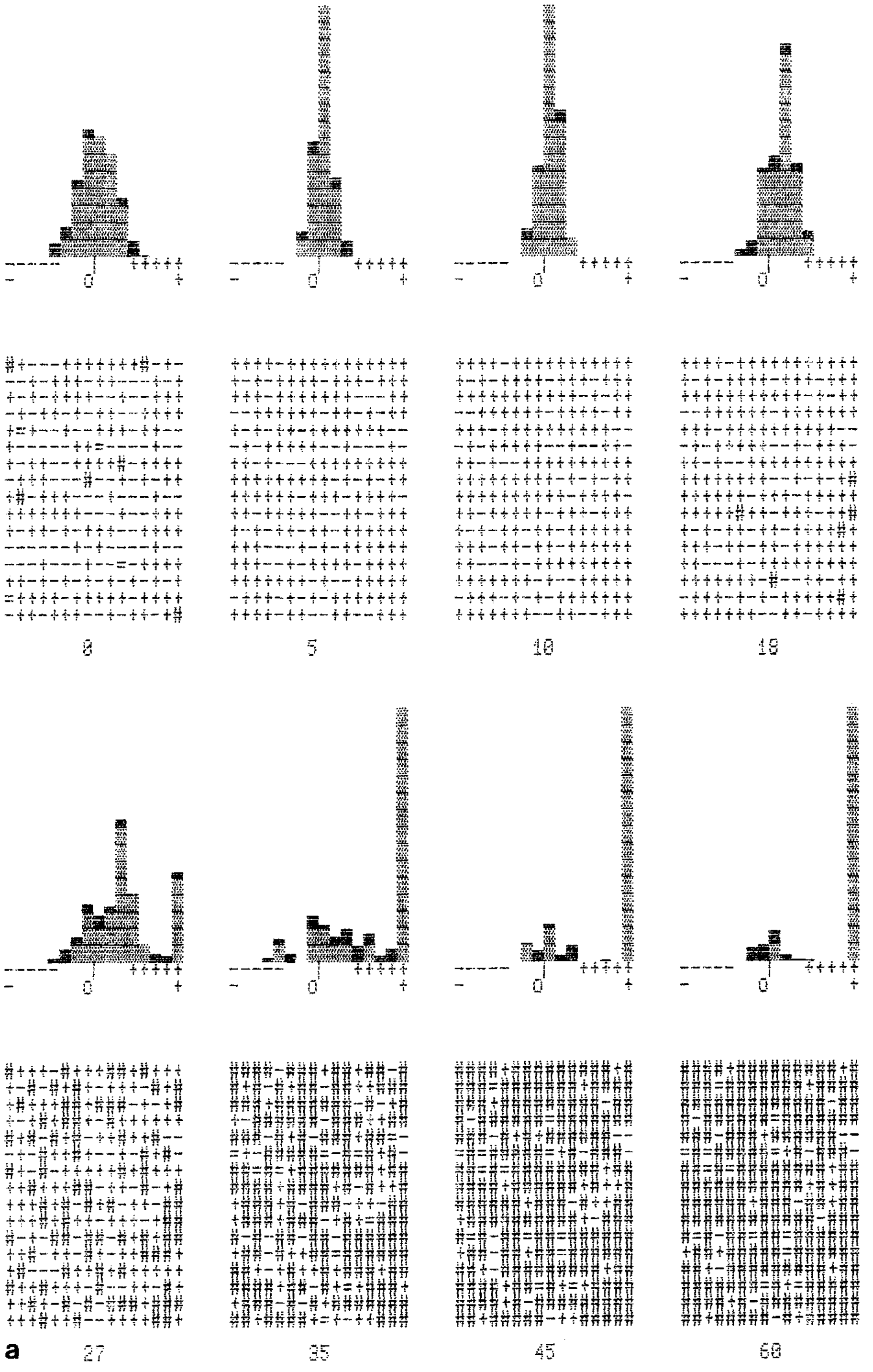


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Fig. 3

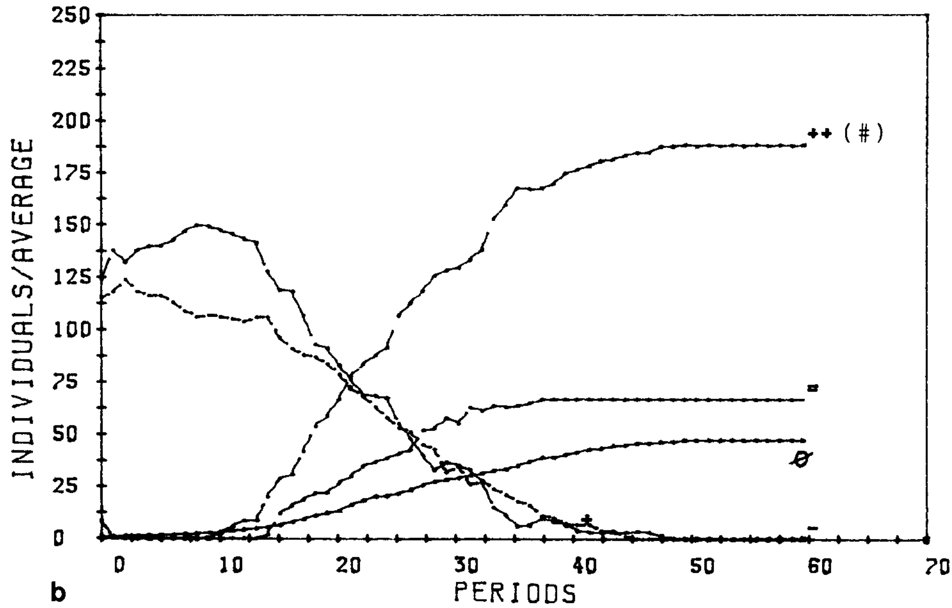


Fig. 3a, b. Dominance of one type of attitude

Some more results

There are some observations from the model which we should try to generalize. For this purpose, these will be summarized under different headings.

Origins of evolution: emergence or creation. The diffusion process as in Figs. 2 and 3 shows a *latency stage* which is totally hidden below the surface. However, this did not mean that nothing happened. Even if the average of β's is clearly below 0.5, *some of the individuals* with a β_i higher than 0.5, who are in an appropriate channel-network, (=additional condition) will take off and their influence will spread until transmitted attitudes *increase the subliminal* β's. In this situation, the process will finally take off and gain momentum. This was the case about period 10 to 20 in our runs (cf. the field-distributions in Figs. 2a and 3a, as well as + +- or =-curves in Figs. 2b and 3b). For the naive observer this take-off *seems* to happen suddenly and unexplainedly.

What we can learn here is that something might just be going on behind the scenes and that we should try to develop sensory instruments for this hidden process. It is in the momentum phase that the innovation emerges and becomes an *agendum*. This emergence can also be *stimulated* deliberately by a certain group or by media, something which we can experience in politics almost every day. Last but not least, given certain favorable conditions concerning A's and β's as well as the structure of the channel network, it can even be created by a *single person's* activities as the simulation of Fig. 4 shows.

Parameters: quality and structure of communication. There are at least two essential determinants of the diffusion process – the *credibility/conviction* parameters β and the existence of communication partners i.e. *structure* of the social network.

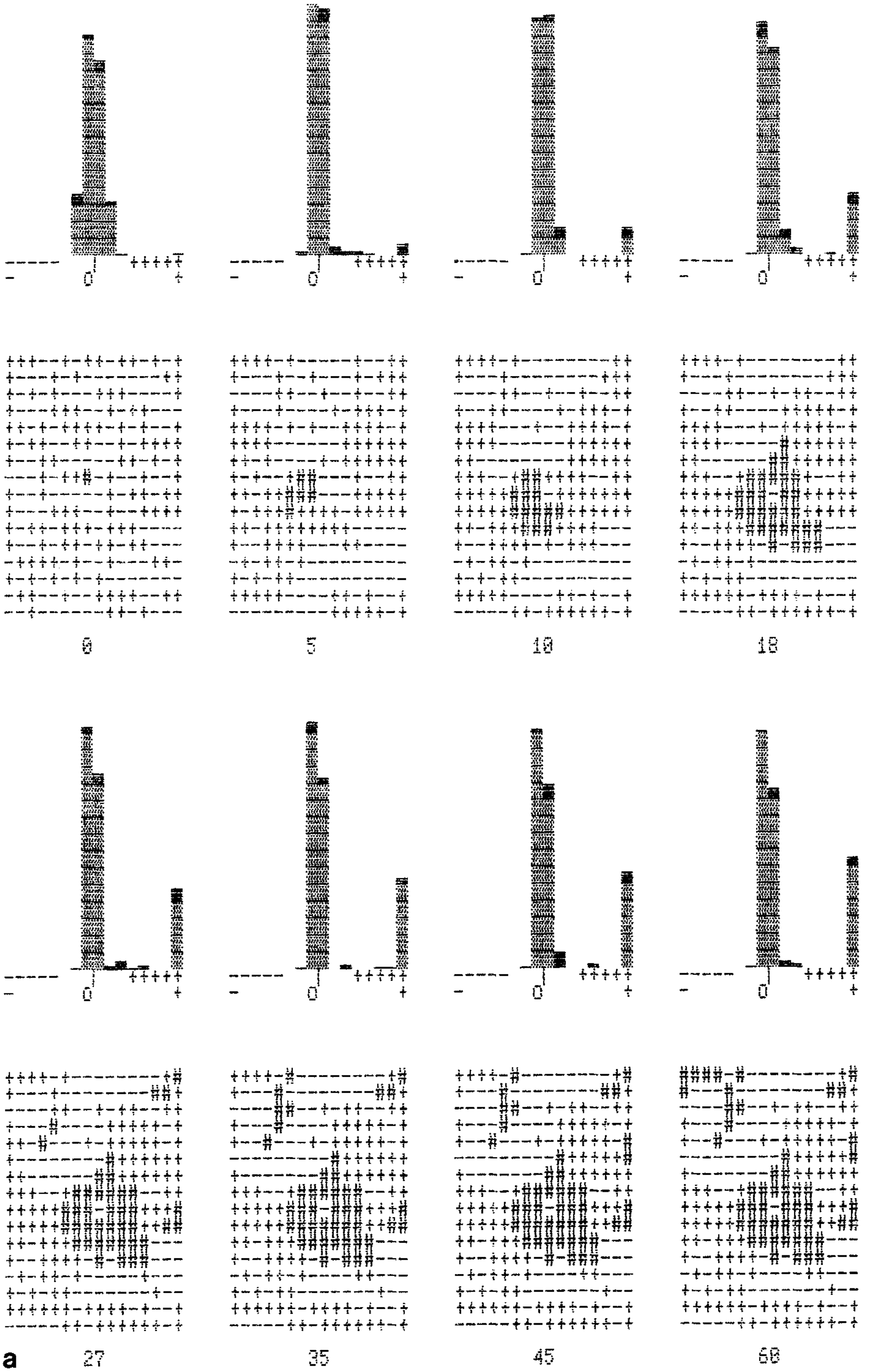


Fig. 4

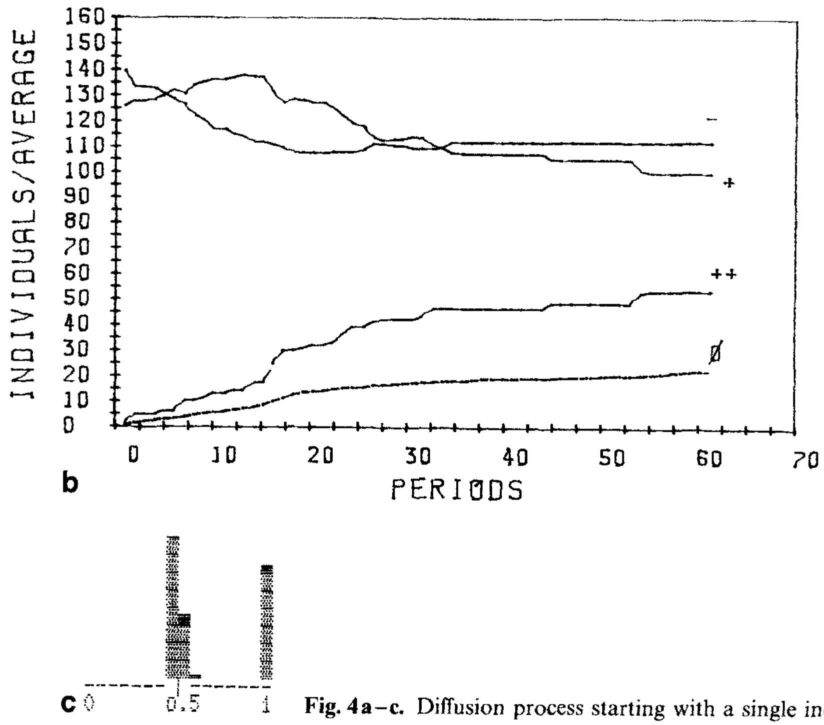


Fig. 4a–c. Diffusion process starting with a single individual

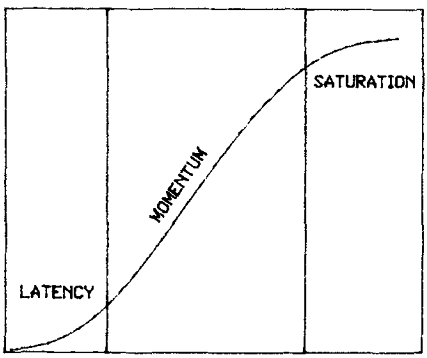


Fig. 5. Phase plot of a typical diffusion process

If we take *homogeneous β's*, then, to gain momentum, they all have to exceed the critical mark of 0.5, otherwise the process stabilizes its average or levels down to attitudes around zero – as many runs, not shown here for lack of space, have shown. If, instead, we have a *distribution of the β's* then the average of the β's may even be *less than 0.5*. As long as the structural *network conditions* for those with $\beta_i > 0.5$ are favorable for a parallel amplification the process will gain momentum, as is shown in Fig. 6. As Fig. 6c indicates, the β-values originally slightly greater than 0.5 took off – the right hand column in the histogram shows a concentration of β's on the interval about 0.86 ... 0.99 after 70 periods – and ended as a successful but partial group innovation. The rest stayed where they were as a result of the channels given in the run.

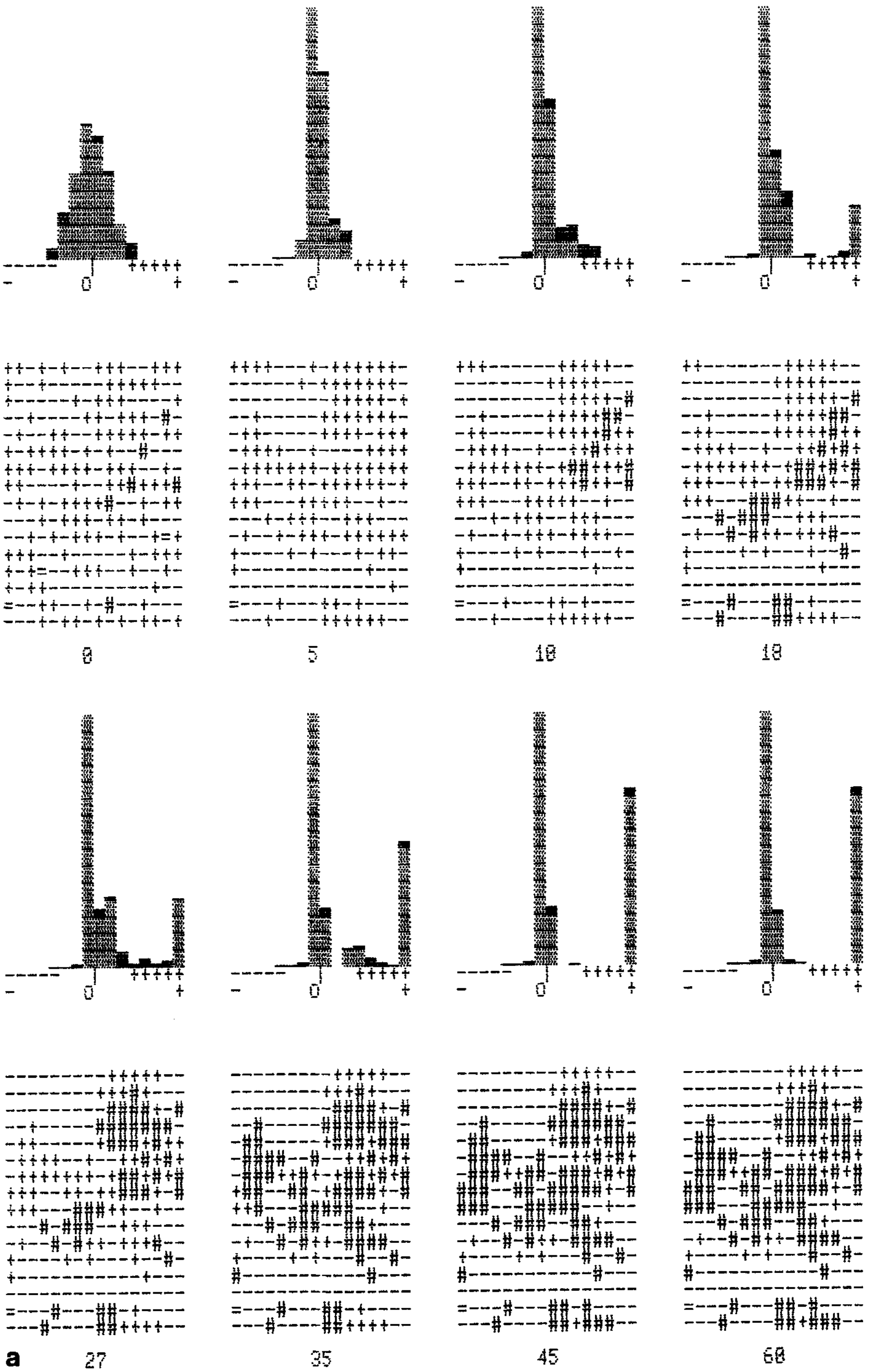
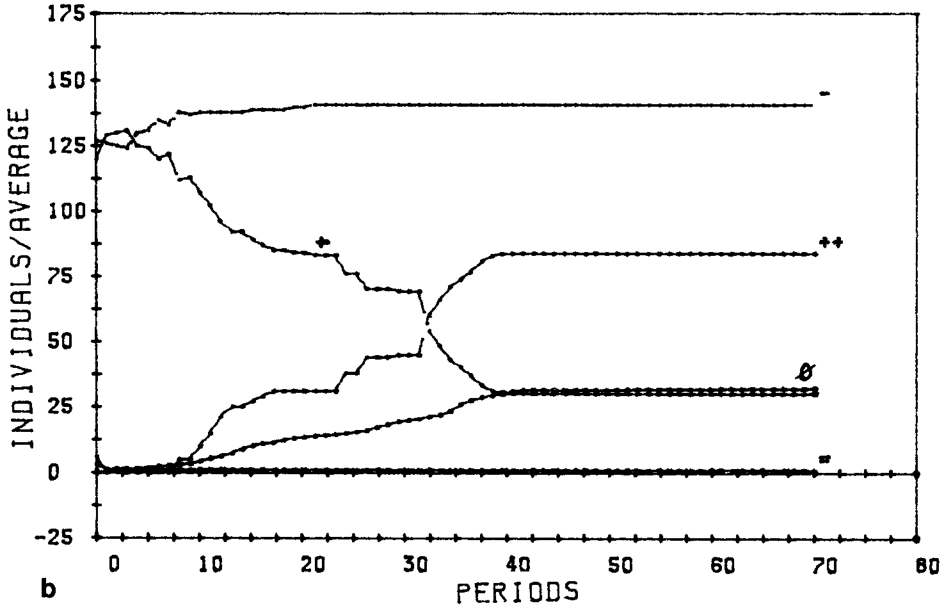


Fig. 6



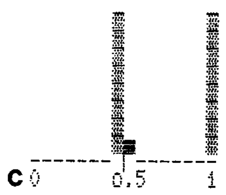
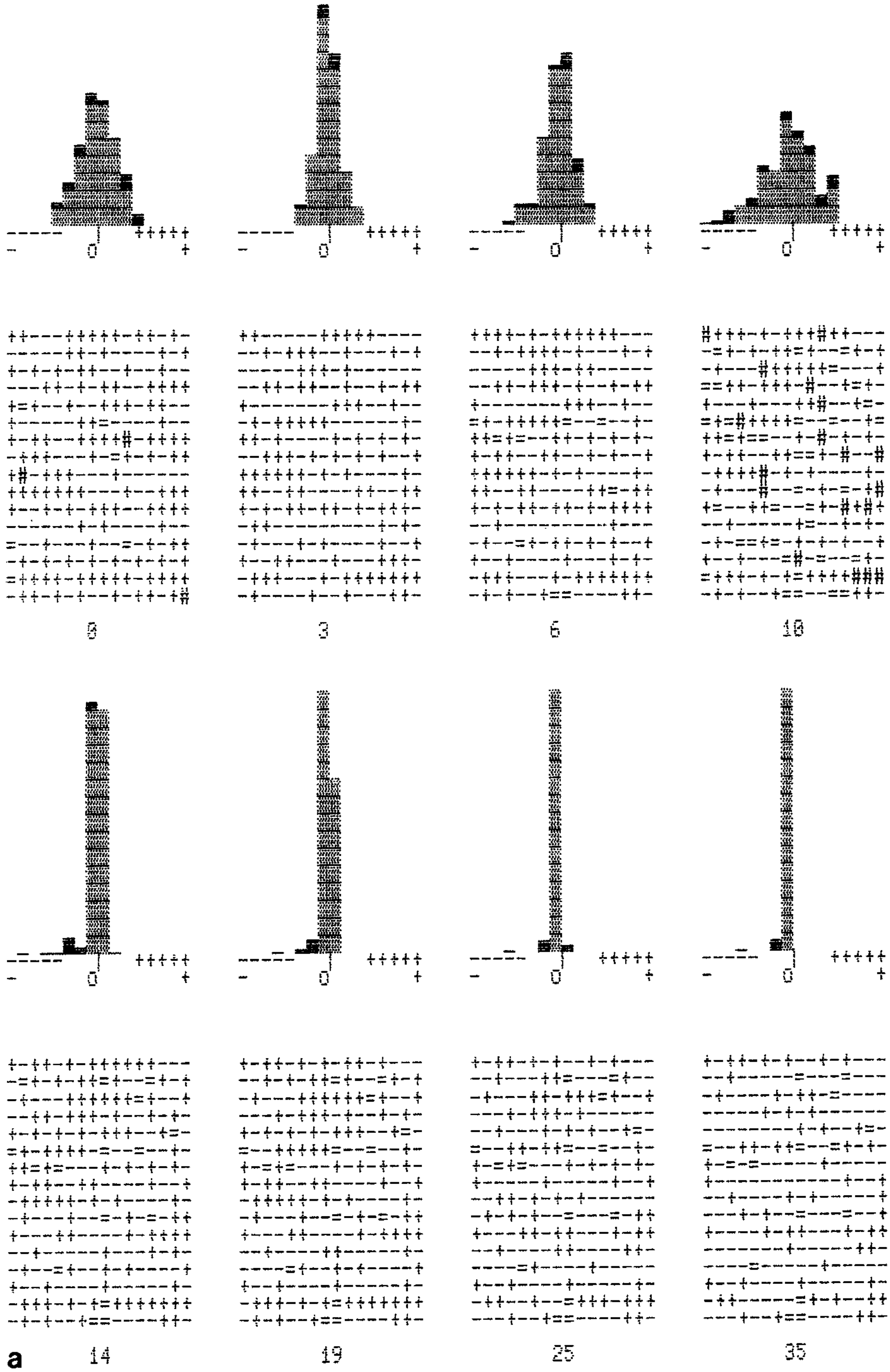


Fig. 6a–c. Independent increase with Gaussian-distributed β_i and $(E(\beta_i) = 0.49$

While this influence of conviction or credibility reflected by the β-values can be labeled as the *qualitative aspect* of communication in the diffusion of innovations process, the *structure of the channels* which forms the network of peers determines both the size and degree of integration of the social system and is responsible for the spread of the diffusion. In Figs. 2 and 3 the telephone-communication type – long distances in the network – was applied, and proved to *quickly mix* the attitudes of the whole population (Compare the steepness of the + +-curves in Figs. 2b and 3b to that in Figs. 4 or 6). In contrast, the *neighborhood model* restricted the range of communication and therefore crystalized "clusters" which mirrored the connectivity of the group. This can be labeled as "regionalization effect" (Figs. 4 and 6), and is also well known from reality.

Another observation supports the importance of the *structural* component in communication (cf. also Rogers 1983, p. 300f.) As the randomly initialized structure of the communication network is not "in harmony" with the attitudes and β-values of the nodes, it often happens that *initially strong attitudes* first vanish and then may reappear after they are fitted to the environment (cf. Figs. 2a or 3a, period 0 to 5). The *harmonization of communicators and channels* is obviously created *during* the diffusion process of communication. This amounts to the suggestion that diffusion is a self organizing and self nourishing process of *harmonizing attitudes and channels*.



a

Fig. 7

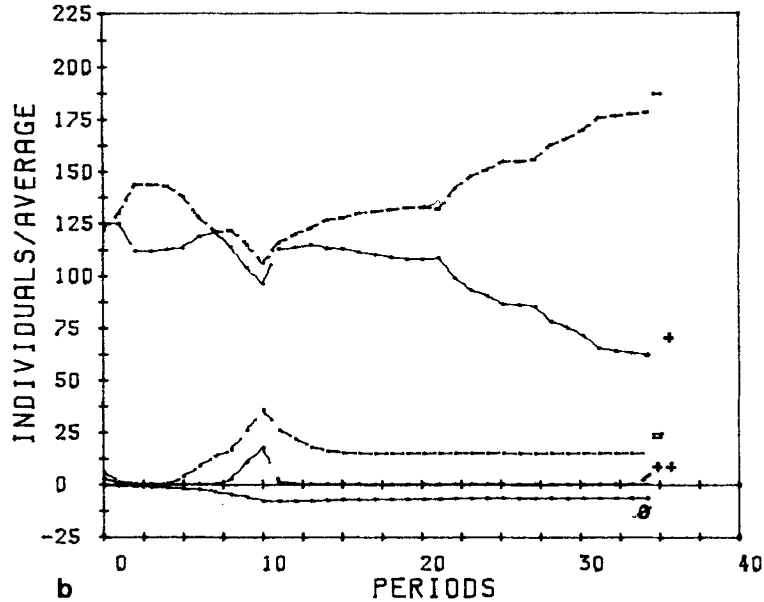


Fig. 7. "Turning point" in the diffusion process

Dynamics. A successful diffusion usually results in a *momentum* which synchronizes the attitudes within the population. Plotting the cumulated number of distinct attitudes against time yields the well known logistic curve (Fig. 5) with its 3 stages. Once the process has reached stage 3 – saturation –, it functions like a *regimen* which takes over or locks out everything else and impedes other developments. This stage forms a stable equilibrium as long as the β's *remain* above 0.5. This is guaranteed by the process and can therefore only be disturbed by an exogenous change, because positive feedback between A's and β's has been assumed. We could understand this situation as "the discovery of the social system's truth", which means *consensus. Its stable regimen means order* and the innovation has been adopted. Thus, the *complete* diffusion of an innovation brings about a stable adherence of the social system to its successfully created institutions, for instance money, even in the form of cigarette-money as in Germany after World War II.

On the other hand, this order may well be *destabilized* if something happens to lower the credibility coefficients β. This is shown for an early stage in Fig. 7, where *all* β*'s* were set to 0.4 in period 10. An example in economics would be a sudden distrust of money when it becomes known that the money is being forged. The current form of money could then become unacceptable.

There are good reasons for assuming that the β's are in a kind of *semantic feed-back context* with regard to the knowledge aspect of the attitudes. To a certain degree, a cognitive dissonance may be bridged by the attitude influencing communication. This means that consensus might rule out the counter effects of a direct perception of "reality". If the gap between reality and consensus in the group grows too wide the β's can turn down, the innovation will be destabilized.

Concluding remarks

Diffusion of innovation is a *prerequisite* for the success of innovations and, as innovations can bring about evolutionary changes, they too can be important for evolutionary processes. In a very *broad sense*, diffusion is always the result of communication processes. It was shown that the simulation approach, because it is more detailed, is able to deliver more insights into these processes than the macro-analytical model with its epidemic bias. Moreover, as the simulation model also reproduced certain well-known features of diffusion such as the logistic curve – a factor which certainly lends support to the model – it allows experiments with special determinants of the process to be made on a microanalytic level.

It was also possible to confirm certain well-known facts at the level of micro-causation concerning the likely success or failure of an innovation. It could be shown, for example, that , if just over half the agents have an even unconsciously negative attitude towards the innovation or if too few people actively believe in it, then the innovation is unlikely to succeed. Beyond these affirmative results, the simulation model provided new insights into the process by which an innovation may become locked in and into how it relates to important determinants such as beliefs and communication channels.

Another major finding was that within the ongoing diffusion there is a process of harmonization between the network structure and the attitudes dimension. We could call this an *integration process* which is the driving force of the "spread". In other words, diffusion is revealed as a self organizing and self nourishing process the result of which is highly sensitive to initial conditions.

As has been shown, diffusion can be modelled by a communication process and, following modern innovation research, this must be included as an important determinant of evolutionary or technological change. If this is conceded then the above results also make it clear that there is an internal dynamic within the diffusion process which, against the background of "prisoner's dilemma"-pay offs must be taken into account in situations of extreme economic uncertainty.

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