Environment and Institutions: a complex dynamical systems approach

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Abstract

Environmental issues are characterised by uncertainty and problems of cooperation. Societal responses to such challenges are Institutions: beliefs, norms, relationships, property rights, agencies etc. We discuss here a bottom-up approach to the emergence of institutions such as beliefs and norms in pollution issues and agri-environmental policy implementation. The models are based on networks of automata, Bayesian updating and coupled map lattices. They exhibit clear organisational properties and regime transitions according to their parameters. The behaviours predicted by these models often differ from the predictions of standard economy based on unbounded rationality.

1 Introduction

Environmental issues are characterised by uncertainty and problems of cooperation.

- Uncertainty has always been a constant of our climatic and biological environment but it recently increased due to the novelty of certain technical processes (e.g. nuclear power, use of new chemicals in agriculture and industry, new seeds). Uncertainty also increased because of the new magnitude and the global aspect of the human impact on environment (e.g. resource depletion, water pollution, global change). Finally, even when the physical and chemical properties of the processes are well understood, their biological impact is much harder to assess.

- The use of environmental resources, or pollution of the environment, might be beneficial to the individual or the firm, user or polluter, and detrimental to the community. (see e.g. Hardin (1968), the tragedy of commons).

Societal responses to such challenges are Institutions such as: beliefs, norms, preferential links, property rights, agencies etc. (as discussed for instance in North (1990) in the general case). A number of religious beliefs and taboos of so called "primitive societies", such as

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animism, are institutions which most probably relate to the preservation of the environment of these societies. Historical records about property rights in relation to the use of environmental resources are well documented (see references in Ostrom et al. 1999 e.g. Ostrom 1990). Agencies to regulate fisheries or air pollution appeared in the modern times.

Most of us are convinced that simple market mechanisms as described in the neo-classical economics of General Equilibria are not sufficient to ensure sustainable development and that new institutions, or at least a renewal of institutions, (the word being used in the above defined meaning) are necessary. Hence the proposals to change property rights, invent new taxation or emission rights, to have new international agreements and agencies. In fact most of the discussion about the role of institutions is presently based on a top down approach: some entity, most often a state, or a collection of states, decide on some environment policy and how to implement it. There are probably situations where we can learn a lot from the top down accounting approach. But such a view neglects issues about uncertainties, inhomogeneities in the appreciation of environmental values, distributive decision making (the fact that decisions are taken by inhomogeneous committees) and obedience of constituents (people concerned by a decision might not abide by the decision).

In those cases when uncertainties and inhomogeneities of views and interests are important, or when obedience to the central government is is not certain, the bottom-up approach makes more sense than top-down. In a bottom-up approach, one starts from individual agents with partial knowledge about their environment. Their choice of decision for action depend upon their motivations and their internal representations of the world. Motivations can concern economic well-being, free time, aesthetic or moral values...They might include discount factors concerning future vs. present. An internal representation of the world (in a modeling context) is typically a set of parameters adjusted by learning which allow agents to do prediction about the usefulness of their actions: e.g. linear predictors, weights in a neural net model, estimated parameters of a function. Both sets of parameters, those shaping motivations and those shaping internal representations, are adjustable by learning. The learning process allows for adaptation and explains the diversity of opinions: agents sample world conditions, but don't share the same experience.

This framework is typical of decision making: how do agents with imperfect knowledge acquire new information and take individual or collective decisions on which product to buy, which technique to use, whether to abide by regulations or subscribe new environmental contract (see further the example of AEMs discussed in section 2). Dynamics becomes more intricate when one takes into account the fact that agents actions impinge on the state of the world, and that the resulting changes of the environment modifies agents parameters. The dynamics of agent interactions unfolds and shapes institutions: beliefs, routines, eventually cooperation ... and the state of the world. Figure 1 exemplifies a typical loop structure with cyclical interactions between agents and their environment. This figure could apply to any societal issue, such as the organisation of a market in economics for instance: in that case we would replace the word environment by market in figure 1. What is specific to a number of ecological economics problems is that the time scales of the dynamics of cognitive and environmental variables are comparable; a standard approximation of economics, namely the simplifying hypothesis of constant beliefs and preferences does not apply to the issues we are dealing with. The hypothesis of constant beliefs and preferences "cut the loops" and makes modeling much easier.
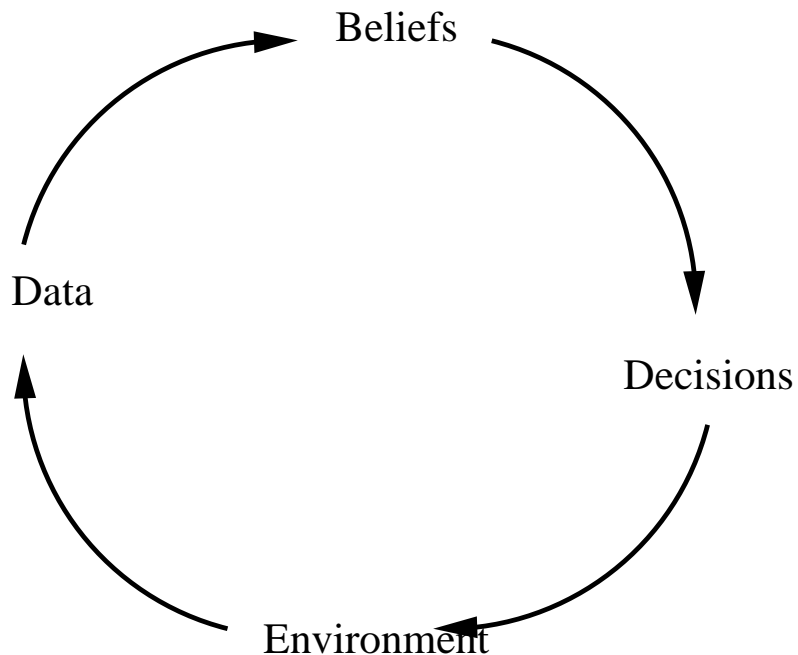
2

Figure 1: The loop of interactions between agent cognitive properties and their environment. Agents take decisions and act according to their beliefs, which are built by sampling and processing data from their environment. These actions change the state of the environment.

In our case, the diversity of the agents, and the complexity of their interactions, both mutual and with their environment, naturally call for a complex dynamical systems approach (Weisbuch 1990). This consists in using numerical simulations as test-beds of simplified socio/environmental systems and concepts taken from non linear dynamics and statistical mechanics to understand the dynamical behaviours observed in the simulations. Rather than staying at this level of generality which gives little insight to those who are not yet familiar with these modeling concepts, we propose to illustrate them with two examples taken from the modeling of environmental issues.

- Adoption of environmental measures by a population of farmers (Weisbuch and Boudjema 1999).

- Pollution by fixed emitters (Weisbuch et al. 1996).

These examples are based on a bounded rationality approach, in the sense that agents have imperfect knowledge about their environment. The institutions that we describe are beliefs and norms of behaviours. Our main focus is descriptive, but the results presented could also be used for policy implementation. Extended versions of the models that we discuss here have been already published with many more simulations and formal computations and we will not give all the details here. Our readers can refer to these publications or their extended versions on our web side http://www.lps.ens.fr/~weisbuch.

Apart from stressing the strong connection between bounded rationality and environmental issues, the purpose of the present paper is to illustrate the wide range of possibilities within the complex systems approach and some of its limits.

2 Innovation diffusion

The discussion in this section will specifically refer to a model of the dynamics of adoption of agri-environmental measures by farmers in Europe, but as said above, there is a large variety of related models discussing similar questions such as: how do social agents take decisions on which product to buy (Föllmer 1974, Kirman 1993, Orlean 1995, Latane and Nowak 1997, Galam 1997, Janssen and Jager 1999), which technique to use (Hägerstrand 1965) or whether to abide by regulations. We here concentrate on the issue of innovation, i.e. we take initials conditions such that a large majority of agents are using the old technique and only a small minority starts using the new one.

The European Union is presently proposing financial help to farmers who accept to modify their agricultural practices towards environmentally friendly practices such as input (fertilisers and pesticides) reduction, biological farming, set-aside etc. (refer to the Agenda 2000 Web site). In practice, at some local level, farmers have to decide whether to accept a contract (to be further called an AEM for Agri-Environmental Measure) implying some financial help in exchange for the adoption of well defined agricultural practices in their farm. Such a reorientation of the Common Agricultural Policy from subsidies to production towards subsidies to environmentally friendly practices involves a lot of changes, equivalent in amplitude to those induced by the technical revolution (mechanisation and use of chemical fertilisers) for farming in the beginning of this century or the green revolution (use of chemical and new cultivars) in the less developed countries. We might expect uncertainties to be very important for farmers (Lazzari 1998), and that the present process will develop in time: hence the idea to use a dynamical approach similar to the one used in the study of technological change.

In fact, most modeling of innovation diffusion is presently based on the ideas that:

- a new innovation is always beneficial;

- the rate of adoption of the innovation is limited by the propagation of information from innovators to potential innovators.

The standard metaphor is then epidemiology, and innovation diffusion is treated as the propagation of an epidemics through a susceptible population: individual "infection" events are thus proportional to a frequency of encounters between infected and non-infected individuals. In the case of random encounters across the whole population, these hypotheses lead to a logistic equation and the well-known S curve for adoption dynamics. We will here depart from the standard metaphor.

- A first feature, different from the hypothesis of random encounter across the whole population, is to suppose the existence of a social network : exchanges of information pertinent to the choice only occurs among individuals directly connected through a social network (we call them neighbours)(Degenne and Forsé 1994, White web site).

- A second feature is the inhomogeneity of agents. We take into account the fact that the innovation might not be equally profitable for all agents and that they care differently about the different aspects of the innovation:

- Some agents might be in a position such that the innovation is clearly beneficial according to their own criteria and they should adopt it as soon as they hear about it;

- for others the extreme opposite is true: whatever other agents are doing, they should not adopt;

- the less determined agents rely on the choice made by their connected neighbours.

We will be interested in the situation where very few agents are initial adopters and when social factors dominate the dynamics of adoption. Farmers choices are based on their e-valuation of the advantages of taking environmental premiums in exchange for environment friendly practices, plus imitation terms taking into account the information that they get from neighbours which have already made their own choice. More specifically, for each choice, adopt or not adopt, farmers compute a utility function taking into account economic factors, considerations about time schedule, pleasure, state of the environment, psychological factors such as fame or good relations with neighbourhood etc ... Let us consider two models for imitation through neighborhood.

2.1 The percolation model

In a very simple model (Solomon et al. 1999) of innovation diffusion a farmer adopts whenever:

- at least one neighbour has adopted;

- The utility of adopting for this farmer is larger than the utility of non adopting.

The notion of a neighbourhood here refers to social neighbours as defined by a social network: a direct link should exist between farmers to be neighbours. One interpretation of the first condition is that awareness about the innovation is triggered by at least one adopting neighbour. The second condition a priori divides the set of potential adopters into those who will never adopt, and those that are susceptible to adopt provided that one of their neighbors adopts. If a small number of individuals initially adopts, the fraction of actual adopters increases in time following the propagation of influence along the social network *reduced to potential adopters*. If this reduced network is random, the phenomenon of percolation (Stauffer and Aharony 1994) dominates the dynamics: if the fraction of potential adopters is larger than the percolation threshold (e.g. 0.59 on a square lattice with nearest neighbors, 0.40 on a square lattice with next nearest neighbours, $1/k$ on a random net with connectivity k) the fraction of adopters approaches one as time increases. In the opposite case, this fraction remains close to zero. The transition between the two dynamical behaviours is a very abrupt function of the fraction of potential adopters. It has been well studied in percolation theory. Close to the transition, the fraction of actual adopters has large fluctuations as a function of the actual distribution of adopters in the networks: the same total fraction of potential adopters might result in adoption fractions varying between zero and one. The above analysis applies to any network, regular or random, with or without loops. What might change between nets of different kind is the percolation threshold.

5

2.2 Networks of threshold automata

The model is generalised (Weisbuch and Boudjema 1999) when we consider the possibility that some farmers may adopt only when several neighbours have already adopted. A possible interpretation is "voting": farmers i add up their neighbours opinion to take decisions. Perceived utilities U_i^o for each option o, adopt or don't, are then computed as the sum of:

- a random term u_i^o fixed a priori at the beginning of the simulation which represents the a priori utility of the option to farmer i;

- plus an imitation term depending upon the choice made by their neighbours.

$$U_i^o = u_i^o + \sum_j J_j \tag{1}$$

where the sum is extended to all neighbours j who chose option o ; J_j is the weight of neighbour's j opinion. Farmers decision are: adopt if the perceived utility of the AEM is larger than its non adoption. Technically speaking, both models are networks of threshold automata (Vichniac 1986, Weisbuch 1990, Galam 1997).

2.2.1 Simulations

Starting for a weak density of initial adopters, simulations show the evolution of the fraction of adopters in time. Their output are spatio-temporal patterns, which sometimes remain localised to a small set of early adopters, or eventually grow to fill a large part of the network (visualization of the spatio-temporal patterns is easy for a 2-d grid, but similar results are also checked on random nets by measuring adoption rate in time). The typical question that we want to answer is:

What is the final fraction of adopters in the farmers population for a given distribution of a priori utilities and a given connection network with influence weights?

2.2.2 Main results

The general answer to the above question is that for a wide range of distributions and connection structures, global information is not sufficient to predict adoption. Most often local information is necessary. Under a large set of social network topologies and hypotheses on the distribution of farmers characteristics, premium uptake depends upon local characteristics of farmers and their network. For the same average characteristics uptake rates can be either 0 or 100 perc. This herding behavior is typical of imitation processes, and we observed it even in the case of agents with a large distribution of characteristics, provided that the width of the distribution is smaller than the social interaction terms. Choice is often uniform but hardly predictable, unless one has local information on the repartition of agent characteristics. This outcome is well understood: adoption patterns are able to grow and fill most of the social network only when some initial adopters are grouped as well characterized seed configurations; when this is not the case, e.g. when they are isolated, one does not observe any further adoption. (see Weisbuch and Boudjema (1999) for a thorough

analysis). The equivalent phenomenon is well known in the physics of phase transitions: a nucleation process is necessary for a phase transition to occur.

These results are very different from those expected when one only takes into account a priori utilities, which would be a model of full rationality. In such a case one easily predicts the adoption of all farmers with a positive difference in priori utilities. To summarise:

- Full rationality yields exact prediction of the fraction of adopters; this fraction can take any value between 0 and 1 according to the distribution of a priori utilities of farmers.

- By contrast bounded rationality yields difficulty of prediction and herd behaviour, i.e. adoption fraction often take values very close to either 0 or 1.

3 Pollution

Economic choices involving pollution, like those concerning common resources, relate to uncertainty with respect to social costs and to the emergence of cooperation among actors. Furthermore, since pollution propagates in space, the temporal dynamics of economic choices is coupled to the spatial dynamics of pollution. We then expect that simulation will produce spatio-temporal patterns of adoption and pollution. The purpose of the model (Weisbuch et al. 1996) described below is to determine under which conditions economic agents would agree to pay the extra cost of devices, such as catalytic converters, that prevent polluting the environment, Thus, once more we discuss adoption under social influence, but also taking into account the influence of the state of the environment on the decision process. In that respect the model implements the complete loop of interactions described in figure 1, which was not the case of the previous section where the state of the environment did not explicitly modify the agents' views.

A simple example that we use throughout the discussion is that of two brands of otherwise equivalent equipments, except for the fact that one brand is polluting and the other one is not. When pollution costs are not taken into account, the a priori utility of the non-polluting equipment is lower than that of the polluting equipment, because of the cost of the depolluting device. If the agents were fully rational (i.e. if they were fully informed) and cooperative (no cheaters), they would accept to pay for the converter a price up to the cost of pollution generated by each polluting equipment. We proposed a model based on bounded rationality which shows that agents only agree to pay a fraction of the cost of pollution. In this model, derived from Arthur and Lane (1993), agents compute the utilities of both brands according to their a priori expectations and the opinion of their neighbors about the brand they have chosen, their risk aversion, and the cost of local pollution. The model supposes no government intervention, except perhaps a tax on polluting equipments, and that the agents have no global view of the real cost of pollution associated with each brand. They simply experience the decrease in utility of the brands due to present local pollution. Due to the locality of information exchange and the diffusion of pollution, agent opinions depend on time and space. The model takes into account several coupled dynamics: those of pollution, of agent internal representations (corresponding to beliefs in figure 1) and of their choices. We are ultimately interested in the time evolution of the market shares of polluting and

non polluting equipments, and how it depends on the parameters governing the economic variables and especially the dynamics of the internal representation of the agents.

3.1 The model

3.1.1 Computation of the utilities

The agents choose equipments according to their "internal representation" of the characteristics of the products. These internal representations are probability distributions of the utility of each product that are computed according to the following procedure.

- Agents access some public information about the performance of each brand i, represented by a normal prior probability distribution , with mean μ_i and standard deviation σ_i.

- They take advice from n other purchasers (in the reported simulations these are the eight closest neighbours on a square grid), among which n_i bought brand i. Only those n_i purchaser that bought brand i contribute to the information about brand i by sending a measure of its utility:

$$X_i = \mu_0(i) - P + \epsilon \ ,$$

where $\mu_0(i)$ is the average utility of brand i in the absence of pollution. Since the sampled purchasers already possess the brand, their opinion about the brand includes the negative effects of pollution. We suppose here that they don't know a priori how much extra pollution is associated with the polluting equipment: the decrease in the experienced utility is then proportional to local pollution, irrespective of which brand they have purchased themselves. Utility is then decreased by the presence of pollution P expressed in the convenient cost units. ϵ, representing measurement error, is a normally distributed random variable with mean 0 and standard deviation σ_{ob}.

The agents process this information to obtain a posterior distribution of performances. This processing is done by taking the convolution products of Gaussian integrals corresponding to the prior and to the information obtained from other purchasers. The average expected posterior utility $\mu_{post,i}$ is then:

$$\mu_{post,i} = \frac{1}{n_i + \alpha_i} [\sum_{j=1}^{n_i} X_{i,j} + \alpha_i \mu_i] \ ,$$

where index j refers to the pooled agent. The mean utilities are averaged with a weighting factor that is inversely proportional to the variance of the distribution:

$$\alpha_i = \frac{\sigma_{ob}^2}{\sigma_i^2} \ ,$$

The Bayesian learning process is thus reduced to the simple iteration of the two above equations.

Economic agents are adverse to risk. The greater the uncertainty in the value of a product, the less they are likely to buy it. To take into account risk aversion of the agents, we use a classical mean variance utility function: one more term, proportional to the variance of the posterior distribution, is added to $\mu_{post,i}$ to compute the effective utility function U_i used by the agents to choose their equipment:

8

$$U_i = \mu_{post,i} - \lambda\sigma^2_{post,i} = \mu_{post,i} - \lambda\frac{\sigma^2_{ob}}{n_i + \alpha_i} \ ,$$

where λ is the risk aversion parameter and $\sigma^2_{post,i}$ is updated by narrowing the variance according to the number of sampled purchasers. The complete expression for U_i is then:

$$U_i = \frac{1}{n_i + \alpha_i}[\sum_{j=1}^{n_i} X_{i,j} + \alpha_i\mu_i - \lambda\sigma^2_{ob}] \ ,$$

Upon computing U_i for each product, purchasers choose the brand with the highest expected utility.

3.1.2 Pollution dynamics

The dynamics of the agent representations and choices interacts with the diffusion dynamics of emitted pollution. Agents occupy the cells of a two dimensional grid that represent space. Polluting equipments generate pollution at a constant rate s. This pollution diffuses in space according to Fick's law, and part of it simply disappears locally (through decomposition for instance). Pollution, P($\mathbf{r}$,t) in $\mathbf{r}$ at time t, obeys the following partial differential equation:

$$\frac{dP(\mathbf{r}, t)}{dt} = D\Delta P(\mathbf{r}, t) - dP(\mathbf{r}, t) + s \ ,$$

where D is the diffusion constant, ΔP the laplacian of P, d the decay term. s, the source term, is only present when the occupant of the cell bought a polluting equipment. The s term strongly couples the dynamics of pollution to that of the agents' choices. The range of possible pollution levels correspond to fixed configuration of choices. Pollution is zero when all agents always bought non-polluting equipments and maximum and equal to s/d when they all have always bought polluting equipments. s/d, the maximum pollution, reflects the cost of pollution, and is the natural scale on which to compare differences in the prior utilities of the agents. However, since the agents only use local information, the gradient of pollution times the range of polling is the relevant parameter to compare differences in prior utilities as we checked in computer simulations.

Technically the model is then based on Coupled Map Lattices: the coupling terms are due to information exchange between neighbouring sites and to pollution. A more detailed exposition of the model is available in (Weisbuch et al. 1996). One interesting feature of the model is that one can vary the influence of past information memorized by the agent with respect to information exchanged with neighbours.

3.2 Simulations

In a typical simulation, one starts from non homogeneous distribution of agent choices and typically follows the time distribution of market shares and the spatial pattern of agent choices. The most influential parameter with respect to which attractor is reached is the ratio of difference in prior utilities of brands to pollution cost (s/d).

- When this ratio is low, the system evolves towards total domination of the non-polluting equipments with a market share of one (figure 2);

9

- When it is high, the system evolves towards a partial domination of the polluting equipments with a market share varying from 75 perc. to one with a specific spatial pattern (figure 3).

The transition between the two regimes is abrupt with respect to the ratio of difference in prior utilities of brands to pollution cost. Other parameters such as agent memory or risk aversion, and initial configurations are less important.

3.3   Main results

The model shows that agents with imperfect knowledge are able to switch to more expensive non-polluting equipments by comparing information about pollution costs obtained from neighboring agents. When information sampling is local, the maximum accepted extra cost for the non-polluting equipment scales as the gradient of the pollution cost times the range of polling; it is then less than the cost of pollution. A surprising result of the simulations are the coexistence regions with regular patterns of cheaters and cooperators as represented in figure 3. Local diffusion of information does not always bring homogeneity of choices. Another interesting result is the fact that invasion of the polluted region by the non-polluting equipments does not always proceed from the non-polluted region (see figure 2). When mixed metastable attractors are reached, the polluted mixed region can be invaded from islets of non-polluting equipments that started as fluctuations inside this region.

4   Conclusions

Emergence of Institutions and Regime transitions

The simple models that we proposed exemplify the use of Complex System Dynamics in describing the dynamical emergence of Institutions such as beliefs and routines. The behaviours that we interpreted as Institutions are well-characterised, and they often involve the domination of one choice, adopt or not, don't pollute (but not the opposite in the example that we discussed). In certain cases, e.g. for the AEM adoption, initial conditions determine the outcome of the dynamical process.

These complex systems exhibit a characteristic behaviour called resilience. When a parameter of the system is varied one observes a stepwise response: little change as long as the system remains in the same dynamical regime, but big changes when the parameter moves across a transition. This response is characteristic of systems made of non linear elements interacting via entangled loops, which is the case of our models and of most environmental systems. In other words, socio-environmental transitions, for instance changing from the domination of one behaviour to some different pattern of behaviour, are most often abrupt:

- they involve large changes in market shares or adopters fraction;

- and they occur for an infinitesimal change in parameters.

As we stressed, the behaviours that are selected through the dynamical processes are quite different from the predictions of unbounded rationality approach. In the approach described here, agents have no strategic thinking. Still they react to the choices of those
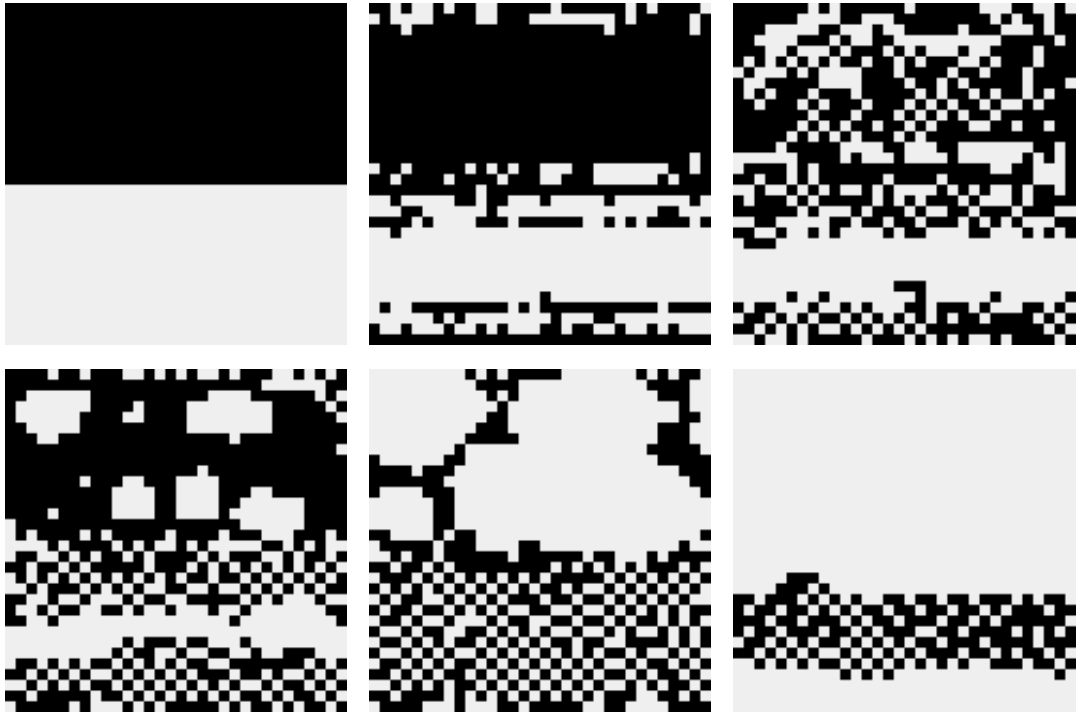
Figure 2: Evolution towards market domination by non-polluting equipments in case of an intermediate difference in prior utilities: The six patterns represent the spatial distribution of choices (black squares are polluters, light grey squares non-polluters) at times t=0 , t=6 , t=10 from left to right for the upper patterns and at times t=13 , t=15 , t=36 from left to right for the lower patterns. Note the apparition and growth of islets of non-polluters from the polluted region at times 13 and 15. The systems evolves towards complete domination of the market by non-polluters at t=100 (not represented in this figure).
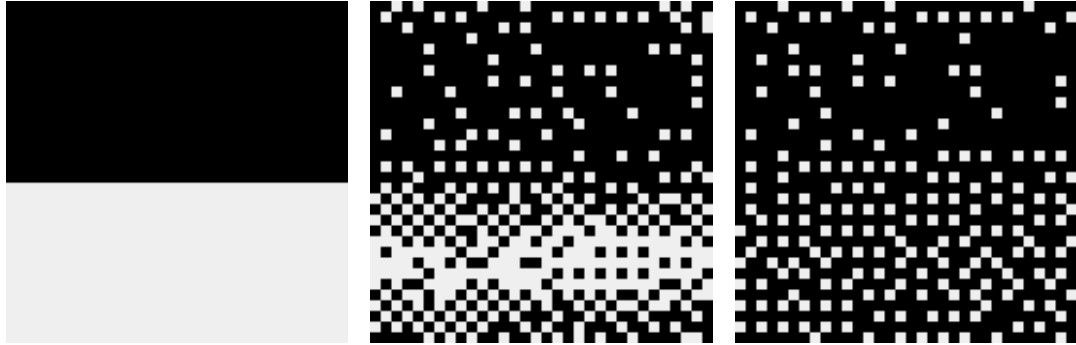
Figure 3: Slow evolution towards a coexistence distribution among polluting and non-polluting equipments in the case of a large difference in prior utilities. The three patterns represent the spatial distribution of equipment choices at times t=0 , t=32 and t=1100, from left to right.

they are connected with and bear the consequences of their decisions in the case of the pollution model. We are not using here any concept or hypothesis from game theory. For instance, an important assumption of standard game theory, constant pay-off matrix, is not necessary in our approach. The constant pay-off matrix would not allow to take into account the lower arrows of the loop in figure 1, namely the fact that actions of the agents gradually change the environment and that these changes modifies agents views.

Where do we stand with respect to comparison with empirical data and with respect to normative approaches?

It should be clear at this stage that we do not pretend to reach the same kind of precision as in accounting or in ecological modeling based on system analysis (refer for instance to the UFIS/ECOBAS ftp-fileserver for ecological models). The reason is obvious: to get any precision in prediction one needs to specify relevant parameters. This knowledge might be available for models dealing with physico-chemical and possibly biological variables, but cognitive and social parameters are much more difficult to assess. In the case of the adoption model e.g., this would mean knowledge of the a priori utilities, (a knowledge most often unknown to farmers themselves which is precisely why they have to resort to imitation !) and of the social influence network. These data are very difficult to assess.

On the other hand, the dynamical properties that we report, i.e. well characterised dynamical regimes separated by sharp transitions, are robust with respect to the model specifications: they remain the same for a wide range of parameters and for important changes in the model, e.g. for regular lattices as for random networks. This is an indication about the range of validity of the models: since some properties, that we call generic, are observed for a large ensemble of models with different complexity and realism, we might expect these properties to remain true for real systems that are much more complicated than the toy models that we described here.

In some sense we have traded the possibility of very specific predictions that we could have made provided that we had a lot of data, for more general predictions which are less sensitive to the availability of data. Still, this does not mean that the models cannot be compared to empirical evidence: for instance in the case of adoption uptake of agri-environmental contracts in Northern Italy, one observed a very different uptake of AEM during the first round: basically most farmers in Lombardia adopted, while those in Piemonte, a similar and neighboring province did not. This contrasted behaviour in similar regions fits with herding behaviour and the sensitivity to the repartition of early adopters that we mentioned in section 2.

Furthermore, the insight that we gain about which factors are important in the adoption of new techniques can be used by agencies trying to promote these techniques. We have shown for instance that when uncertainty about the new technique, and thus social factors are important, more concentrated effort should be made to promote the new technology during the early stages than if individual were fully rational (a more detailed discussion of other possible strategies can be found in Weisbuch and Boudjema 1999).

On the opposite, observing the same generic properties for one model and some real system does not prove the model or validates its detailed assumption. In the case of Lombardia and Piemonte above mentioned, other explanations were proposed, such as the fact that propaganda for the AEM was conducted differently in the two provinces. This alternative explanation is not even contradictory with ours: a minor change in the repartition of ear-

ly adopters due to the nature of propaganda might have been enough to ensure success in Lombardia.

The real challenge is to test series of models and to classify them according to the generic properties that they share with real systems. This challenge is not the standard challenge in Science, at least according to the Popper's falsifiability test, but it is more relevant to environmental challenges faced by societies:

- What policies would bring *robust* results in view of the inherent uncertainties about environmental issues?

- How to implement these policies across populations that are inherently inhomogeneous in terms of interests and cultural values, not to mention their limited obedience.

Prospective concerning other types of institutions

We have here illustrated the notion of dynamical emergence of institutions in the relation to environment for the case of beliefs - what is best? - and social norms of behaviour - polluting or not, adopting or not - (although sociologists might dispute using the term norm since our agents are not *consciously* following the norm). We might also consider that the subsets of agents with the same beliefs and behaviours constitute emergent social structures since the behaviours are re-enforced through social interactions.

Property rights could also be described as emergent institutions according to evolution of power gained by certain groups, interest for the future and cooperation inside the group and properties of the environment such as sensitivity to human exploitation. The same approach could also lead to understanding the emergence of environmental agencies as intermediaries between users and the environment.

To take a more general perspective, we have tried to show how complex system dynamics offers a handle on how to deal with the intricate dynamics of cognition, social factors and environment. The bad news for the modeler is the complexity of the task and the limitation of the kind of predictions that can be made as we stressed above. On the other hand, since agents change their views and preferences according to the state of the environment, some hope for future improvement in the real world might be envisioned. Our civilisation is not doomed to a chaos of pollution and resource exhaustion: this is good news for us as citizens.

Agenda 2000, http://europa.eu.int/cornm/dg06/envir/programs/index_en.htm

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