RECOGNITION OF INVESTMENT OPPORTUNITIES AND GENERATION OF INVESTMENT CYCLES

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Abstract

Innovations cause entrepreneurs' mental models not to hold, generating optimism when innovations open up new fields of activity and pessimism when investments in fields that used to be safe no longer yield the usual returns. The state of optimism or pessimism in the minds of entrepreneurs eventually propagates to the whole economy, triggering up- and downswings of aggregate investments.

1 Introduction

Investing means to have a vision of the future, to believe it with a force and with a determination that goes well beyond the kind of "rational choice" utility maximisation can describe, and to commit oneself to a project that requires a great deal of will and persistence. When an individual risks his assets to become an entrepreneur, or when a manager risks his position in order to convince his company to pursue a certain strategy, there is much more involved than comparing the utilities of given alternatives. The "more" is a vision of these alternatives, of their possible consequences, and of a net of causal relationships that connect alternatives to consequences.

Many great economists stressed that investments are the engine of capitalism: Schumpeter (1911) first of all, and also Keynes (1936), who coined the expression "animal spirits" to designate the conviction by which entrepreneurs follow their visions. Unfortunately, formalisation of animal spirits has never been attempted, since it is an issue that is clearly out of the reach of the tools of decision theory.

This paper stems from a (possibly entrepreneurial) conviction: that formalisation of "animal spirits" is possible, and that it passes through the injection of some elementary concepts of cognition sciences into decision theory. An entrepreneur's "vision" is his mental model, a net of causal relationships connecting to one another mental categories that are peculiar to him in a way that is peculiar to him, a vision that the others can call "animal spirits" only if they don't share it, because their minds organise information in different ways. Consequently, if an entrepreneur's mental model is assumed to be known, it is possible to think sensible rules whereby this mental model is validated or rejected by empirical experience, and "animal spirits" arise or decay.

This is what this paper sets out to do. It does not present a realistic model, in the sense that one cannot use it (as it is) to describe a manager's behaviour. It is a methodological paper, in the sense that it proposes a new method. Clearly, this can be done best in an over-simplified setting by means of unrealistic assumptions, which have the purpose of isolating behaviour from influences by any other factor.

The paper consists of two main sections: the first one explains a single entrepreneur's decision model, the second one tests it in an artificial economy where many entrepreneurs interact with one another, as well as with consumers. Finally, a conclusion points to strengths and weaknesses of the above model, suggesting directions for future research.

2 Entrepreneurs' cognitive processes

Individuals simplify the mess of information they receive by classifying it into a manageable number of mental categories. Neither the number of mental

categories, nor the criteria by which information is classified are constant with time; furthermore, the same individual may use different mental categories in different situations, and categories may not be constructed around a single prototype (Lakoff, 1987; Clark, 1993).

However, for the sake of simplicity we shall neglect these insights: the mental categories we shall describe will be fixed in number, and they will obey fixed classification criteria. Nonetheless, they will retain the main concept of a mental category, namely that of a "box" whose content changes according to the novelties an individual encounters.

A mental model is a sort of map that provides orientation in decision-making by telling an individual at any time what it is 'normal' for him to expect; it is, in other words, a set of causal relationships that link a set of possible causes with a set of possible effects. A mental models can be seen as a net of connections that link mental categories to one another; however, the mental model that we shall ascribe to our decision-makers will be no more complex than a set of one-to-one relationships.

Let us describe entrepreneurs' cognitive processes by means of two kinds of mental categories: one for the 'actions' they undertake in order to produce and sell goods (usually entailing an act of spending), the other for the 'results' they obtain from customers (generally associated with proceeds). The 'situation' faced by an entrepreneur is a set of action-result pairs that occurred recently, while his 'behaviour' is the particular action he undertakes.

The actions entrepreneurs undertake, as well as the results they obtain, involve innovation of the qualitative features of goods, tastes and technologies, and can change with time in unpredictable ways. Nonetheless, we shall assume that entrepreneurs classify any action and any result in the following mental categories:

A_-: "Stand-by": the category for all entrepreneurial actions that require little money outlays, involve little innovation, but also little risk.

A_+: "Investments": the category of actions that, on the contrary, need large money outlays and involve important innovations, although they inevitably bear larger risks.

R_-: The category of mediocre results one normally expects from actions of category A_-.

R_+: The category of good results entrepreneurs expect from actions of category A_+.

Entrepreneurs evaluate the possibilities they are able to contemplate by means of a function u defined over their mental categories; let us stipulate that u measures utility if it is applied to result categories, and disutility if it is applied to action categories. Thus, it is obviously $u(A_-) < u(A_+)$ and $u(R_-) < u(R_+)$. Furthermore, since the prospect of a result of category R_+ must be such that it is convenient to undertake an action of category A_+ although it requires a larger effort than an action of category A_-, it must be also $u(R_+) - u(A_+) > u(R_-) - u(A_-)$.

If no innovation is introduced in the economy, the content of mental categories does not change with time; hence, in this case utility can be thought to be defined over the objects contained in mental categories. In this particular case, which is the one that is usually assumed, utility refers to goods, not to the way a decision-maker perceives goods.

If no novelty is supposed to appear, decision-makers only need to observe and measure the conditional probabilities of possible results for any given action, and take a decision that maximises their expected utility:

$$J(A) = \left[p(R_- \mid A)\, u(R_-) + p(R_+ \mid A)\, u(R_+) \right] - u(A) \qquad (1)$$

where $A \in \{A_-, A_+\}$.

However, if innovations do take place, (1) no longer suffices. An innovation is recognised by a decision-maker by the fact that his old mental model does not work anymore. For example, a new technology may make typing machines obsolete and disclose new possibilities for computers; consequently, a mental model entailing causal relationships like "If I produce typing machines I will make good profits" and "If I produce computers nobody will buy them, because they are too big" may no longer be a reliable guide to decision-making. Thus, we must add to expected utility a term that measures the extent to which innovations cause a mental model to fail.

Let us assume that the mental model is constituted by the one-to-one relationships between action categories and result categories shown in fig.(1a): once an action of kind A_- has been undertaken a result of kind R_- is considered to be 'normal', and once an action of kind A_+ has been undertaken a result of kind R_+ is considered to be 'normal'. In other terms, the mental model of fig.(1a) says that good revenues are the

normal outcome of investing, and that mediocre revenues are the normal outcome of hiding money under a mattress.

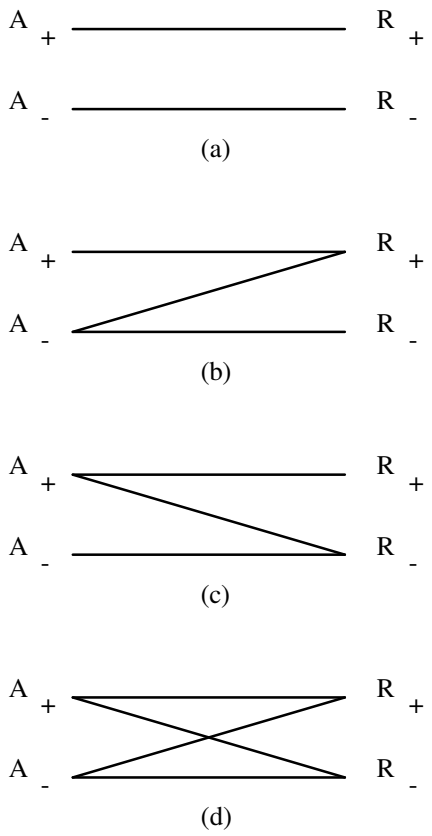

Figure 1

When correspondences other than those of case (a) occur, our entrepreneur may think that the categories and the model he is using are no longer appropriate to detect the relevant features of a reality where novelties are emerging. For instance, a new technology can open up new profit possibilities, a circumstance which would show up as the connections of case (b). But it can also cause the unexpected failure of investments on a field that used to be safe, in which case connections are as in (c). It can also produce both effects at a time, as it is shown in (d).

If the relations between mental categories are either as in (b), or (c), or (d), our entrepreneur is likely to think that this is the signal that an innovation is emerging, and that this innovation might have profound consequences for his activity. Independently of the probability distribution of successes and failures he might have computed in the past, misfunctioning of his mental model is likely to change the confidence he attaches to this probability distribution. Whether optimism as in (b), pessimism as in (c), or confusion as in (d), misfunctioning of his mental model inevitably alters his state of mind.

However, it is important to remark that a mental model says what it is 'normal' to happen, not what must happen all the times. Consequently, it is by no means obvious that relationships like those illustrated in (b), (c), (d) must be interpreted as failures of the mental model. They can also be interpreted as situations that occur rarely, though sometimes do: even with no innovation there is a positive probability that "safe" investments fail.

The trouble is that the emergence of novel profit possibilities shows up exactly in the same way as long-standing low-probability events do: it is up to the entrepreneur to decide whether what he is observing is the signal that the world is changing, or to discard it as worthless information. In other words, it is up to any single entrepreneur to detect the new profit possibilities opened up by an innovation, or to miss them. And from an entrepreneur's point of view, this is no little difference.

From the modeller's point of view, however, it easy to overcome this problem. In fact, it is sensible to assume that entrepreneurs use only the most recent information to evaluate the appropriateness of their mental model, while they use all information at their disposal to evaluate probability distributions of successes and failures. Only the most recent data can regard emerging innovations; on the contrary, it makes sense to use new and old information alike in order to calculate a probability distribution which is useful precisely to the extent that the present situation is analogous to the past ones.

Thus, let us assume that entrepreneurs are endowed with a memory of length L, and that they use all of its data to calculate a probability distribution of their successes and failures. On the contrary, their confidence in this probability distribution derives from the most recent data only, say the ones in the first $M \ll L$ memory locations.

The first M memory locations must be scrutinised in order to detect any deviance from the mental model illustrated in fig.(1a): if connections occurred, that are not those of the mental model, then the decision-maker does not have absolute confidence in the probability distributions he calculates using data from all L memory locations. Note that, unlike probability, it does not matter how many times one of these connections occurred, but only whether it occurred or not. Think to an entrepreneur who realises that some new technology allows high profits with relatively little effort, a circumstance which shows up as a set of

connections like those of fig.(1b): it does not matter whether he receives one or two news about this novel possibility, the crucial issue is realising that such a new profit possibility exists.

Let us for simplicity neglect any process of information diffusion by assuming that information is immediately available to all entrepreneurs, and for free. Each time an entrepreneur undertakes an action and receives a result, a new pair action-result enters the memories of all entrepreneurs (and obviously, the oldest pair exits at the same time). In this way, all entrepreneurs rely on the same data for their calculations; let us arrange these data in a matrix **D** of elements (A, R). With N entrepreneurs, matrix **D** has L rows and N columns.

Let us adapt to our oversimplified example a formalism that has been described elsewhere for the general case (Fioretti, 1998, 2001). Let us represent the relationships entailed in the first M rows of matrix **D** by means of a simplicial complex K made by two simplices A_- and A_+ having R_- and R_+ as vertices. In case (a), simplex A_- is constituted by the single point R_- while simplex A_+ is constituted by the single point R_+: the two simplices have no point in common and no simplicial complex exists, since A_- and A_+ are not connected. In case (b) simplex A_+ is still constituted by the single point R_+, but simplex A_- is the segment between R_- and R_+: the two simplices have vertex R_+ in common, simplicial complex K is made of a segment and one of its extreme points. Case (c) is analogous, just exchange R_- and R_+. In case (d) both A_- and A_+ are segments between R_- and R_+: the two simplices have one edge in common and simplicial complex K is constituted by two overlapping segments.

Let us stipulate that the complexity of a set of isolated simplices is zero, while the complexity of a simplicial complex is given by the dimension of the common face between the two simplices, plus one. Then, in the four cases of fig. A the complexity of simplicial complex K is $c_a(K) = 0$, $c_b(K) = c_c(K) = 1$ and $c_d(K) = 2$, respectively.

Let us agree that simplices A_- and A_+ contribute to the complexity of the whole simplicial complex in proportion to their dimension. Hence, $c_a(A_-) = c_a(A_+) = 0$; $c_b(A_-) = 1$, $c_b(A_+) = 0$; $c_c(A_-) = 0$, $c_c(A_+) = 1$; $c_d(A_-) = c_d(A_+) = 1$.

If complexity measures how "complex" a situation appears to the decision-maker, "confidence" must be its opposite. Let us define a 'degree of confidence' as follows:

$$\omega(A) := 1 - \frac{c(A)}{c(K)} \qquad (2)$$

where $A \in \{A_-, A_+\}$ and where $\omega \in \{\omega_a, \omega_b, \omega_c, \omega_d\}$ and $c \in \{c_a, c_b, c_c, c_d\}$, respectively.

This degree of confidence takes values in the $[0, 1]$ interval. In our case, these values are: $\omega_a(A_-) = \omega_a(A_+) = 1$; $\omega_b(A_-) = 0$, $\omega_b(A_+) = 1$; $\omega_c(A_-) = 1$, $\omega_c(A_+) = 0$; $\omega_d(A_-) = \omega_d(A_+) = 1/2$.

The objective function entrepreneurs maximise must entail a traditional part that depends on the probability distributions of successes and failures, as well as a cognitive part that depends on the confidence they have in their mental model. Let us use expected utility to represent the traditional part, but let us multiply it by the degree of confidence in order to represent the cognitive part.

However, the degree of confidence should have opposite effects when it refers to results that are better than those foreseen by the mental model, from when it refers to results that are worse than those foreseen by the mental model. For example, case (b) of fig. A should generate optimism, while case (c) should generate pessimism. In the first case, when the degree of confidence is less than one the objective function should increase. In the second case, when the degree of confidence is less than one the objective function should decrease.

Let us take account of this effect by raising the degree of confidence to the following exponent:

$$k(A) := \frac{u(R) - u(A)}{\overline{\Delta u}} \qquad (3)$$

where $A \in \{A_-, A_+\}$, and where $\overline{\Delta u}$ is the average of all $u(R) - u(A)$ differences. In our case $\overline{\Delta u} = [u(R_+) - u(A_+) + u(R_-) - u(A_-)]/2$, and $k(A)$ is subjected to the following restrictions:

$k_a(A_-) = k_a(A_+) = 1$; $k_b(A_-) < 1$ and $k_b(A_+) = 1$; $k_c(A_-) = 1$ and $k_c(A_+) > 1$; $k_d(A_-) < 1$ and $k_d(A_+) > 1$.

Hence, our new objective function is:

$$J(A) = [\omega(A)]^{k(A)} [\, p(R_- | A)\, u(R_-) + p(R_+ | A)\, u(R_+)\,] - u(A) \qquad (1')$$

where $A \in \{A_-, A_+\}$.

The central body of this objective function is its traditional part: expected utility, which makes sense as long as there is little innovation. On the contrary, innovations produce sudden jumps of the degree of confidence and sharp changes in the behaviour of entrepreneurs: the resulting investments can propagate to the whole system and eventually generate a business upswing.

Possibly, the meaning of the degree of confidence defined above can be better understood by making a reference to classifier systems (Holland, 1975). Classifier systems model categories by means of strings of zeroes, ones, and "don't care" characters # - this is not quite the nature of mental categories, and it is not an assumption of this paper; however, it is useful as a first approximation. From time to time, classifier systems activate procedures to create new categories, by means of random mutation of string characters or random recombination of parts of the old strings. A question classifier systems do not address is: When do these procedures need to be activated ?

The answer given in this paper is: categories need to be changed when the mental model they support does not work any more. After an individual recognised that his mental model is no longer a reliable guide to decision-making, but before a new mental model is constructed, an individual is hardly capable of decision-making. Sudden jumps in behaviour caused by (mis)functioning of an individual's mental model are particularly likely to happen in environments where novelties are the norm, as e.g. in the case of investments involving new technologies.

3 Investments Cycles

Let us now apply the above ideas to a model of investments cycles. The continuous introduction of innovations is supposed to keep the economy away both from perfect competition and monopoly; thus, our framework is rather that of imperfect competition.

Let us consider a population of entrepreneurs that interact with one another, as well as with a population of consumers. No other economic agents exist.

In order to allow each entrepreneur to trade with any other entrepreneur as well as with any consumer, let us assume that: i) All goods can be either consumed or used as production factors; ii) At least one good can be exchanged with any other. In order to avoid any constraint from past decisions on current production possibilities, let us also assume that: iii) No capital goods exist; iv) No inventories exist; v) Labour contracts refer to one production period only.

Entrepreneurs undertake actions towards other entrepreneurs as well as towards final consumers, receiving corresponding results from both kinds of agents. Consumers are supposed to behave in a more passive way: they return results to entrepreneurs, but they do not undertake actions by themselves. The actions entrepreneurs undertake consist of organising the production and sale of goods that generally entail some novel qualitative features, require new tastes to be appreciated and new technologies to be produced. The results entrepreneurs receive concern the reception of these goods by the market.

The categories by which actions and results are classified are A_-, A_+, R_-, R_+; however, due to restrictions $(i) \div (v)$ these categories can capture product innovation only. Technological innovation has a very limited scope in this model, since no capital goods exist: the only "technological innovation" this model is able to capture is learning by doing of pure labour. Tastes innovation is also minimal, since consumers accept the innovations proposed by entrepreneurs but do not carry out innovations on their own.

Let the number of entrepreneurs be fixed to N, and let $x \in [0, 1]$ denote the proportion of entrepreneurs who invest, i.e. who undertake an action of category A_+. It is $x = 0$ if all entrepreneurs undertake actions of category A_- and $x = 1$ if all entrepreneurs undertake actions of category A_+.

As long as at $x = 0$ all returned results belong to category R_- and at $x = 1$ all returned results belong to category R_+, the entrepreneurs' mental model is confirmed: they either observe (A_-, R_-) or (A_+, R_+) all the times. In this sense $x = 0$ and

$x = 1$, which can be identified with "recession" and "growth", respectively, are equilibrium points.

However, even at equilibrium entrepreneurs do innovate: at $x = 0$ they innovate because they hope to get a result of category R_+, and at $x = 1$ they innovate because they fear that their competitors' innovations may turn their result into one of category R_-. Innovations can be unexpectedly successful, which is the case when at $x = 0$ a result of category R_+ obtains. Or they can be unexpectedly unsuccessful, which is the case when at $x = 1$ a result of category R_- obtains.

Thus, even when the economy is at one of the two equilibrium points ($x = 0$ or $x = 1$), an unexpected result may suddenly change the degree of confidence and eventually push the system towards the other equilibrium. This mechanism can easily produce an irregular cycle where the economy continuously jumps from one equilibrium to the other.

The exogenous inputs to our model are: [I] the probabilities of obtaining a certain result category by entrepreneurs who are willing to undertake an action of a certain category, and [II] the probabilities of obtaining a certain result category by consumers.

Let inputs [I] be: $p_E(R_+ | A_- ; A_-) = \varepsilon_-$, $p_E(R_- | A_+ ; A_+) = \varepsilon_+$, $p_E(R_+ | A_+ ; A_-) = \delta_-$, $p_E(R_- | A_- ; A_+) = \delta_+$, where e.g. ε_- is the probability that an entrepreneur who is willing to undertake an action of category A_- returns a result of category R_+ to somebody who undertakes an action of category A_- towards him. It is obviously $0 \le \varepsilon_-, \varepsilon_+, \delta_-, \delta_+ \le 1$, with the following additional qualifications:

a) Entrepreneurs who undertake actions of category A_+ tend to give results of category R_+ more often than entrepreneurs who undertake actions of category A_-. Thus, $\delta_- < 0.5$ and $\delta_+ < 0.5$.
b) It is very unlikely that the cross connection of case (b) in fig. A occurs when one meets an entrepreneur who undertakes A_-, and it is equally unlikely that the cross connection of case (c) occurs when one meets an entrepreneur who undertakes A_+. Thus, $\varepsilon_- \ll 1$ and $\varepsilon_+ \ll 1$.

Let inputs [II] be $p_C(R_- | A_-) = \beta$ and $p_C(R_+ | A_+) = \gamma$, with $0 \le \beta, \gamma \le 1$. It seems reasonable to assume $\beta \gg 0$ and $\gamma \gg 0$.

Let us assume that the number of consumers is the same as the number of entrepreneurs, so that $p(R | A) = 1/2\ p_E(R | A) + 1/2\ p_C(R | A)$.

Probabilities $p_E(R | A)$ can be calculated by weighting probabilities $p_E(R | A ; A)$ with the fraction of entrepreneurs who are willing to undertake actions of kind A_- or A_+, respectively. Hence, probabilities $p(R | A)$ can be expressed as follows:

$$p(R_- | A_-) = \frac{1}{2}\left[(1-x)(1-\varepsilon_-) + x\,\delta_+\right] + \frac{1}{2}\beta$$

$$p(R_+ | A_-) = \frac{1}{2}\left[(1-x)\,\varepsilon_- + x(1-\delta_+)\right] + \frac{1}{2}(1-\beta)$$

$$p(R_- | A_+) = \frac{1}{2}\left[(1-x)(1-\delta_-) + x\varepsilon_+\right] + \frac{1}{2}(1-\gamma)$$

$$p(R_+ | A_+) = \frac{1}{2}\left[(1-x)\,\delta_- + x(1-\varepsilon_+)\right] + \frac{1}{2}\gamma$$

(4a) (4b) (4c) (4d)

Equations (4a ÷ d) express objective function $J(A)$ as a function of x; in their turn, entrepreneurs undertake an action of category A_- if $J(A_-)$ is greater than $J(A_+)$, and vice versa. In this way the model is closed, and simulations can be carried out; figure (2) illustrates the corresponding flow chart.

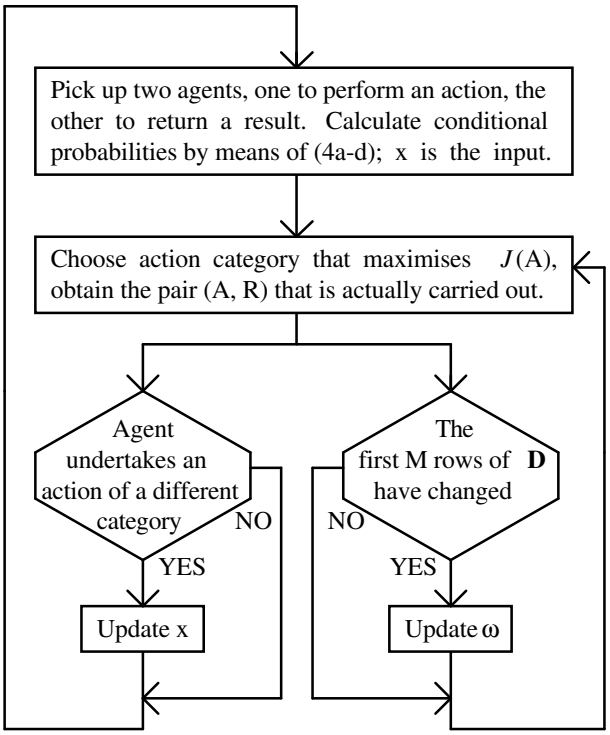

Figure 2

At each time interval one entrepreneur (it does not matter which one, since they all receive the same information) undertakes an action towards a randomly chosen agent (who can be either a consumer or another entrepreneur), and receives a result from him. The $(A|R)$ pair obtained in this way enters matrix **D** and may produce a sudden jump of the degree of confidence.

At the same time, the action undertaken by the entrepreneur causes a smooth change of x and, through $(4a \div d)$, a corresponding change of probabilities $p(R|A)$. In this way, at the beginning of the next time interval $J(A_-)$ and $J(A_+)$ take new values.

In order to compare simulations with one another, the random numbers generator will produce the same sequence of numbers throughout every run. Oscillations will be observed in x, the fraction of investing entrepreneurs. Since x must oscillate in $[0, 1]$, its initial value will be set at 0.5.

The following parameter set was chosen to illustrate the functioning of the model: $N = 10$; $M = 5$; $\delta_- = \delta_+ = 0.4$; $\varepsilon_- = \varepsilon_+ = 0.1$; $\beta = \gamma = 0.9$; $u(A_-) = 10$; $u(R_-) = 11$; $u(A_+) = 100$;

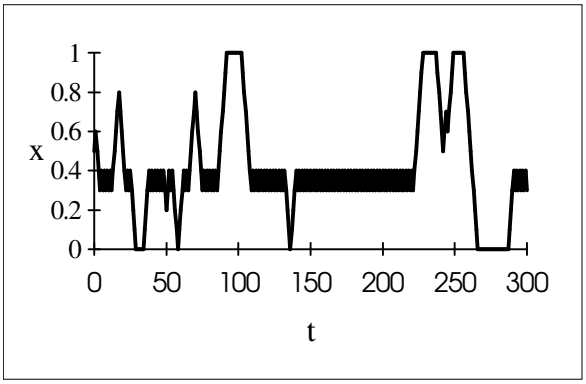

Figure 3

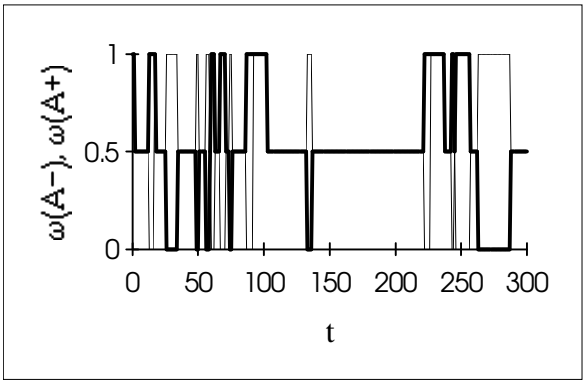

Figure 4

$u(R_+) = 100,000$. Fig.(2) depicts x, while fig.(3) shows the corresponding oscillations of $\omega(A_-)$ (thin line) and $\omega(A_+)$ (thick line). Each picture covers 300 runs.

Comparing figures (3) and (4) it is evident that, in general, periods of growth begin when $\omega(A_+)$ takes a high value and/or $\omega(A_-)$ takes a low value. The macroeconomic behaviour of the whole economy stems from microeconomic interactions, which on some occasions trigger avalanches that spread to the whole system.

Other simulations highlighted that the number of entrepreneurs N is a crucial parameter, since by increasing N oscillations become ever smaller. The reason is that the single action one entrepreneur undertakes causes x to vary by a $\Delta x = 1/N$; thus, if N is large trend inversions occur after x varied by smaller amounts. Possibly, this effect would disappear if the economy would be modelled as constituted by partial markets where a few entrepreneurs operate, instead of a single market every entrepreneur has access to.

Other important parameters are obviously L and M. In the simulation above it was assumed that probabilities $p(\mathrm{R} \mid \mathrm{A})$, which entrepreneurs calculate from the data contained in their memories, could be expressed in terms of x: this amounts to assume that entrepreneurs know the state of the economy or, equivalently, that $\mathrm{L} = \infty$. M was arbitrarily set to $\mathrm{M} = 5$; simulations with $\mathrm{M} = 2$ and $\mathrm{M} = 10$ produced similar results.

4 Conclusions

The model presented in the above sections is likely to strike the reader for being a wear one, or perhaps - in the mind of a supportive reader - for being an innovative one. Let me try to assess its merits and limits, in order to help the reader to frame it within existing literature and to envisage the kind of research it might trigger.

Its basic merit, I believe, lies in modelling a piece of economic literature that has been deemed to be out of the reach of formal models hitherto. This should strike the reader as a possibility that could not be conceived before - a sudden link from a "A_-" to a "R_+" in the reader's mind, hopefully.

Also note that this is achieved without assuming the set of possible categories to be limited and known to the modeller, as e.g. when one assumes to represent mental categories by means of strings of given symbols and given length. Clearly, this is the flip side of not being concerned with the way mental categories arise - the model above only deals with recognising that given mental categories are no longer appropriate.

The model makes a number of unrealistic assumptions, like e.g. absence of capital goods, perfect information, or the very fact of assuming that entrepreneurs have two action categories and two result categories only. Since this is a methodological model, and since the above limitations could be easily overcome in a more detailed setting, I do not think that this kind of critique really applies.

Rather, its basic weakness lies in its implicit assumption that the evaluation of a mental model's appropriateness can be described by means of an algorithm, as the procedure for computing the degree of confidence is. I actually do not think that this is true; to me, the algorithm presented above is just a useful representation in the researcher's mind.

The other weakness is an obvious consequence of not being concerned with the way mental categories and mental models arise: all entrepreneurs involved in the simulation have been assumed to be endowed with the same categories, since no procedure to describe how different categories interact and evolve has been designed. While this would be technically easy to do, I am not comfortable with assuming that the evolution of mental categories can be reproduced by simulations isolated from the real world Within the realm of algorithmic computation, the model presented in this paper already reached the limit of what it is sensible to do: mere detection of a mental model's misfunctioning..

Rather, I think that further research should endow agents with sensory organs that construct symbols and meaning at the same time, through the payoffs they receive from their environment (Cariani, 1998, 1998). This route is extremely difficult to pursue, because it implies that computer simulations are not enough - sensors that react to continuous, non-symbolic signals are needed. Nonetheless, I deem it is the only way to understand and reproduce the evolution of mental categories, and of the mental models that rest upon them.

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