A model of primary and secondary waves in investment cycles

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Summary

Schumpeter maintained that oscillations of macroeconomic variables are only the "secondary wave" of business cycles, a reflex of more fundamental "primary waves" at the microeconomic level caused by the innovative activity of entrepreneurs. Uniting Schumpeter's concern for innovation with Keynes' concern for uncertainty and expectations formation, this article focuses on the behaviour of entrepreneurs confronting uncertainty caused by innovation.
Entrepreneurs' behaviour is reconstructed by modelling the functioning of their cognitive processes when innovations appear. Recognition of the possibilities opened up by a successful innovation generates a state of optimism in the minds of single entrepreneurs, which eventually propagates to the whole economy triggering an investments upswing. Likewise, unsuccessful innovations can trigger a downswing.

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1. Introduction

Joseph A. Schumpeter maintained that business cycles cannot be understood by looking at macroeconomic variables only, since these are ultimately determined by the behaviour of entrepreneurs at the microeconomic level. Schumpeter referred to the investments undertaken by single entrepreneurs as the "primary wave" which, under favourable circumstances, can propagate throughout the whole economic system, generating the well-known "secondary wave" at the macroeconomic level (Schumpeter 1939). There is some empirical evidence supporting this view: the large degree of independence of regional and sectoral economic variables with respect to their macroeconomic aggregates suggests that macroeconomic fluctuations are a consequence of microeconomic disturbances, rather than the reverse (Quah 1994).

According to Schumpeter, the driving force of economic development is the introduction and diffusion of innovations that lower costs and restore profitability. However, while Schumpeter focused on the behaviour of single entrepreneurs and postulated the arrival of "innovations swarms" in order to explain cycles (Schumpeter 1911), modern Schumpeterians stress rather the role of diffusion processes in transforming disordered innovative activity at the microeconomic level into a coherent macroeconomic wave (Silverberg and Lehnert 1993, 1994).

This article investigates a particular aspect of the process of innovation adoption, namely the recognition of the worth of an innovation and the decision to invest on it. It focuses on the moment where an entrepreneur realises that an innovation is opening up new fields of activity while, at the same time, closing old ones. On these occasions, the emergence of an innovation affects the confidence that entrepreneurs attach to their actions, triggering bursts of optimism and pessimism that are essential to explain real investments. Rather than rational decision-making, this mode of behaviour reminds of Keynes's "animal spirits" (Keynes 1936, 1937a, 1937b).

This article moves from the conviction that "animal spirits" can only be understood and rationalised if interpreted in cognitive terms, i.e. as deriving from the inadequacy of existing mental categories to capture novelties when they appear. Individuals are likely not to be able to understand the value and the drawbacks of something they have never seen before. They are prone to sudden changes of the confidence they attach to their expectations.

Confidence changes when a mental model does not work anymore, because the mental categories it is based upon must be re-formulated in order to enlarge (or restrict) the possibilities that an individual is able to conceive. Thus, by modelling mental models it is possible to formalise the arousal of confidence states.

The model of confidence oscillation expounded in this article applies an algorithm for complexity evaluation that is based on cognition of a system's behaviour (Fioretti 1998, 1999). However, acquaintance with the general model is not required in this self-contained, simplified case.

Section 2 explains the way a decision to invest on a novel field is linked to a change of mental models. Section 3 highlights an empirical feature of investing behaviour that lends itself to be modelled by a simple mental model. Section 4 entails the mathematical description of this mental model, defines a *degree of confidence* and utilises self-organisation principles to link "primary" and "secondary" waves in investment cycles. Section 5 presents simulations of investment cycles that illustrate the kind of decision-making this model can explicate. Finally, section 6 concludes with an assessment of the potentialities and the limitations of the model exposed herein.

2. Investments and Mental Models

In general, formal investment models provided by the economic literature are not concerned with recognising the value of an innovation and convincing oneself that success will accrue to him who will devote his resources to make it marketable. On this particular field, Schumpeter's and Keynes's intuitions did not receive any formalisation hitherto. Investment models work at a less detailed level, where psychological considerations have already been lumped into economic magnitudes.

This is true for the investments acceleration principle, which is based on the observation that decision-makers are likely to react to variations of demand rather than its level (Clark 1917), as well as for Tobin's *q*, which is based on market evaluation of a firm's perspectives (Tobin 1969). Less obviously, this is equally true for option-pricing investment models as well, where irreversibility makes investments depend on uncertainty of the relevant variables (Dixit and Pindyck 1994).

According to Dixit-Pindyck's model, a series of fairly realistic assumptions such as irreversibility of investment, imperfect competition and decreasing returns to scale at firm's level establishes a negative relationship between investments and the variance of returns on investments (Caballero 1991). While perfectly compatible with Schumpeter's and Keynes's insights, my question is: How do decision-makers evaluate the statistical properties of costs and revenues?

Dixit-Pindyck's model prompted a number of empirical investigations that highlighted a negative influence of uncertainty on investments, where uncertainty is measured by the variance of macroeconomic variables, both real and monetary (Driver and Moreton 1991; George and Morisset 1995; Price 1995; Caballero and Pindyck 1996; Goel and Ram 1999; Guiso and Parigi 1999; Calcagnini and Saltari 2000; Ghosal and Loungani 2000), the variance of macroeconomic forecasts (Ferderer 1993), the variance of indicators of political instability (Alesina and Perotti 1996; Svensson 1998; Lehmann 1999) or the variance of indicators of corruption (Wei 1997). But apart from all these *ex post* confirmations of the existence of an inverse relationship between uncertainty and investments, one can reasonably ask how managers actually carry out *ex ante* evaluations of prospective investments.

Dixit-Pindyck's model derives from option-pricing theory in financial markets. As such, it requires complete markets for a set of given goods that exist long enough to enable statistical calculations. Unsurprisingly, the only empirical application of Dixit-

Pindyck model at a very detailed level (Harchaoui and Lasserre 2001) regards copper mining, a sector where product innovation does not exist and process innovation is embedded in machineries that are produced by other industries.

Although it is formally possible to think managers as calculating the variance of subjective probability distributions over the acceptance of a novel product, this should be viewed as a scheme for *ex post* description rather than a procedure for *ex ante* evaluation of decision-making. If we want to capture Schumpeter's and Keynes's insights on decision-making, we must model managerial psychology, vision and modes of deliberation (Lane, Malerba, Maxfield and Orsenigo 1996; Witt 1998). In order to do that, it is necessary to get acquainted with a few basic concepts regarding cognition.

Firstly, the concept of a *mental category*. Individuals simplify the mess of information they receive by classifying it into a manageable number of mental categories, a sort of containers whereby they highlight differences between information that is classified in different categories and blur differences within categories. Classification of information into mental categories is, clearly, an instance of bounded rationality (Simon 1982), but it is not an instance of algorithmic computation. In fact, neither the number of mental categories, nor the criteria by which information is classified are given once and for all. Furthermore, the same individual may use different mental categories in different situations, categories may not be constructed around a single prototype and, in general, mental categories may have fuzzy boundaries (Barsalou 1987; Lakoff 1987; Hampton 1993; Clark 1993).

Secondly, the concept of a *mental model*. 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 (Johnson-Laird 1983). At a more detailed level, and consistently with a line of thought that places intelligence in the structure of information flows within a distributed system (Hebb 1949; Hayek 1952), a mental model can be seen as a net of connections that link mental categories to one another.

In any case, mental categories and mental models should not be viewed as evolving independently of one another. Rather, mental categories are constructed in order to fit into a particular mental model, and a mental model is arranged with the purpose of simplifying causal links between mental categories.

One possibility for eliciting managers' mental constructs is that of carrying out a linguistic analysis of corporate documents, such as annual reports to shareholders (Sigismund Huff 1990; Sigismund Huff, Narapareddy and Fletcher 1990). Figure A illustrates the mental model of *Admiral*, a TV sets maker, derived by means of this technique out of documents spanning the period 1960-63 (Narayanan and Fahey 1990).

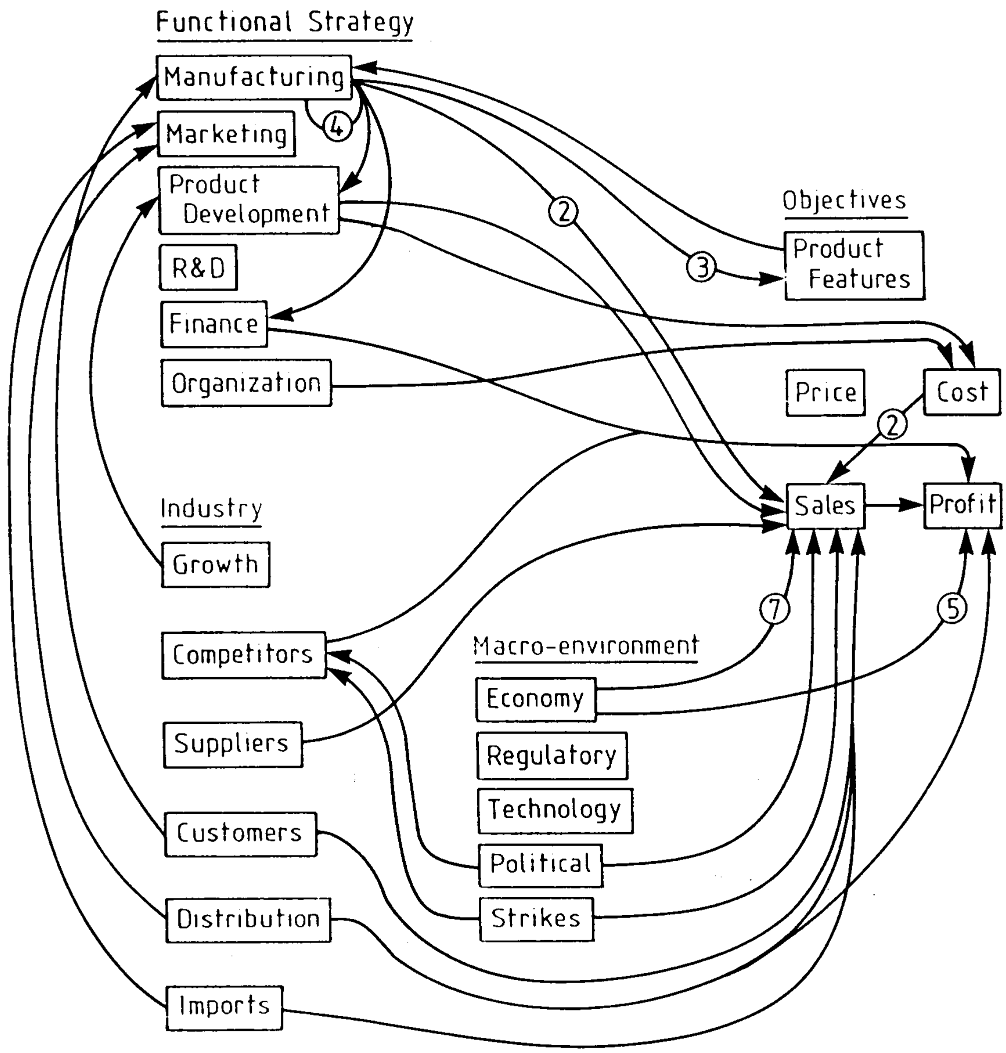

FIGURE A
The mental model of *Admiral*'s managers in the years 1960-63, elicited by Narayanan and Fahey (1990) out of corporate documents. © *John Wiley and Sons* 1990

According to figure A, in the early 1960s *Admiral*'s managers classified information in categories regarding functional strategy (*Manufacturing*, *Marketing*, *Product Development*, *Finance* and *Organization*), industry conditions (*Growth*, *Competitors*, *Suppliers*, *Customers*, *Distribution* and *Imports*), macroeconomic environment (*Economy*, *Political*, *Strikes*) and objectives (*Product Features*, *Cost*, *Sales* and *Profit*). In figure A, these categories are linked by arrows that represent the managers' view of causal relationships between them. Strategic action followed accordingly.

Obviously, mental models change with time. New categories are formed, old categories are dismissed, and causal links are rearranged. Figure B illustrates the evolution of *Admiral*'s managers' mental models from 1960-63 to 1964-66, 1967-70 and 1971-73 (Narayanan and Fahey 1990). In 1974, *Admiral* dismissed TV sets production.

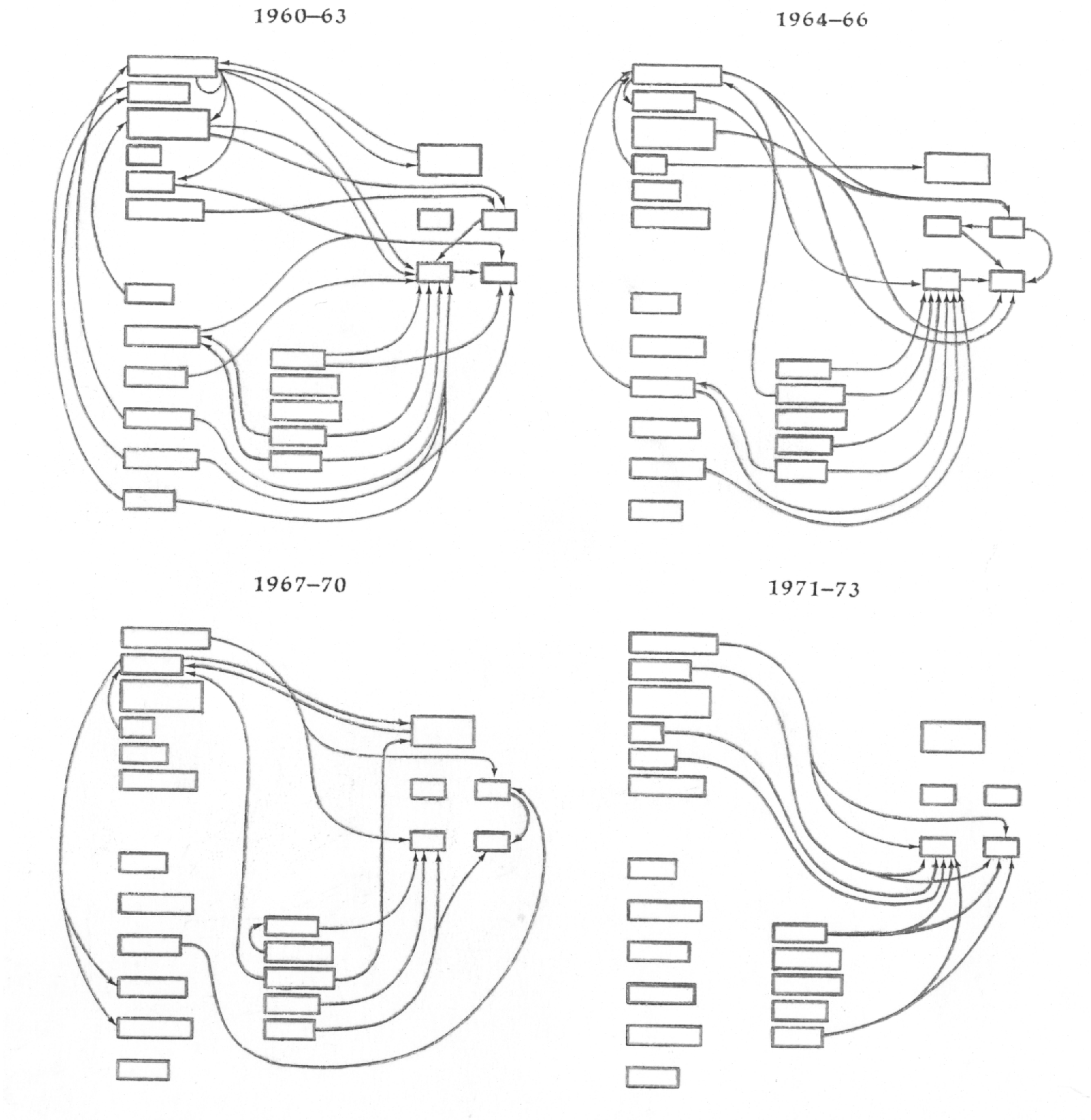

FIGURE B
The sequence of mental models of *Admiral*'s managers in the years 1960-63, 1964-66, 1967-70 and 1971-73, elicited by Narayanan and Fahey (1990). This sequence should be read from left to right, from top to bottom. In order to ease comparison, all mental categories envisaged by the management between 1960 and 1973 have been drawn. In order to simplify the picture, details concerning the purpose of single categories have been erased. © *John Wiley and Sons* 1990

Changes of the mental model correspond to fundamental environmental and strategic changes in the history of *Admiral*, such as Japanese penetration of U.S. market, construction of a facility for colour tubes production, or early switch to solid-state technology. Mental models do not change very often, but when they do, that happens because important novelties appear.

Not all investments imply the adoption of innovations, but those envisaged by Schumpeter and Keynes do. Thus, a decision to invest reflects a change of the underlying mental model. This is the basic consideration underlying the decision-making model presented henceforth.

Since this article does not want to focus on a specific case-study but rather to elicit general features of investment decision-making, a much simpler mental model will be employed than those illustrated in figures A and B. The ensuing Section 3 provides a rationale for the mental model that will be expounded in Section 4.

3. Animal Spirits

Most economists regard *animal spirits* as a whimsical idea, but most economists finish their papers later than they expected. Moreover, they persist to expect finishing their papers earlier than they will actually do, even if that already happened a number of times. Most importantly, this "irrational" behaviour is good for their profession, since if they would correctly estimate the time they need in order to finish a paper, they probably would not embark in the enterprise of writing it (Kahneman and Lovallo 1994).

Overconfidence is a widespread attitude of human behaviour, one that was selected through millennia of evolution because it is good for society that some individuals explore novel possibilities. Overconfidence means that when a decision setting has novel features, humans evaluate that situation as unique rather than stressing similarities with past experiences and drawing statistical inferences from them.

Consider an individual who is starting a business. Statistically, enterprises that are similar to the one that he has in mind may have, say, a 50% chance of success. But this chance was computed by ignoring the specificities of *his* particular enterprise, and it is exactly *these* specificities that make the difference between failure and success. This is absolutely true, even if decision-makers may not evaluate correctly the specificities of their enterprises so in the end they collectively build up a mere 50% probability of success.

Overconfidence is a widespread phenomenon that has been highlighted by a number of laboratory experiments. Moreover, group experiments showed that organisations are not less prone to overconfidence than single individuals are (Dosi and Lovallo 1997; Camerer and Lovallo 1999). Possibly, it is the reason for stock markets prices to be distributed according to power laws with fat tails, independently of herding effects (Gopikrishnan, Plerou, Gabaix and Stanley 2000; Gopikrishnan, Plerou, Gabaix, Amaral and Stanley 2001).

Overconfidence arises when decision-makers firmly believe a mental model that promises a rosy future for them and their organisation. But sometimes empirical experience discomfirms rosy mental models, e.g. during the series of events that led *Admiral* to withdraw from the television industry. Risk aversion then takes the place of bold activism, narrow mental models and timid choices result. Oscillation between these two extremes is a widespread feature of human behaviour, a common finding of a long series of experiments (Kahneman and Lovallo 1994).

These are the stylised facts upon which we will build a simple model of investing behaviour. They are coherent with Keynesian and psychoanalytical insights (Winslow 1986), and they are supported by empirical data showing that investments, even at plant level, are actually a series of spikes (Caballero, Engel and Haltiwanger 1995; Doms and Dunne 1998; Cooper, Haltiwanger and Power 1999).

Ryall (1996) models switching between alternative hypotheses by inserting or deleting a causal link in what we called a mental model. We shall adopt a similar representation, where investing will depend on empirical experience suggesting or discomfirming certain causal links.

4. A Model Mental Model

Let us describe entrepreneurs' cognition by means of two classes 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 pairs action-result that occurred recently, while his *behaviour* is the particular action he is undertaking.

The actions entrepreneurs undertake, as well as the results they obtain, involve innovation of the qualitative features of goods, tastes and technologies. However, although the qualitative features of their actions and results will change with time in unpredictable ways, we shall assume that entrepreneurs classify them in the following given set of mental categories:

A_-: The category of all entrepreneurial actions that require little money outlays, involve little innovation, but also little risk. Actions of this kind are not likely to lead to great production and profit expansion, but they are undertaken if the desire for safety is strong enough. Performing an action of category A_- denotes a high preference for liquidity.

A_+: The category of actions that, on the contrary, need large money outlays and involve important innovations, although they inevitably bear larger risks. Nevertheless, actions of this kind can be undertaken if one expects from them a much better result than from any action of category A_-. In other words, actions of category A_+ are investments in the most genuine sense of this term.

R_-: The category of mediocre results one normally expects from actions of category A_-. On the contrary, obtaining a result of category R_- from an action of category A_+ can be a disaster if a large money outlay was involved.

R_+: The category of good results entrepreneurs expect from actions of category A_+. Of course, it may happen that a result of category R_+ is obtained from an action of category A_-: this is an unlikely, but a particularly favourable happening.

With some simplification, actions of category A_+ can be called *investment decisions* while actions of category A_- can be called *stand-by decisions*.

Decision-makers recognise innovations by the fact that old mental models do not work anymore. For instance, a new technology may make typing machines obsolete and disclose new possibilities for computers. Then, 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.

Let us assume that the mental model of entrepreneurs is constituted by one-to-one connections between action categories and result categories as shown in figure C: once an action of category A_- is undertaken a result of category R_- is considered to be the normal outcome. Likewise, and once an action of category A_+ is undertaken a result of category R_+ is considered to be normal. In other terms, the mental model of figure C says that good revenues are the normal outcome of investing and that mediocre revenues are the normal outcome of hiding money under a mattress.

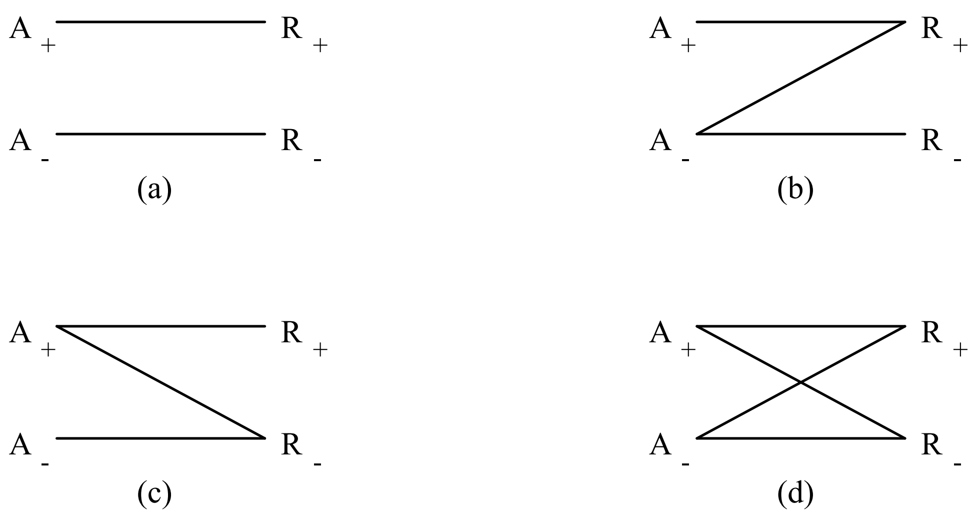

FIGURE C
Top left (a), the mental model of entrepreneurs. Top right (b), a new causal link arises when innovation opens up new investment possibilities. Bottom left (c), a new causal link arises when innovation makes investments unprofitable, that used to be safe. Bottom right (d), both of these new causal links occur at a time.

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 may open new profit possibilities, a circumstance that would show up as the connections of case (b). But it may also cause the unexpected failure of investments on a field that used to be safe, in which case connections are as in (c). It may also produce both effects at the same 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, one that might have profound consequences for his investments. Independently of the probability distribution of successes and failures that he might have computed in the past, misfunctioning of his mental model is likely to change the confidence he attaches to its prescriptions. Whether optimism as in (b), pessimism as in (c), or confusion as in (d), misfunctioning of his mental model inevitably alters his "animal spirits".

However, it is important to remark that a mental model says what is 'normal' to happen, not what must invariably happen all the times. Consequently, it is by no means obvious that correspondences like those illustrated in (b), (c), (d) should be interpreted as failures of the mental model. They could be interpreted equally well as situations that occur rarely, though sometimes do. Even without innovations, 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 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.

However, from the modeller's point of view it is very easy to overcome this difficulty. In fact, it is sensible to assume that entrepreneurs use only the most recent information in order to evaluate the appropriateness of their mental models, while they use all information at their disposal in order 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 that is useful precisely to the extent that the present situation is similar 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 figure C, case (a). If connections occurred, that are not those of the mental model, then the decision-maker does not have absolute confidence in the probability distributions that 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 of 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 figure C, case (b): it does not matter whether he receives one or two news about this novel possibility, the crucial issue is realising that such a novel profit possibility exists.

Let us represent the relationships entailed in the first M memory locations by means of a simplicial complex $\mathscr{K}$ 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 uniting R_- and R_+: the two simplices have vertex R_+ in common, simplicial complex $\mathscr{K}$ is made of a segment and one of its extreme points. Case (c) is similar to (b), 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 $\mathscr{K}$ is made by two overlapping segments.

Let us stipulate that the complexity of isolated simplices is zero, while the complexity of a simplicial complex $\mathscr{K}$ is (Fioretti 1998, 1999):

$$c(\mathscr{K}) = \sum_{q=0}^{Q} \frac{q+1}{s_q} \tag{1}$$

where q is connection level, defined as the dimension of common faces between simplices, s_q is the number of disjoint classes of simplices that are connected at level q, and Q is the largest value attained by q in $\mathscr{K}$.

In the four cases illustrated in figure C, application of equation (1) yields $c_a(\mathscr{K}) = 0$, $c_b(\mathscr{K}) = c_c(\mathscr{K}) = 1$ and $c_d(\mathscr{K}) = 2$, respectively. Furthermore, if we stipulate that simplices A_- and A_+ contribute to complexity according to their dimensions (Fioretti 1998), we obtain $c_a(A_-) = c_a(A_+) = 0$; $c_b(A_-) = 1$, $c_b(A_+) = 0$; $c_c(A_-) = 0$, $c_c(A_+) = 1$; $c_d(A_-) = c_d(A_+) = 1$.

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

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

where $\mathrm{A} \in \{\mathrm{A}_-, \mathrm{A}_+\}$.

This degree of confidence takes values in the $[0, 1]$ interval. In our case, these values are: $\chi_a(\mathrm{A}_-) = \chi_a(\mathrm{A}_+) = 1$; $\chi_b(\mathrm{A}_-) = 0$, $\chi_b(\mathrm{A}_+) = 1$; $\chi_c(\mathrm{A}_-) = 1$, $\chi_c(\mathrm{A}_+) = 0$; $\chi_d(\mathrm{A}_-) = \chi_d(\mathrm{A}_+) = 1/2$.

At this point, we can suppose that our entrepreneurs behave as follows:

- If empirical experience confirms their mental models, illustrated in case (a) of figure C, then they calculate probabilities $p(\mathrm{R} \mid \mathrm{A})$ over the whole length L of their memories and they undertake actions of category A_- or A_+ according to the rule of expected profit maximisation.
- If empirical experience highlighted innovations that opened up new profit possibilities, i.e. if they view a situation like in case (b) of figure C, then they undertake actions of category A_+.
- If empirical experience highlighted innovations that are likely to force firms to abandon established fields of activity, i.e. if they view a situation like in case (c) of figure C, then they undertake actions of category A_-.
- If empirical experience is ambiguous as in case (d) of figure C, they decide not to make any decision, wait for better information and, in the meantime, keep doing the kind of action that they used to do.

These assumptions translate into saying that, if a decision has to be taken, then entrepreneurs maximise objective function:

$$J(\mathrm{A}) := \chi(\mathrm{A}) \left[p(\mathrm{R}_- \mid \mathrm{A}) P(\mathrm{R}_-) + p(\mathrm{R}_+ \mid \mathrm{A}) P(\mathrm{R}_+) - C(\mathrm{A}) \right] \qquad (3)$$

where $A \in \{A_-, A_+\}$. In equation (3), $C(A_-)$ and $C(A_+)$ denote the costs associated with action categories A_- and A_+, respectively; $P(R_-)$ and $P(R_+)$ denote the proceeds associated with result categories R_- and R_+, respectively; $p(R \mid A)$ express the conditional probabilities of obtaining a result of category R after pursuing an action of category A. It is, obviously, $C(A) \geq 0$ and $P(R) \geq 0$.

Within square brackets, equation (3) includes expected profits $\pi(A)$. Expected profits are decisive when $\chi_a(A_-) = \chi_a(A_+) = 1$, i.e. in case (a) of figure C.

On the contrary, in case (b) or (c), where $\chi_b(A_-) = 0$ and $\chi_b(A_+) = 1$ or $\chi_c(A_-) = 1$ and $\chi_c(A_+) = 0$, the degree of confidence determines which category of action will be undertaken. Since degrees of confidence may vary abruptly as a consequence of the latest (A, R) pair, innovations produce sudden jumps of the degrees of confidence and sharp changes in the behaviour of entrepreneurs. The ensuing "primary" investments waves may then propagate to the whole system and eventually generate a "secondary wave" at the macro level.

Finally, in case (d) no change of the course of action is undertaken, so equation (3) is not used at all. In a more general modellisation of cognitive processes, case (d) would trigger a reformulation of the mental model as well as of the underlying mental categories.

5. A Toy Economy

Let us now apply the above ideas to a model of investment cycles that has no pretension of realism, but which is able to highlight the interplay of "primary" and "secondary" waves. Continuous introduction of innovations is supposed to keep the economy away from both perfect competition and monopoly, in the difficult realm 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. Although entrepreneurs hire workers in order to constitute firms, since decision-making will be ascribed to single entrepreneurs we shall always speak of "entrepreneurs", never of "firms".

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) Any one good can be exchanged with any other one; iii) All entrepreneurs know which actions other entrepreneurs have undertaken and which results they obtained.

In order to avoid any constraint of past decisions on current production possibilities, let us also assume that: iv) No capital goods exist; v) No inventories exist; vi) 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. On the contrary, consumers are supposed to behave in a more passive way: they return results to entrepreneurs but they do not undertake actions of their own. The actions that 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 that 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_+. These categories mainly capture product innovation. In fact, due to absence of capital goods, they do not record technological innovation except in the very limited sense of 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 N be the number of entrepreneurs. Let us arrange the experiences made by entrepreneurs in a matrix **E** that represents their short-term memory, the one they use in order to evaluate confidence in their mental models. Matrix **E** has M rows and N columns, where element e_{mn} represents the pair (A, R) obtained by the n-th entrepreneur m time steps ago. Whenever an entrepreneur undertakes an action and receives a result, the corresponding column of matrix **E** is scaled down by one position (the oldest experience is forgotten) and the new (A, R) pair enters the first row of **E** (the new experience is learned). Assuming perfect information, let us stipulate that matrix **E** is accessible to all entrepreneurs.

Let $x \in [0, 1]$ denote the proportion of entrepreneurs who undertake an action of category A_+. It is $x = 0$ if all entrepreneurs undertake actions of category A_- and it is $x = 1$ if all entrepreneurs undertake actions of category A_+.

As long as at $x = 0$ $(x = 1)$ all returned results belong to category R_- (R_+), entrepreneurs' mental models are confirmed. In fact, they either observe $(\mathrm{A}_-, \mathrm{R}_-)$ or $(\mathrm{A}_+, \mathrm{R}_+)$, all the times. In this sense, $x = 0$ and $x = 1$ are equilibrium points.

However, even at equilibrium entrepreneurs innovate. In fact, at $x = 0$ they innovate because they hope to get a result of category R_+, while 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 equilibrium, either at $x = 0$ or at $x = 1$, 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 economy described above is a system composed by a large number of interacting particles which generate a coherent macroscopic behaviour, a situation that is known in physics as *self-organisation* (Nicolis and Prigogine 1977). Self-organisation occurs when some state variables are unstable and much slower than the stable ones. While the fast and stable variables drive the system towards the equilibrium of the basin of attraction it is in, the slow and unstable variables (also called *order parameters*) push the system out of its basin of attraction and towards another basin of attraction and another equilibrium state (Haken 1983, 1987).

The order parameters of our system are $\chi(\mathrm{A}_-)$ and $\chi(\mathrm{A}_+)$. They are unstable, since they may suddenly take on a different value, they are slow in the sense that they stay at a value long enough for the fast and stable variable x to move onto another equilibrium, and they are responsible for the economy to jump in and out of its two equilibria.

The model needs parameters that specify the behaviour of entrepreneurs. Let these parameters be: $p(\mathrm{R}_+|\,\mathrm{A}_-;\mathrm{A}_-)=\varepsilon_-$, $p(\mathrm{R}_-|\,\mathrm{A}_+;\mathrm{A}_+)=\varepsilon_+$, $p(\mathrm{R}_+|\,\mathrm{A}_+;\mathrm{A}_-)=\varphi_-$ and $p(\mathrm{R}_-|\,\mathrm{A}_-;\mathrm{A}_+)=\varphi_+$, 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, $0\le\varepsilon_-,\varepsilon_+,\varphi_-,\varphi_+\le 1$.

Let us assume that, with N entrepreneurs, there are $N-1$ consumers. In this way, for any entrepreneur it is equally likely to meet a consumer or another entrepreneur.

By assuming that L is sufficiently large for entrepreneurs to correctly estimate probabilities $p(\mathrm{R}|\,\mathrm{A})$, these can be expressed as follows:

$$p(\mathrm{R}_-|\,\mathrm{A}_-) = \frac{1}{2}\left[(1-x)(1-\varepsilon_-) + x\,\varphi_+\right] + \frac{1-x}{2} \tag{4a}$$

$$p(\mathrm{R}_+|\,\mathrm{A}_-) = \frac{1}{2}\left[(1-x)\,\varepsilon_- + x(1-\varphi_+)\right] + \frac{x}{2} \tag{4b}$$

$$p(\mathrm{R}_-|\,\mathrm{A}_+) = \frac{1}{2}\left[(1-x)(1-\varphi_-) + x\,\varepsilon_+\right] + \frac{1-x}{2} \tag{4c}$$

$$p(\mathrm{R}_+|\,\mathrm{A}_+) = \frac{1}{2}\left[(1-x)\,\varphi_- + x(1-\varepsilon_+)\right] + \frac{x}{2} \tag{4d}$$

The terms in square brackets represent the outcome of encounters between entrepreneurs. On the contrary, the rightmost terms of equations $(4\mathrm{a}\div\mathrm{d})$ represent the outcome of encounters between consumers and entrepreneurs. These terms have been supposed to depend on the actions undertaken by entrepreneurs, through the channel of wages. In this way, the Keynesian multiplier enters the model.

Equations $(4a \div d)$ allow to express objective function $J(\mathrm{A})$ as a function of x. In their turn, entrepreneurs undertake an action of category A_- (A_+) if $J(\mathrm{A}_-)$ ($J(\mathrm{A}_+)$) is greater than $J(\mathrm{A}_+)$ ($J(\mathrm{A}_-)$). In this way the model is closed, and simulations can be carried out.

At each time interval a randomly chosen entrepreneur undertakes an action towards an agent who may either be a consumer or another entrepreneur, and receives a result from him. The $(\mathrm{A}|\mathrm{R})$ pair obtained in this way enters matrix **E** and may eventually 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 $p(\mathrm{R}|\,\mathrm{A})$. In this way, at the beginning of the next time interval $J(\mathrm{A}_-)$ and $J(\mathrm{A}_+)$ will take new values. For greater clarity, figure D displays a flow chart of the steps involved.

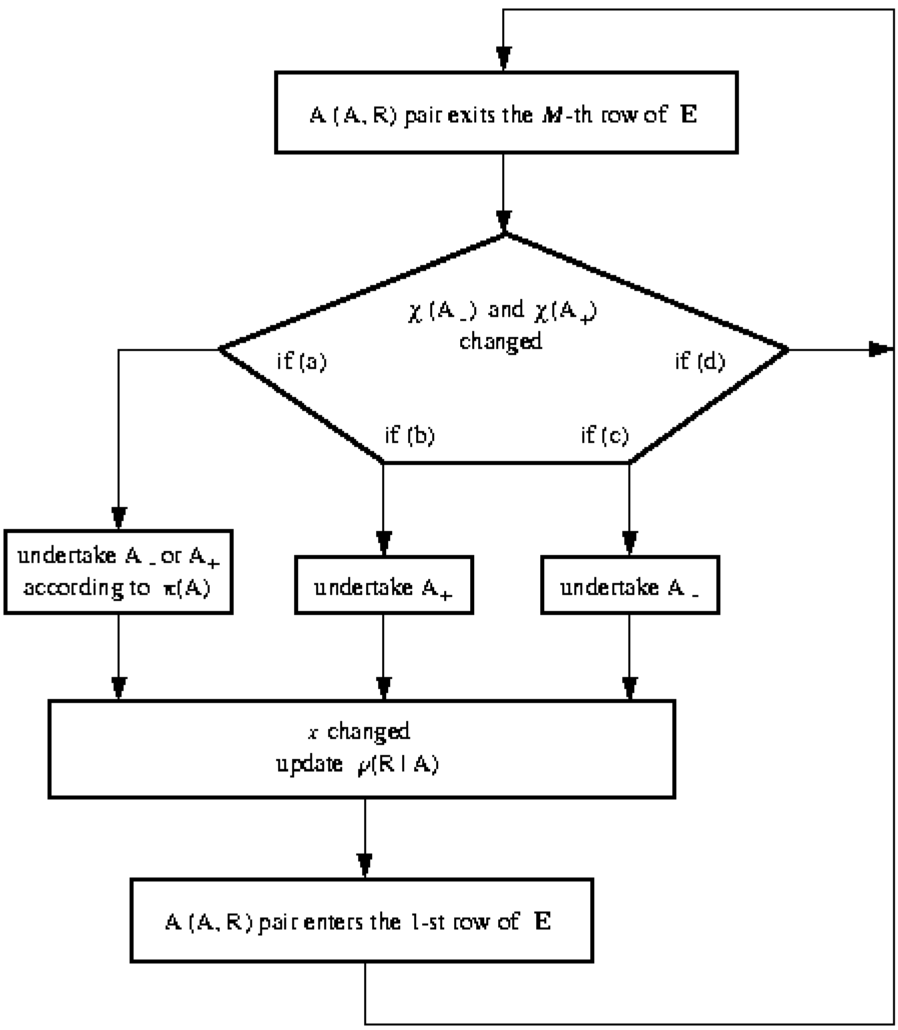

FIGURE D
Flow scheme of the simulations. Confidence can either change because a pair (A, R) is forgotten (it exits **E**), or because it is experienced (it enters **E**). In both cases, the programme evaluates whether confidence is in state (a), (b), (c) or (d). If it is in state (d), it loops until enough confusing (A, R) pairs are forgotten. Otherwise, an entrepreneur undertakes an action, *x* changes and conditional probabilities are updated. The new (A, R) pair eventually causes confidence to change again and a new cycle begins.

This model requires the following set of exogenous parameters in order to run: M (the memory length), N (the number of entrepreneurs), $C(\mathrm{A}_-)$, $C(\mathrm{A}_+)$, $P(\mathrm{R}_-)$ and $P(\mathrm{R}_+)$ (the costs and proceeds associated with action categories and result categories, respectively), ε_-, ε_+, φ_- and φ_+ (the probabilities for entrepreneurs who are determined to undertake actions of a certain category to return particular results to actions undertaken by others). Although ten parameters are admittedly many, most of them are bound to one another by the following requirements:

I. Memory must be short in order to allow interesting dynamics of confidence change, definitely shorter than the number of agents (which are N entrepreneurs plus $N-1$ consumers). Thus, it must be $M \ll 2N-1$.

II. Since at each time step only one entrepreneur acts, a large N would slow down the diffusion of modes of action to the point that confidence change would occur before the economy approaches either $x=0$ or $x=1$. Thus, in order to have interesting dynamics it must be $N \; not \gg 0$.

III. Actions of category A_+, although more costly, must be more attractive than actions of category A_-. Thus, it must be $C(A_-) < C(A_+)$, $P(R_-) < P(R_+)$, and $P(R_+) - C(A_+) > P(R_-) - C(A_-)$.

IV. The possibility of obtaining a result of category R_- after having invested in an action of category A_+, must be a terrific one. Conversely, the possibility of obtaining a result of category R_+ after having committed to an action of category A_-, must be an exciting one. Thus, let us require that $P(R_-) - C(A_+) \ll P(R_-) - C(A_-)$ and $P(R_+) - C(A_-) \gg P(R_+) - C(A_+)$.

V. It is very unlikely that case (b) of figure C occurs when one meets an entrepreneur who is determined to undertake an action of category A_-. Similarly, it is very unlikely that case (c) of figure C occurs when one meets an entrepreneur who is determined to undertake an action of category A_+. Thus, it is safe to assume that $\varepsilon_- \ll 1$ and $\varepsilon_+ \ll 1$.

VI. Entrepreneurs who undertake actions of category A_+ tend to give results of category R_+ more often than entrepreneurs who undertake actions of category A_- do. Thus, we require that $\varphi_- \leq 0.5$ and $\varphi_+ \leq 0.5$.

VII. However, the probability of returning a result of category R_- (R_+) to an action of category A_- (A_+) must be larger than the probability of returning a result of category R_- (R_+) to an action of category A_+ (A_-). Thus, it must be $\varphi_- > \varepsilon_-$ and $\varphi_+ > \varepsilon_+$.

Let us begin with a suitable set of parameters that satisfies constraints $(\mathrm{I} \div \mathrm{VII})$. A possible choice is: $M = 2$; $N = 5$; $C(\mathrm{A}_-) = 100$; $C(\mathrm{A}_+) = 1{,}000$; $P(\mathrm{R}_-) = 101$; $P(\mathrm{R}_+) = 1{,}100$; $\varepsilon_- = \varepsilon_+ = 0.1$; $\varphi_- = \varphi_+ = 0.4$. Initial values can be set at $x_0 = 1/2$, $\chi_0(\mathrm{A}_-) = 1/2$, $\chi_0(\mathrm{A}_+) = 1/2$.

Figure E depicts *x* during the first 500 steps of a typical simulation. Figures F and G illustrate the corresponding oscillations of $\chi(\mathrm{A}_-)$ and $\chi(\mathrm{A}_+)$, respectively.

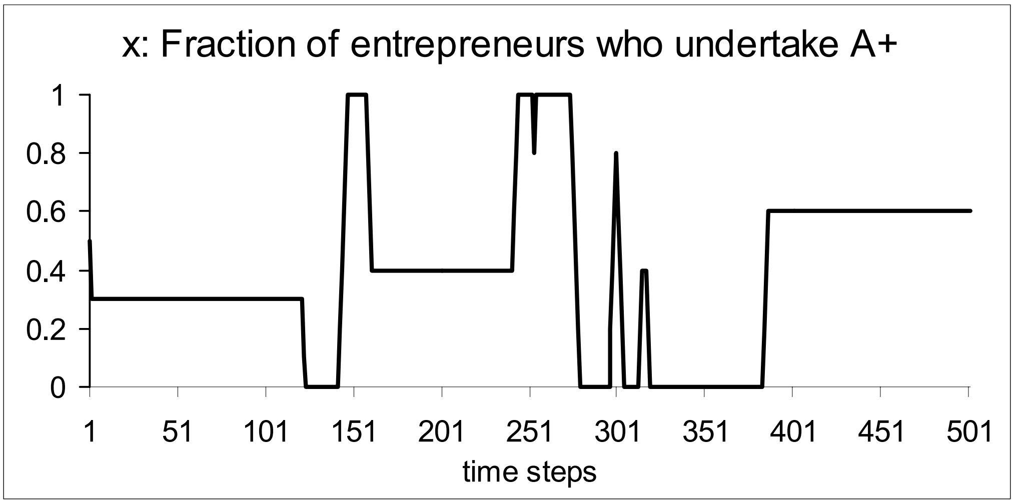

FIGURE E
The trend of *x*, which is the proportion of entrepreneurs who are undertaking actions of category A_+. All parameters at their base values.

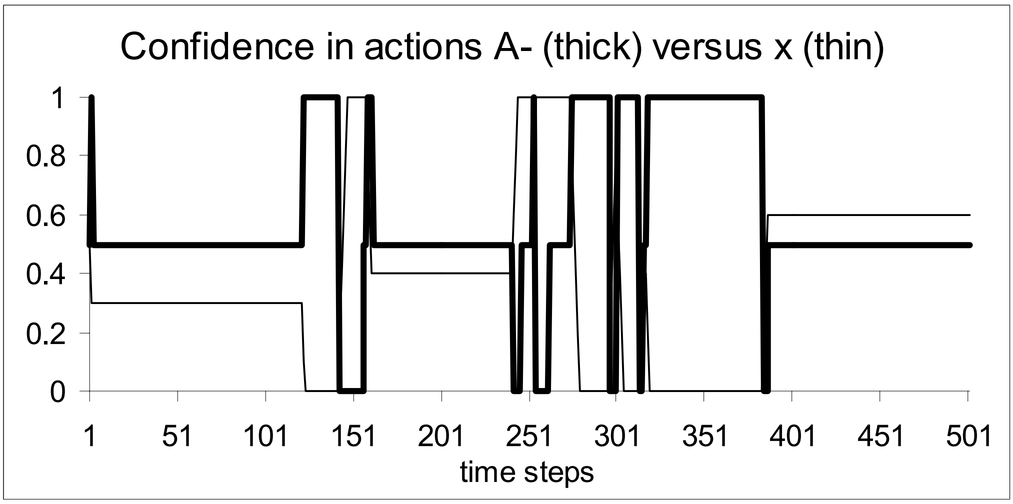

FIGURE F
The trend of $\chi(\mathrm{A}_-)$ (thick line) versus the trend of *x* (thin line). All parameters at their base values.

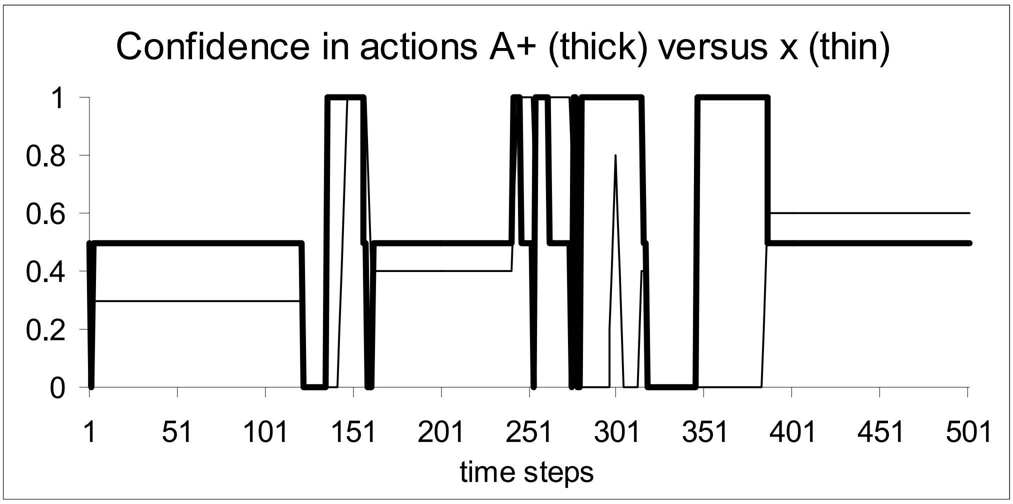

FIGURE G
The trend of $\chi(\mathrm{A}_+)$ (thick line) versus the trend of *x* (thin line). All parameters at their base values.

By observing figures F and G it is evident that sudden changes of $\chi(\mathrm{A}_-)$ and/or $\chi(\mathrm{A}_+)$ generally trigger variations of *x*, but also that this is not always the case. Degrees of confidence change as a consequence of microeconomic events, the "primary wave" that eventually propagates to the whole economy showing up in *x* as a "secondary wave".

Thus, macroeconomic behaviour stems from microeconomic interactions that occasionally trigger investment avalanches. Eventually, but not always, these avalanches may spread over the whole system.

Figures F and G also highlight that, at a few rare times, a change of confidence is favoured by macroeconomic conditions. This can be observed, for instance, around the 300-th step of figure G, where a high confidence in actions of category A_+ fails to establish a durable high level of *x*, which in its turn favours confidence to go down again.

Finally, periods of constant *x* at $0 < x < 1$ generally correspond to both $\chi(A_-)$ and $\chi(A_+)$ at 0.5. During these periods, contradictory experiences disconfirm entrepreneurs' mental models as in case (d) of figure C, so they do not dare of changing the action that they are undertaking.

It is important to realise that this model is similar in kind to deterministic chaos models. In fact, a small randomness introduced by random pairing of agents and random endowment of agents with probabilities ε_-, ε_+, φ_-, φ_+ is amplified until a large macroscopic effect is produced. In order to illustrate how different the outcomes of this model can be, figure H reports ten runs that have been obtained using the same parameters that generated figure E (reproduced within figure H as the first graph top left).

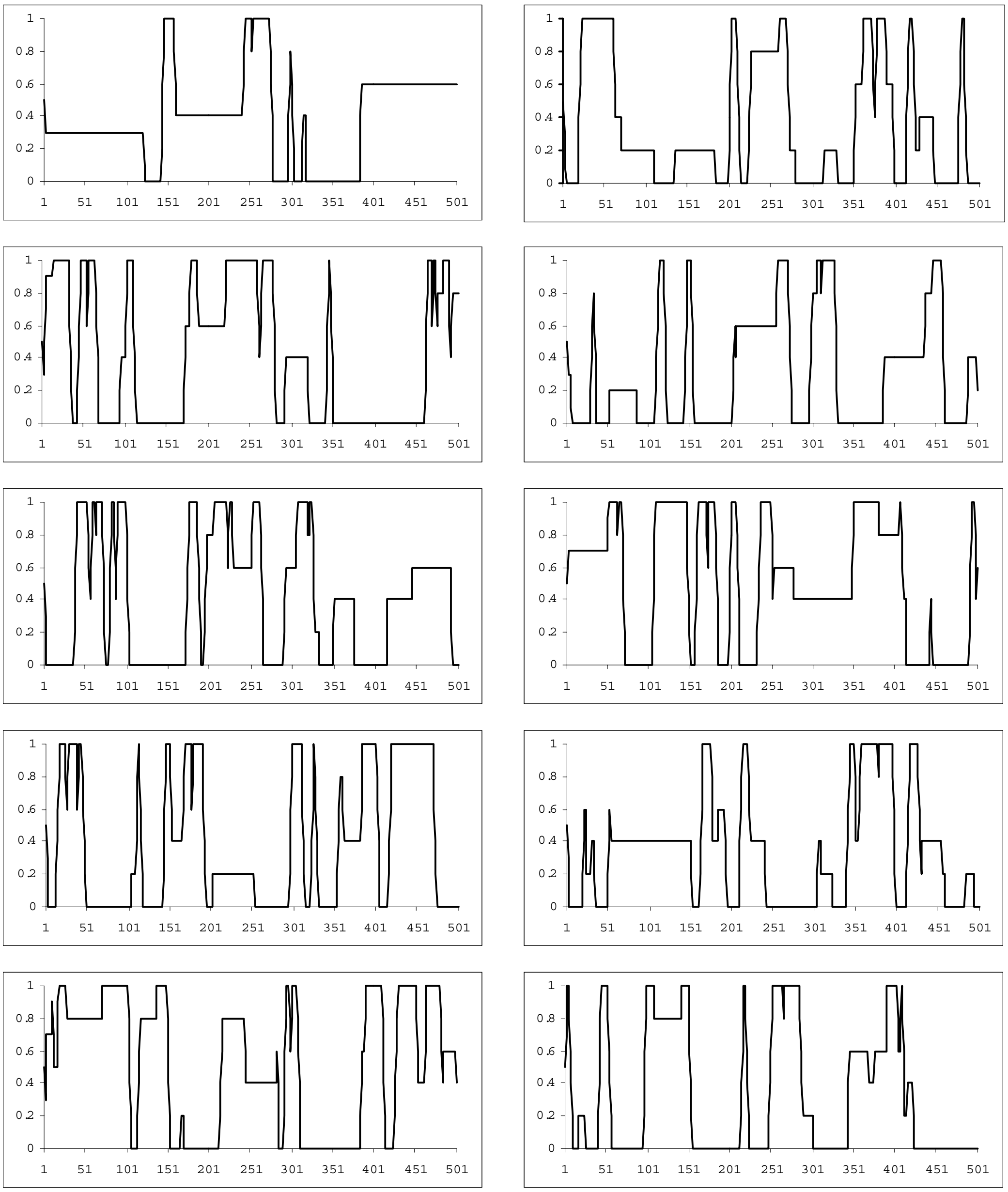

FIGURE H
Ten time series of *x* generated with all parameters at the same values as in figure E. The graph of figure E is here reproduced top left. Little similarity can be discerned between these ten pictures.

However, individual time series may be very different from one another and yet share some common statistical features over long periods. Figure I illustrates the outcome of a simulation that is similar in any respect to those of figures E and H, except that it has been run for 5,000 steps, ten times longer than the previous ones.

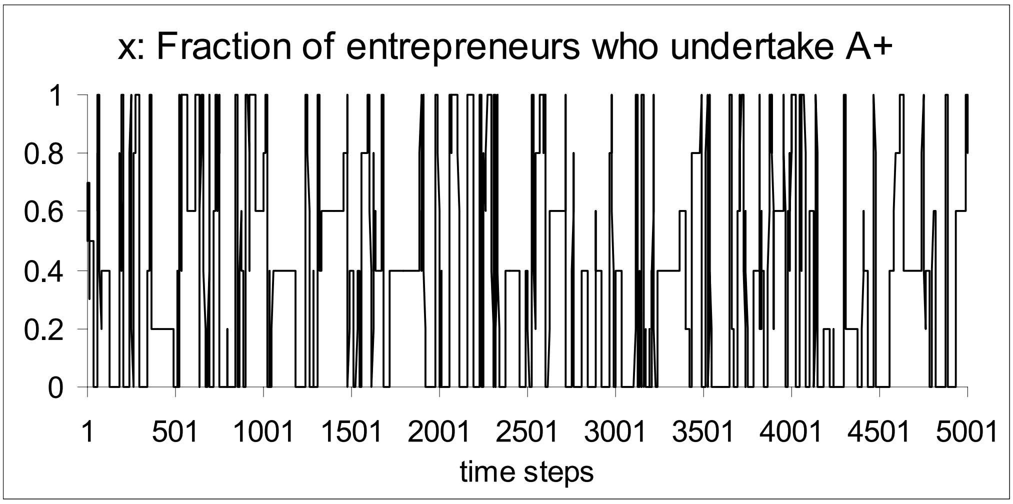

FIGURE I
A time series of *x*, 5,000 steps. All parameters at the same values as in figures E and H.

Intuitively, the graph of figure I appears more akin to the typical volatility of empirical investment time series. This impression stems from the fact that a large number of observations highlights statistical regularities.

Thus, evaluation of the model's sensitivity to parameters should be made with respect to indicators that are computed over very long time series. To this aim, for each set of parameters 500-steps simulations have been repeated 10,000 times, yielding a total of 5,000,000 time steps. Furthermore, in order to measure the extent of variation over two such long runs, two of them have been carried out with all parameters at base values.

The following indicators have been chosen in order to characterise the outcome of the model: 1) The number of times x is at level zero; 2) The number of times x is at level one; 3) The number of times a variation of x occurs. These indicators have been denoted by z, o and v, respectively.

Parameters have been varied as follows. M, the memory length whose base value is $M = 2$, has been tested at $M = 1$ and $M = 3$. N, the number of entrepreneurs whose base value is $N = 5$, has been tested at $N = 4$ and $N = 6$. Costs and proceeds have been sampled by defining proceeds in terms of rates of return to the corresponding costs ρ_- and ρ_+, by multiplying costs by a coefficient σ, and by exploring variations of $\rho = \rho_+/\rho_-$ and σ. Since base values of costs and proceeds implied $\rho = 10$ and $\sigma = 1$, with $\rho_- = 1\%$ and $\rho_+ = 10\%$, tests have been made with $\rho = 5$, $\rho = 20$ ($\rho_+ = 5\%$, $\rho_+ = 20\%$ with $\rho_- = 1\%$), $\sigma = 0.1$ and $\sigma = 10$. Finally, probabilities ε_-, ε_+, φ_-, φ_+ are constrained by $(\text{V} \div \text{VII})$ not to move a lot away from their base values $\varepsilon_- = \varepsilon_+ = 0.1$ and $\varphi_- = \varphi_+ = 0.4$, so simulations with $\varepsilon_- = \varepsilon_+ = 0$, $\varepsilon_- = \varepsilon_+ = 0.2$, $\varphi_- = \varphi_+ = 0.3$ and $\varphi_- = \varphi_+ = 0.5$ have been carried out.

Table 1 illustrates the values attained by z, o, v averaged over 10,000 repetitions of 500-steps simulations. Two evaluations with base parameter values have been carried out in order to measure the extent of random variations.

Table 1

	z	o	v
Base Values (B.V.)	165.86	71.05	75.21
Base Values (B.V.)	164.92	71.28	75.38
$M = 1$ (B.V. 2)	284.05	57.64	112.34
$M = 3$ (B.V. 2)	88.18	49.65	39.37
$N = 4$ (B.V. 5)	229.28	79.18	85.73
$N = 6$ (B.V. 5)	121.97	58.17	59.29
$\sigma = 0.1$ (B.V. 1)	164.50	71.65	75.30
$\sigma = 10$ (B.V. 1)	164.39	71.45	75.51
$\rho = 5$ (B.V. 10)	165.78	71.67	75.89
$\rho = 20$ (B.V. 10)	165.56	70.92	75.16
$\varepsilon_- = \varepsilon_+ = 0$ (B.V. 0.1)	485.01	5.43	4.92
$\varepsilon_- = \varepsilon_+ = 0.2$ (B.V. 0.1)	84.67	55.51	73.97
$\varphi_- = \varphi_+ = 0.3$ (B.V. 0.4)	153.22	68.12	69.69
$\varphi_- = \varphi_+ = 0.5$ (B.V. 0.4)	174.11	74.17	80.77

Table 1 highlights that the outcomes of this model are strongly dependent on memory length and, to a lesser extent, on the number of entrepreneurs. In accordance with requirement (II), the number of entrepreneurs had to be kept quite low in order to avoid that confidence changes before the economy ever reaches $x = 0$ or $x = 1$. Consequently, following requirement (I) *M* had to be kept low as well. Higher values of *M* and *N* would be possible if several entrepreneurs would be allowed to act at each time step.

On the contrary, costs and proceeds appear to have very little impact on the model. This is hardly surprising, because only when case (a) of figure C occurs do these entrepreneurs evaluate expected profits. However, one may want to investigate whether there exist values where costs and rates of return influence the outcome of the model. Table 2 makes clear that the lowest values of σ and ρ where this occurs are either contradictory with requirement (IV), or clearly unrealistic.

Table 2

	z	o	v
Base Values (B.V.)	165.86	71.05	75.21
Base Values (B.V.)	164.92	71.28	75.38
$\sigma = 10^{11}$ (B.V. 1)	65.71	169.55	75.32
$\rho = 1000$ (B.V. 10)	65.18	170.89	75.37

Finally, probabilities ε_-, ε_+, φ_-, φ_+, have a sizeable impact on the model. Note that, since it does not matter how many times cross-connections like those of cases (b) and (c) of figure C occurred, but only whether they did occur or not, the effect of a variation of small probabilities like ε_-, ε_+ is much greater than the effect of a variation of large probabilities like φ_-, φ_+.

6. Conclusions

The model presented in this article combines Keynes' insights on "animal spirits" with Schumpeter's concern with innovation. It does not claim that this is what either Keynes or Schumpeter had in mind, but it shows that this cultural operation is possible, and that it yields interesting results.

Modellisation of entrepreneurs' cognitive processes is by far the most original and innovative content of this model. While it cannot claim to exhaust the range of meanings that Keynes attached to the expression "animal spirits", it discloses a possibly fruitful path towards the quantification of non-probabilistic, cognitive uncertainty. Note also that the proposed "degree of confidence" does not substitute probability, but integrates it with an assessment of the reliability of its cognitive background.

Probability judgements make sense to the extent decision-makers want to stress the similarity of the present situation to the past ones. On the contrary, the degree of confidence expresses the suspicion that the present situation might entail innovative elements. So probability evaluation can be said to express long term expectations, whereas the degree of confidence stems from short term expectations. Thus, the model is also interesting because short-term and long-term expectations influence each other in a way that Keynes had appreciated (Kregel 1976). However, a large number of issues have been expunged from Keynes' grand vision of expectations formation, conventions and uncertainty.

Similar considerations could be made with respect to its relationship with Schumpeter. Cognitive models like this can tell us a lot about the processes whereby entrepreneurs arrive at the idea of combining production factors in novel ways, as Schumpeter expressed himself. However, the model presented in this paper did not say how novel mental categories can be created but only when the need for novel mental categories is felt.

Thus, the main shortcoming of this model with respect to the ideas expressed by both Keynes and Schumpeter is that it does not even attempt to say how entrepreneurs may change their mental models. What Shackle called “unpredictable hypotheses” (Shackle 1961), are definitely out of its scope.

This is actually an issue that requires a modelisation of the structure of cognitive interactions between economic agents. On the contrary, this model is still within the boundaries of methodological individualism. A consequence of its acceptance is that decision-makers may eventually doubt their mental models, but they never gather for a brain storming with peers.

On the whole, the model presented in this article has a methodological, rather than theoretical or empirical value. Although it gave just a hint of what is possible to do by injecting cognitive sciences into economics, the author is firmly convinced that this is an extremely promising avenue for future research.

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