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A SIMULATION APPROACH TO A WORLD WITH LEARNING

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Abstact

The main objective of the firm in economics-based models is to maximize profit. Dropping this objective in order to make the models more realistic complicates the analysis and is seldom done, thus leaving management action out of the picture. In this paper we try to understand how management decisions give rise to aggregate results. In particular, we develop a simulation model of an economy in which emphasis is placed on managers' decision-making criteria. The key decision managers have to make is which projects their firms will undertake. Project selection has an impact on the firm, as the firm's profile may change through learning.

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A SIMULATION APPROACH TO A WORLD WITH LEARNING

In economics-based models the objective of the firm is to maximize profit or, in a more modern formulation, to maximize firm value. Under certain assumptions (unbounded rationality being a crucial one), microeconomic theory is able to show that maximizing firm value maximizes social welfare (see, for example, Jensen, 2000, for a brief statement of the argument). Dropping the profit maximization assumption in order to make the models more realistic complicates the analysis and is seldom done, and so management action out is left of the picture. Although firm value, as a decision-making criterion, is supposed to refer to companies' long-run value, in practice the decision-making process is heavily influenced by financial analysts' emphasis on short-run variables such as quarterly earnings.

In this paper we depart from the economics-based approach by positing that a company's long-run value depends on intangible variables related to learning and motivational capital. In particular, we develop a simulation model[1] of an economy in which emphasis is placed on managers' behavior, in such a way that aggregate results depend on actual business decisions.

In Section 1 we describe the model and give some intuition regarding its most relevant features. In Section 2 we make explicit the interconnection between the decisions of the agents involved, as well as other technical aspects. In Section 3 we present the results of the simulated scenarios, and in Section 4 we draw some conclusions.

1. A World with Motivation and Learning

We study the short and long-term behavior of a population of companies that have aspirations (goals) as to what type of company they would like to be in the future. Managers of these companies make decisions based on their (possibly inaccurate) understanding of the company's characteristics. The key decision they have to make is which projects their firms will undertake. Interaction among companies takes place in successive rounds, representing periods in which a project can be selected and completed.

In addition to carrying out projects (whether successfully or unsuccessfully), companies and managers can learn from experience, i.e., their behavior may change depending on observed results. In order to evaluate the performance of the companies operating in the economy, we use the number of successfully completed projects as an indicator of the total (aggregate) value

[1] See Davis et al. (2007), Harrison et al. (2007), Gilbert (2008), Miller and Page (2007).

created. At the same time, companies' changing profiles are taken an indicator of the economy's potential, understood as companies' ability to successfully undertake better projects in the future.

1.1. Company Value

Following Pérez López (1993), we characterize firms according to the following attributes, which correspond to three types of motives: a) *Effectiveness,* or the degree to which a company achieves sufficient measurable (usually financial) results to adequately compensate its members in economic terms (extrinsic motives); b) *Attractiveness,* or the degree to which employees develop professionally and enjoy their jobs (intrinsic motives), and c) *Unity,* or the degree to which employees identify with the organization's goals and values, and with the other members of the organization (transcendent motives, as defined by Pérez López).[2]

A firm's *profile* is described by a triplet (U,A,E), where the first element indicates whether the firm has *Unity* (U), the second, whether it has *Attractiveness* (A), and the third, whether it has *Effectiveness* (E). A "1" indicates the presence of an attribute, a "0" its absence.

We use the letter *x* to designate a generic company. For instance, *x*=(0,1,1) represents a firm that has effectiveness and attractiveness, but no unity. Likewise, the profile of a firm that has attractiveness and unity, but no effectiveness, will be (1,1,0); and so forth.[3] Throughout this paper we will use the terms *profile* and *type* interchangeably.

There are seven meaningful types of firms $x=(x_1,x_2,x_3)$, namely, (0,0,1), (0,1,0), (1,0,0), (0,1,1), (1,1,0), (1,0,1), and (1,1,1).[4] We shall refer to these types or profiles by integer numbers (from 1 to 7), in such a way that the integer's binary representation corresponds to (x_1,x_2,x_3).[5]

1.2. Project Potential

Projects, too, are characterized in terms of *effectiveness, attractiveness,* and *unity,* and are represented by $y=(y_1,y_2,y_3)$. If a project has a "1" in a particular attribute, a company that has that attribute is more likely to succeed in executing that project. In other words, the probability that a firm succeeds when carrying out a particular project will be higher if there is a match between the company profile and the project profile. For example, if a project has the profile *y*=(0,1,1), a firm that has effectiveness and attractiveness is more likely to succeed with the project than a firm that lacks those attributes.

At the same time, a "1" in a particular project attribute means that the project has the *potential* to facilitate the development of that attribute in companies that undertake it. If a company undertakes a project with $y_2=1$, the firm is more likely to develop attractiveness during that round, even if it does not ultimately succeed with the project. For example, a company that lacks attractiveness will know that its chances of succeeding with *y*=(0,1,1) are slim, yet its managers may decide to undertake the project as a means of developing attractiveness in their firm.

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[2] In the terminology of Pérez López, transcendent motives refer to the satisfaction of other people's needs.

[3] This is of course a simplification, intended to avoid unnecessary technical complexities. A natural extension of the model would be to include different *intensities* for each attribute, between 0 and 1.

[4] Profile (0,0,0) is not meaningful for obvious reasons.

[5] The integer number associated with type (x_1,x_2,x_3) is $x_1 \cdot 2^2 + x_2 \cdot 2 + x_3$. For example, by type 1 we mean *x*=(0,0,1); by type 4, *x*=(1,0,0); profile 5 will be *x*=(1,0,1); and profile 7, *x*=(1,1,1).

1.3. Project Selection and Learning

At the beginning of each period, companies select the projects they would like to develop. Once selected, the projects are carried out and either succeed or fail. Project selection takes into account:

(i) Managers' knowledge of the company's current profile.

(ii) Managers' knowledge of a project's probability of success.

(iii) Managers' goals regarding the type of company they would like to be in the future.

Each management team has preferences with regard to the type of company they would like to be. These preferences are described by

$$\bar{\gamma} = (\bar{\gamma}_1, \bar{\gamma}_2, \bar{\gamma}_3, \bar{\gamma}_4, \bar{\gamma}_5, \bar{\gamma}_6, \bar{\gamma}_7) \quad (1)$$

where each component represents the relative importance that managers assign to each of the seven company types. The values of these parameters remain fixed throughout successive rounds.

We assume that managers allocate their time, resources, and efforts in such a way that the results satisfice (but do not necessarily maximize) their goals or expectations. We explicitly assume that managers are willing to forego short-term results in exchange for learning and the future development of the firm's potential. While the target profile $\bar{\gamma}$ remains fixed throughout the simulations, the knowledge mentioned in (i) and (ii) above may evolve through time. Companies and managers *can and do learn.*

On the one hand, managers learn about what type of company their company is. This process takes place by looking at each period's results and updating, in a Bayesian way, the probability distribution that describes their imperfect knowledge about the true profile of their firm.[6]

On the other hand, managers also learn about the success probability of the different types of projects.[7] We implement this learning via a neural network that is trained initially and learns from experience thereafter. The network does not fully exploit the information existing in the observations, as in the Bayesian case; instead, it takes an approximate point of view, more consistent with managers' bounded rationality (see Section 2).

Figure 1 shows the basic structure of the model. In the next section we make explicit the interconnection between the decisions of the agents involved, as well as other technical aspects.

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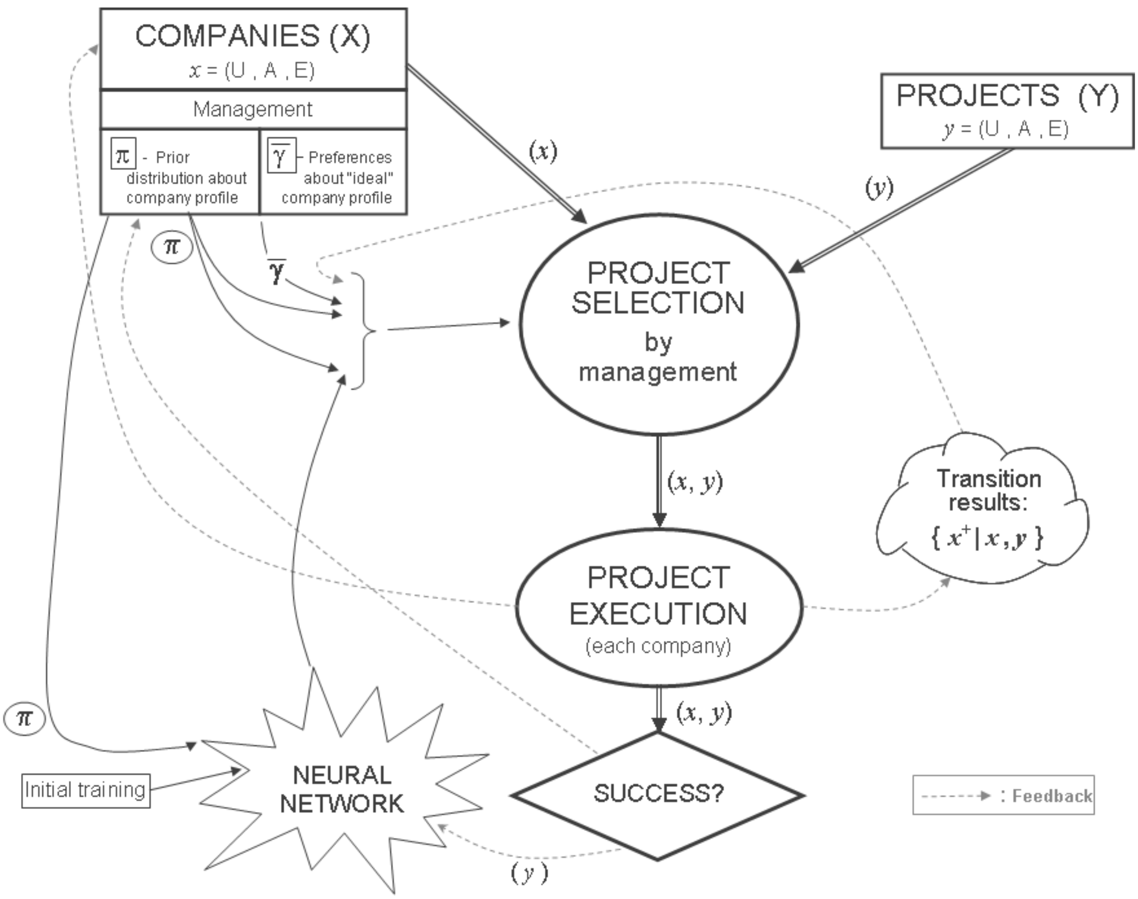
[6] Managers may think they are running an attractive company (i.e., one in which employees enjoy their jobs), but it may be that employees think otherwise. If, as a consequence of their (wrong) beliefs, managers take on a project that requires attractiveness, the company is likely to fail, although at the same time it may develop attractiveness. Managers can learn by revising their beliefs about the company's profile.

[7] As an example, managers may observe the performance of firms that undertake projects with the profile $(1,y_2,y_3)$, that is, projects that have the potential to develop unity. Based on this information and their knowledge of their own company's profile, managers can select the projects that are most likely to contribute to developing unity in their firm.

Figure 1

Simplified Model Structure



2. Structure of the Model

The process by which managers select projects depends on three elements: the type of company they would like to be in the future; the (incomplete) knowledge they have about the company's profile, which is updated along the way; and the (incomplete) knowledge they have about a project's chances of success, which is also updated along the way.

The interplay of these elements gives rise to a rich variety of decision patterns. As an illustration, note that managers may think they are running a particular type of company, when in fact they are running some other type. As success depends on what the company is actually able to do (its true profile), managers have an interest in learning about that profile. At the same time, some managers may not be interested exclusively in immediate financial results, but also in long-term goals, such as improving the satisfaction of their employees, or developing the company so that it can undertake more challenging projects in the future.[8] The fact that, after working on a particular project, a company's profile may change (i.e., it may acquire an

[8] Another extension of the model would be to allow for "the environment" becoming more demanding with the passing of time and generating more projects that require, say, unity. We have not included this possibility so far.

attribute it did not have before, or it may lose an attribute) means that decision patterns may change along the way, making the model quite rich and more realistic.

2.1. Knowledge of Company Profile

A key element of the model is the way in which managers form their beliefs about the type of company they run. As they do not know the true profile of the firm, we endow managers with a *prior* (a probability distribution), π, defined as follows:

$$\pi(x) \;=\; \pi(x_1, x_2, x_3) \;=\; P\,(\text{true profile of the company is } (x_1, x_2, x_3))$$

We assume that the initial distribution is uniform over all possible profiles, which is a non-informative prior distribution and a reasonable assumption in decision making under uncertainty (which may be easily modified at a later stage, on the basis that management is supposed to know better than that). As new information becomes available, the probability distribution is updated in a Bayesian way.

2.2. Probability of Success

Another important element is the way in which managers form their beliefs about the possibility of success in a given project. Let P_T(x,y) be the "true" probability of success, defined for all pairs (x,y) as

$$P_T(x, y) = P(success \mid company = x, project = y)\,. \tag{2}$$

Managers' subjective perception of (2) will be denoted by P_S(x,y). Note that while managers make their decisions based on P_S, the actual frequency of successes and failures in the simulations will be determined by P_T. The process by which managers form their subjective perceptions is modeled by means of a neural network. In particular, the system makes public all quadruples

{Initial Profile of firm; Project Type; Success or Failure; Final Profile of firm}

generated during each round. Based on this information, companies update their knowledge (thus simulating the learning process of their management teams). For simplicity, we assume that the learning process is the same for all companies, in the sense that it is the same type of neural network that processes the information in all firms. We thus deal with three probability measures:

(i) P_T(x,y) is the "true" probability that a company with profile *x* succeeds when it undertakes a project with profile *y*. This probability is assumed to be a feature of the "environment," determined by the modeler.

(ii) P_S(x,y) is the subjective estimate that a company of type *x* will succeed if it undertakes a project of type *y*. This measure is updated as new information is generated by the environment in each round, and should converge to P_T(x,y).

(iii) P_F(x,y) is a frequency. It tells us how often a project of type *y* has actually succeeded when undertaken by a company of type *x* during the different rounds. As time goes by, it should converge to P_T(x,y).

2.3. Evolution of Profiles

A third key element of the model is the fact that, after working on a project, a company may develop a desired attribute, or it may lose it (because its choice of project was short-sighted or inappropriate).

The modification of profiles is modeled by means of a transition matrix, which specifies the probability that, in a given period, a company will evolve from one profile to another as a consequence of undertaking a particular project. Consider a company with the profile $x=(x_1,x_2,x_3)$ that undertakes project $y=(y_1,y_2,y_3)$. The company's profile at the end of the round will be denoted by $x^+=(x_1^+,x_2^+,x_3^+)$:

$$(x_1,x_2,x_3) \xrightarrow{(y_1,y_2,y_3)} (x_1^+,x_2^+,x_3^+)$$

The new profile is modeled by drawing from the probability distribution

$$P\,[\,x^+=(x_1^+,x_2^+,x_3^+)\mid x=(x_1,x_2,x_3),\; y=(y_1,y_2,y_3)\,]$$

where we explicitly assume that the new value of each attribute is independent of the new value of the other attributes. The probability that, after one round, $x_1^+=1$ (that is, that after having worked on a project, the company has acquired unity) will be denoted by $g_1(x_1,y_1)$. In an analogous way, $g_2(x_2,y_2)$ and $g_3(x_3,y_3)$ will denote the probability that the company has acquired attractiveness ($x_2^+=1$) and effectiveness ($x_3^+=1$). In general,

$$g_i(x_i,y_i) \;=\; P(x_i^+=1\mid x_i,y_i)\,, \tag{3}$$

where $g_i \in [0,1]$. Given the independence of the attributes, if a company chooses to undertake project (y_1,y_2,y_3), each attribute of the company (each x_i) will evolve according to a controlled Markov chain[9], with transition matrix A_i:

$$A_i \;=\; \begin{bmatrix} P(x_i^+=0\mid x_i=0,y_i) & P(x_i^+=1\mid x_i=0,y_i) \\ P(x_i^+=0\mid x_i=1,y_i) & P(x_i^+=1\mid x_i=1,y_i) \end{bmatrix}$$

Using (3), this matrix can be written as

$$A_i \;=\; \begin{bmatrix} 1-g_i(0,y_i) & g_i(0,y_i) \\ 1-g_i(1,y_i) & g_i(1,y_i) \end{bmatrix} \tag{4}$$

Note how it is the project that determines the matrix. Note also that the matrix is unknown to managers (as its components are a characteristic of the environment, determined by the modeler).

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[9] See Chung (1982), Taylor and Karlin (1998), or Heyman and Sobel (2003).

In order to simplify notation, we let λ_i denote the probability that a company lacking an attribute acquires it after working on a project with that attribute. That is, for i=1,2,3,

$$\lambda_i \;=\; g_i(0,1) \;=\; P(x_i^+ = 1 \mid x_i = 0, y_i = 1)$$

Likewise, we let μ_i denote the probability that a company loses an attribute after working on a project that does not have it:

$$\mu_i \;=\; 1 - g_i(1,0) \;=\; P(x_i^+ = 0 \mid x_i = 1, y_i = 0)$$

for i=1,2,3. We impose the following conditions on these parameters:

1) *Invariance,* which requires that attributes cannot change when the initial company value and project value are the same. In particular, for i=1,2,3:

$$g_i(1,1) \;=\; P(x_i^+ = 1 \mid x_i = 1, y_i = 1) \;=\; 1$$

and

$$g_i(0,0) \;=\; P(x_i^+ = 1 \mid x_i = 0, y_i = 0) \;=\; 0$$

2) *Entropy,* which means that a weak project attribute is less determinant of the final result than a weak company attribute. For i=1,2,3, we assume that

$$g_i(0,1) \leq g_i(1,0)$$

3) *Difficulty,* which states that improving effectiveness is easier than improving attractiveness, and this in turn is easier than improving unity. We also require that losing unity is easier than losing attractiveness, and this in turn is easier than losing effectiveness. We write:

$$\lambda_1 \leq \lambda_2 \leq \lambda_3 \qquad \text{and} \qquad \mu_1 \geq \mu_2 \geq \mu_3$$

2.4. Decision Making

Two criteria are used to choose projects. One captures the idea that managers would like to choose the project that maximizes expected NPV. This, however, would require them to compute the success probability P_T(x,y), which is not observable. A solution could be to use the subjective perception P_S(x,y), but the problem is that managers do not know the true profile of their firm. We thus consider the following version of the Expected NPV,[10]

$$V(y) \;=\; NPV(y) \cdot \sum_{all\, x} P_S(x,y) \cdot \pi(x)$$

As we are assuming that the financial value of all projects is the same, we may assume NPV(y)=1 for all *y*, which yields:

[10] Note that the summation has seven terms, as there are only seven company profiles.

$$V(y) = \sum_{all\ x} P_S(x,y) \cdot \pi(x)$$

The other criterion has to do with managers' aspirations (goals) regarding the type of company they would like to have in the future. The idea we try to model is that managers choose the project that will bring them closer to their goal. We proceed in two steps: first, we take into account the wishes or desires of the management team, represented by $\bar{\gamma}$; second, such desires are tempered by the "imitation effect," which is the attraction that managers may feel toward the projects that successful companies chose in the past.

In order to make things concrete, note that

$$\sum_{\substack{all\ projects\ y \\ undertaken\ by\ x}} P_T(x,y)$$

is an estimate of the success of a company with profile x. As $P_T(x,y)$ is not observable and $P_S(x,y)$ is different for each company, we will use the frequency measure $P_F(x,y)$. If one considers the expected net present value of a project as a measure of success, since all projects are alike, the above expression is a proxy for the total value earned by a company in a given simulation round. In an analogous way,

$$G(x) = \sum_{\substack{all\ companies \\ of\ type\ x}} \sum_{\substack{all\ projects\ y \\ undertaken\ by\ x}} P_F(x,y)$$

is a proxy for the total value earned by all companies of type x. The function G will be used to model the inclination to imitate companies that have been successful in the past. Note that G(x) can be computed with the data generated by the system in each round.

Managers' preferences regarding future company profile were given by (1), where the components, $\bar{\gamma}_x$, represented the relative importance that managers assign to each company type. These preferences, which remain fixed throughout successive rounds, should be combined with the fact that managers are not blind to what goes on in their environment (imitation effect).[11] How to combine the two variables is open to discussion, but in line with the tradition of System Dynamics (see, for example, Meadows, 2008), we adopt a multiplicative approach. We therefore define $\gamma_x = \bar{\gamma}_x \cdot G(x)$, so that

$$\gamma = (\ \bar{\gamma}_1 G(1),\ \bar{\gamma}_2 G(2),\ \bar{\gamma}_3 G(3),\ \bar{\gamma}_4 G(4),\ \bar{\gamma}_5 G(5),\ \bar{\gamma}_6 G(6),\ \bar{\gamma}_7 G(7)\ )$$

The second criterion used by managers to choose projects is thus:

$$W(y) = \sum_{x^+} \gamma_{x^+} \cdot P(x^+ \mid y)$$
$$= \sum_{x^+} \gamma_{x^+} \left(\sum_{x} P(x^+ \mid x, y) \cdot \pi(x) \right)$$

where the probability is to be understood as an (observed) frequency.

[11] This approach goes beyond the concept of mimesis in neo-institutional theory (Di Maggio and Powell, 1983).

Note that we have developed two indices, V(y) and W(y). While the former relates to the project's efficiency (its capacity to generate short-term profits), the latter captures how closely the project is aligned with managers' preferences regarding the future of the company. We combine the two indexes as follows:

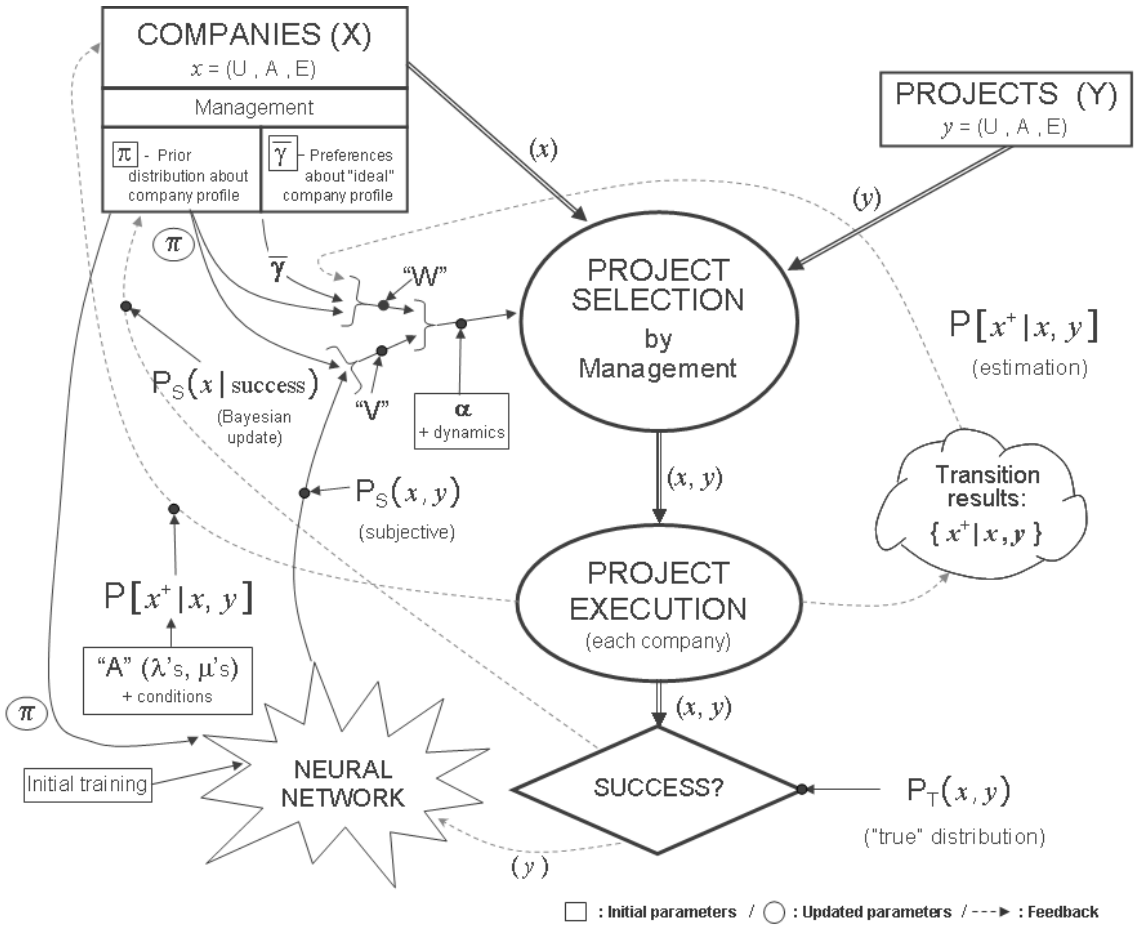
$$D(y) = (1-\alpha)\cdot V(y) + \alpha\cdot W(y)$$

where α is the managers' willingness to sacrifice short-run profits in exchange for a better company profile in the future. Managers do not maximize this index; rather, they fix a threshold, T, and choose the first project for which $D(y)\geq T$.[12]

If $\alpha=1$ (complete willingness to sacrifice immediate profits), the decision criterion becomes $D(y)=W(y)$, meaning that the weight in the decision-making process is carried by the managers' long-term vision of the type of company they would like to be in the future. If $\alpha=0$, the decision index would be $D(y)=V(y)$, meaning that managers exclusively seek short-term profits. Figure 2 shows the detailed structure of the model.

Figure 2

Detailed Model Structure



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12 Projects of different types are successively "offered" to each company in a random order.

3. Simulations and Preliminary Results

In this section we report the results of the simulations. The objective is to illustrate the kind of output that the model can produce and its potential to provide insight into the dynamics of an economy that takes account of learning, as well as decision making at the firm and management level.

Unless otherwise stated, we consider N=1000 companies, which we allow to interact for H=300 periods. For simplicity, we assume that all projects take one period to complete, and that firms undertake only one project per period.

We also assume that all projects have the same economic value and require the same investment conditions, independent of which company undertakes them. For example, if the NPV of a project is €10 million, we assume that this is so no matter what company carries out the project.[13] This means that the number of successful projects in a round is a measure of the aggregate value generated in the economy.

As a consequence of the projects it undertakes, a company's profile may change, making the company better or less well prepared to successfully undertake projects in the future. We may therefore consider the distribution of company profiles at the end of a round as a measure of the future potential of the economy.[14] This does not mean that managers will necessarily undertake more demanding or challenging projects; whether they do so will depend on:

(i) Their target profile ($\bar{\gamma}$).

(ii) How "boundedly rational" they are (the threshold T).

(iii) How willing they are to forego immediate results in order to develop attractiveness and unity in their firms (α).

We start with the following assumptions, some of which are modified later on:

1) The initial distribution of firms is uniform.

2) All firms have the same preferences regarding target profiles ($\bar{\gamma}$ is the same for all companies).

3) All management teams have the same initial perception regarding the profile of their firm (same priors).

4) Each company has the same degree of bounded rationality (the threshold T is the same for all companies).

5) Each firm has the same willingness to forego immediate economic results in favor of "better" future profiles (α is the same for all companies).

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[13] A way to express this fact is to assume that the NPV of all projects is 1.

[14] The idea is that the capacity of a company to successfully undertake any type of project is higher as its profile *approaches* x=(1,1,1).

6) Changes in profile are governed by the same transition matrix for all companies (the matrices A_i of section 2.3). This assumption can be interpreted as depending on the "environment," rather than being decided by managers. We initially adopt the following values:

$$\lambda 1 = 0.1, \quad \lambda 2 = 0.2, \quad \lambda 3 = 0.3$$

$$\mu 1 = 0.9, \quad \mu 2 = 0.8, \quad \mu 3 = 0.7$$

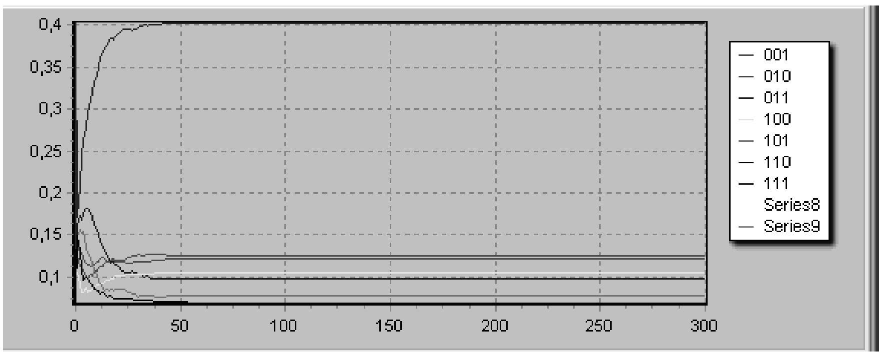
3.1. Parameters related to project selection (α, *T*)

(a) Case 1: α*=1 and low values of T*

For these values the evolution of the different types of companies quickly stabilizes (in fewer than 50 periods) to 40% of (1,1,1)s, and lower percentages of other profiles. In particular, profile (1,0,0) stabilizes at 10% of the population.[15] The complete evolution is shown in Figure 3, where time (number of rounds) goes in the horizontal axis and the percentage of each company type goes in the vertical axis (the red curve corresponds to (1,1,1)s, the yellow to (1,0,0)s, and so forth):

Figure 3

Evolution of company profiles for α=1 and low values of *T*



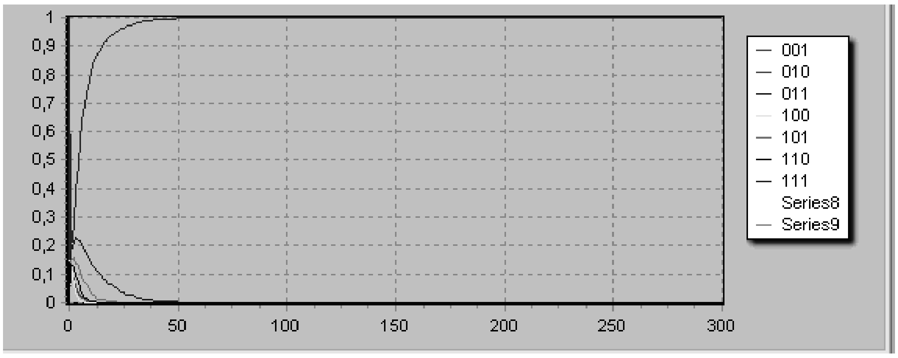
(b) Case 2: *α=1 with increasing values of T.*

[15] The 40% of type-7 companies is due to the structure of the matrices A_i (see equation (4)).

If we hold α=1 and increase the value of the threshold *T*, the proportion of type-7 companies quickly goes up to 100%. The situation is more or less the same even for *T=1*, as can be seen in Figure 4.

Figure 4

Evolution of company profiles for α=1 and *T*=1

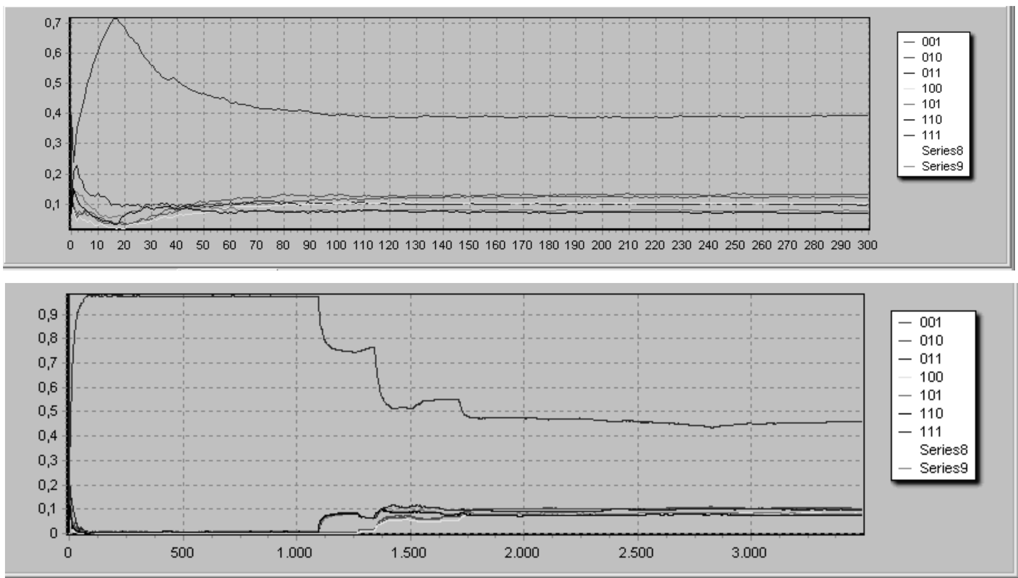


(c) Case 3: *α=0*.

When α=0, it takes high values of *T* to get to 100% of type-7 firms. For lower values of *T*, stabilization occurs at 40% of (1,1,1)s, although with increasing instability.[16] In Figure 5 one can see that the proportion of (1,1,1)s can even reach 100% during transitory periods of "false" stabilization, then falling back to 40%. Note how a longer time is needed to converge to 40%. In the simulations that follow we will let the model run for more than 300 periods in order to ensure that we do not miss potential changes that may not be observable in the shorter run.

Figure 5

Evolution for α=0, *T*=0.9 and *T*=0.99



For *T=1* stabilization happens at 100% of (1,1,1)s:

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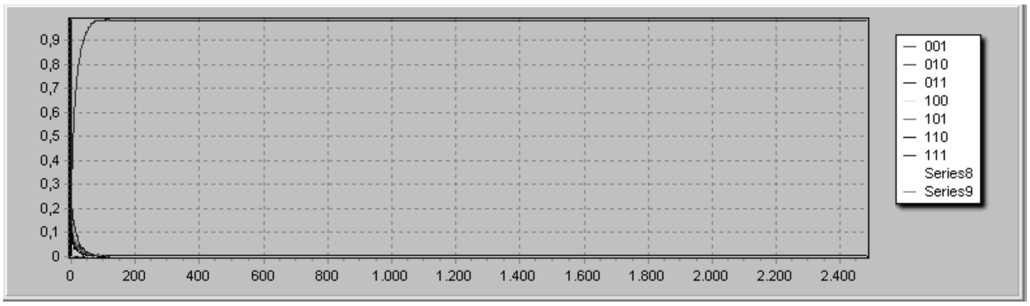
[16] Given the model configuration, getting to 40% of (1,1,1)s is the "standard low."

Figure 6

Evolution for α=0 and T=1



The behavior is analogous if $0<\alpha<1$. For a fixed value of α, the final proportion of type-7 companies is 40% if the value of T is low, while for higher values of T it rises to 100%. As the fixed value of α gets higher, the transition from 40% to 100% takes place at lower values of T (as would be expected). The evolution path, however, is sometimes unstable and slow, as can be seen in Figures 7 and 8.

Figure 7

Evolution of company profiles for α=0.66, T=0.395 and 0.4

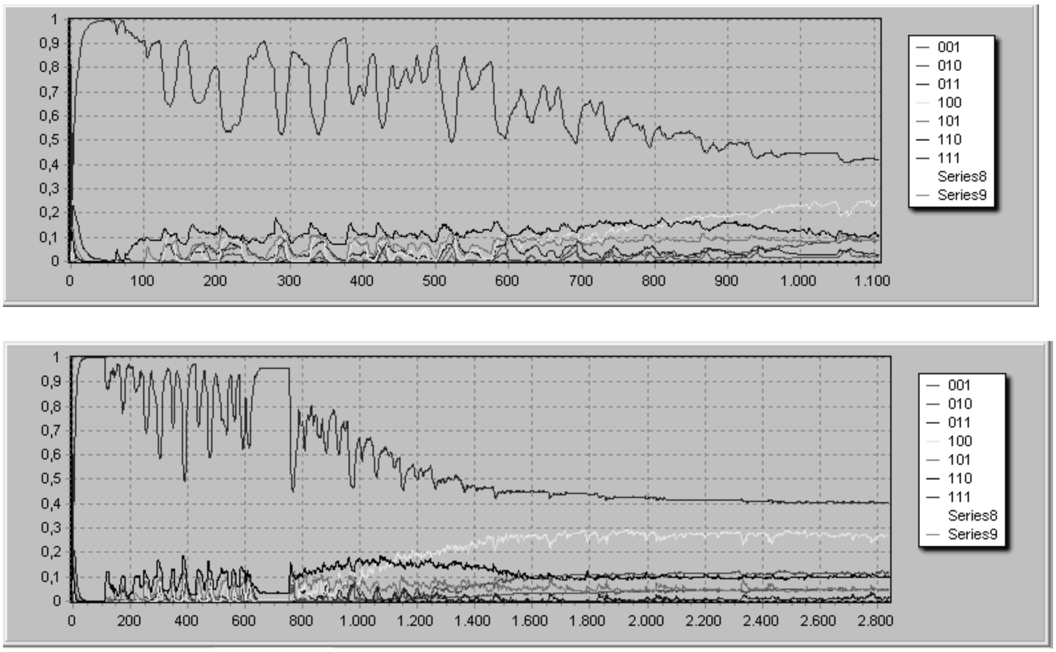
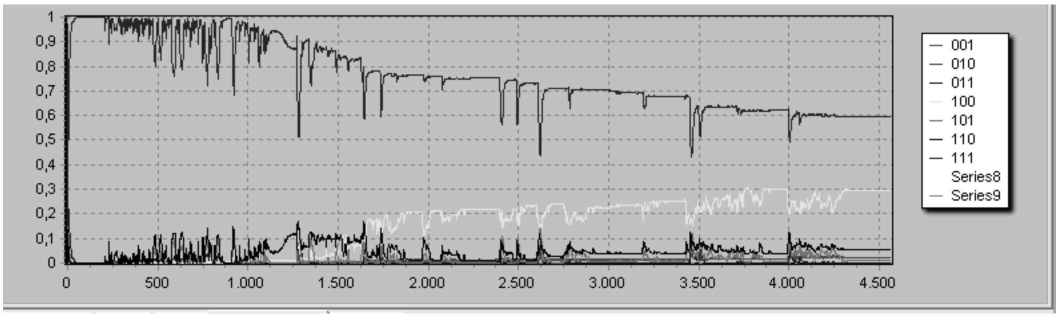
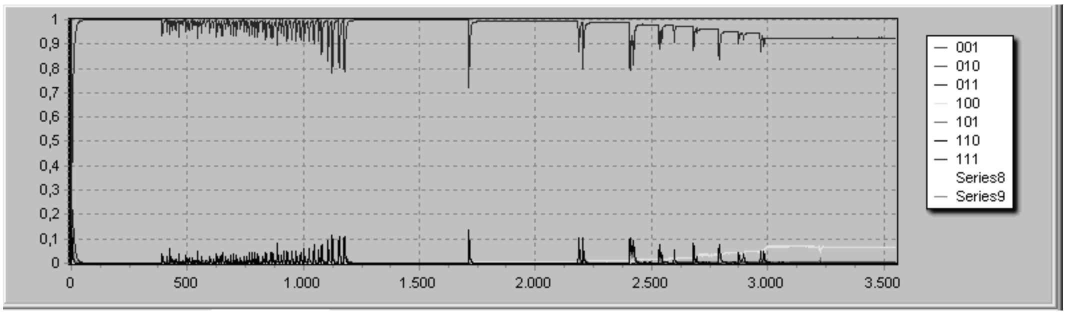


Figure 8

Evolution of company profiles for α=0.7, T=0.315 and α=0.74, T=0.29





(d) Interpretation

Combinations of "coherent" values of α and T (like high values of both parameters) tend to produce more stable evolutions. However, it is possible to *compensate for* a limited willingness to forego immediate profits (a low value of α) with a more demanding threshold (higher values of T) in order to get a population of companies with greater future potential. In other words, a company with a "short-term" culture can end up having a "long-term" culture if its managers are more demanding with regard to project selection (positive learning may take place as a result of undertaking "high quality" projects).[17]

We can also see that once the evolution starts to deteriorate, it is difficult to turn it around. Furthermore, transitions from a stable situation to a worse one seem to be triggered by accepting an unusually bad project, or undertaking a sequence of not-so-good projects that start an episode of dysfunctional learning.

3.2. Parameters related to the "environment" (matrices A_i)

To further illustrate the model's behavior, we carry out additional experiments in different "environments." These new environments are generated by changing the values of the probabilities in the transition matrices A_i.

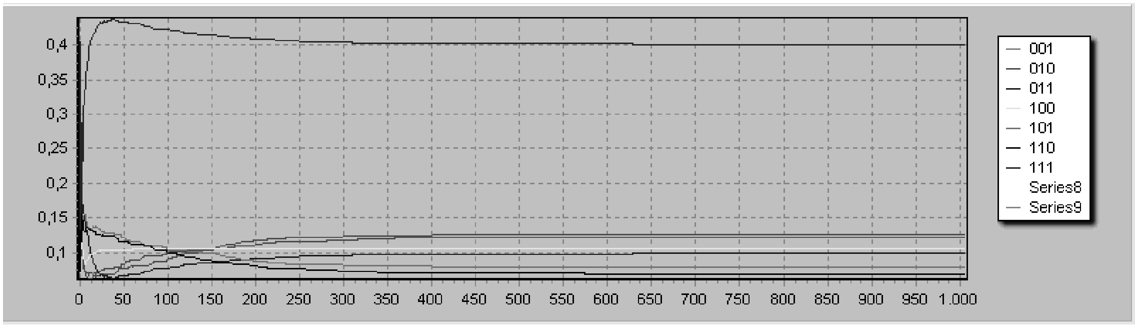
a) Environment 1: Easier to lose unity (higher μ_1)

[17] This phenomenon can also be interpreted as an interesting interplay between *exploration* and *exploitation* in the March tradition (March, 1991).

If we set μ_1=0.99 we obtain that, for α=1 and T=0, the final proportion of type-7 companies goes to 40%, as before (see Figure 9).

Figure 9

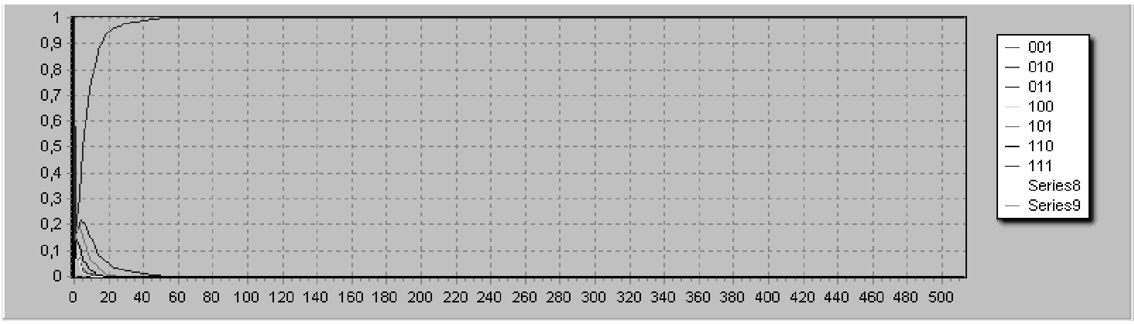
Evolution of company profiles for μ_1=0.99, α=1 and T=0



However, if we increase the value of T, the final proportion quickly goes to 100%:

Figure 10

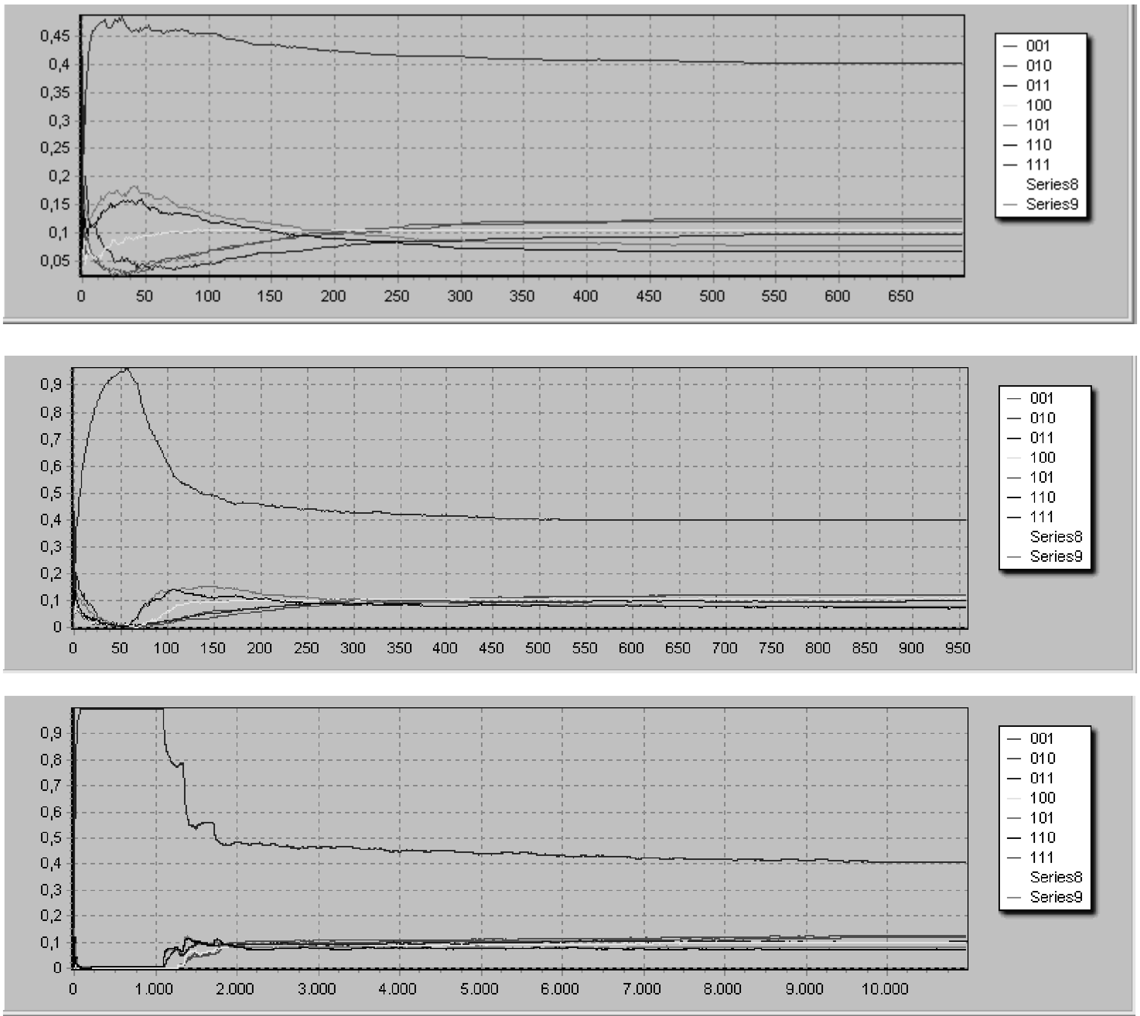
Evolution of company profiles for μ_1=0.99, α=1, and T=0.1



If we now let $\alpha=0$ and choose low values of T, an equilibrium is reached at 40% of (1,1,1)s. For higher values of $T<1$, the 40% equilibrium is still reached, but at a slower pace and with increasing instability. See Figure 11, where one can observe how the proportion of (1,1,1)s stays at 100% for longer periods of time.

Figure 11

Evolution of company profiles for $\mu_1=0.99$, $\alpha=0$, and $T=0.8$, 0.95 and 0.99



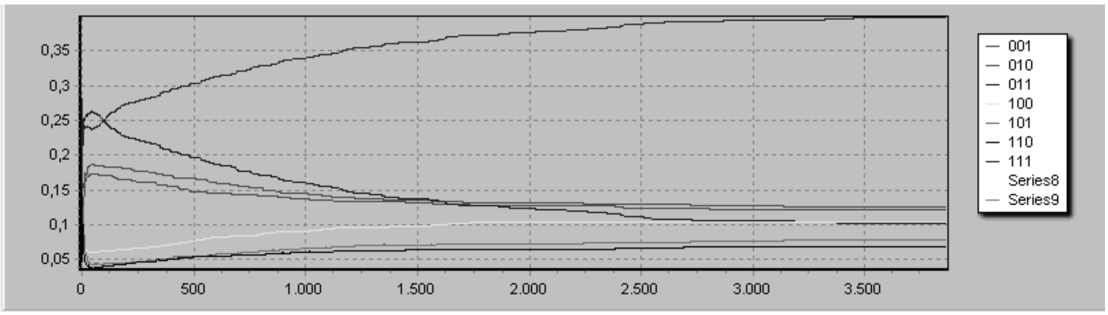
Only for $T=1$ does the proportion of (1,1,1)s become stable at 100%. All these changes in behavior mimic closely the results obtained with the initial value ($\mu_1=0.9$). Increasing μ_1 to 0.99 did not generate substantial changes.

b) Environment 2: Harder to acquire unity (lower λ_1)

If we set λ_1=0.001 we obtain that, for α=1 and *T*=0, the final proportion of type-7 companies also goes to 40%, but it never goes above 40%, and the evolution is slower (see Figure 12).

Figure 12

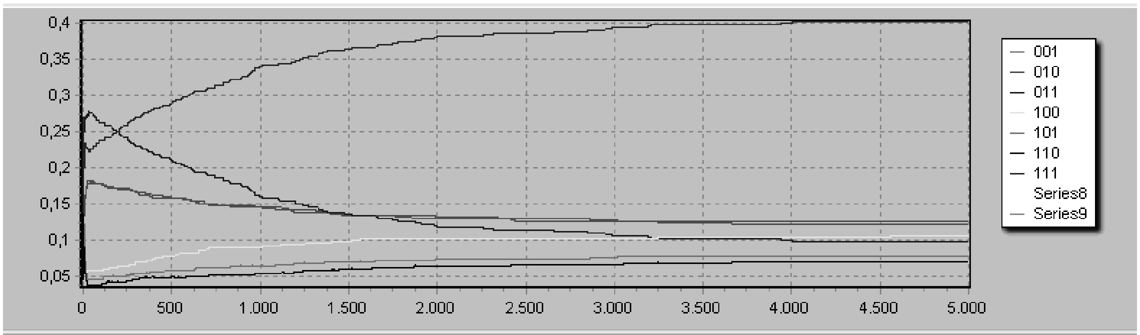
Evolution of company profiles for λ_1=0.001, α=1 and *T*=0



For higher values of *T* the proportion reaches 100%, but through a slower evolution. If we let α=0 and choose low values of *T*, the proportion of (1,1,1)s goes to 40%, but with a different dynamics, as can be seen in Figure 13.

Figure 13

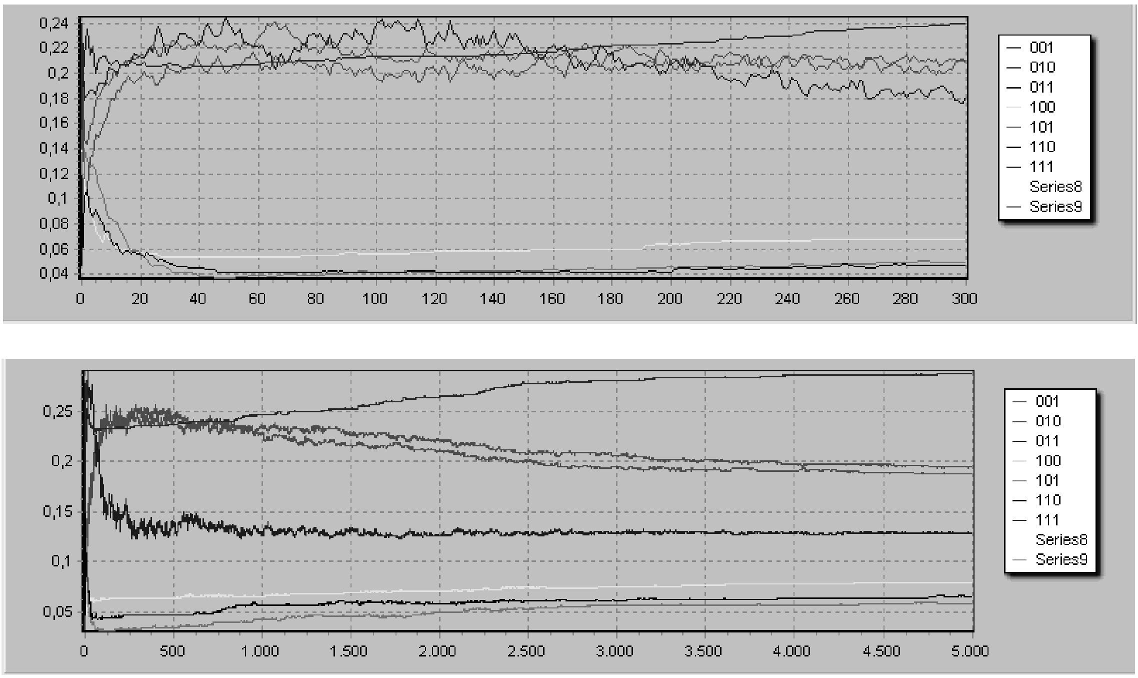
Evolution of company profiles for λ_1=0.001, α=0 and *T*=0.1



As T becomes higher, instability appears and the stable state occurs at a lower proportion of type-7 companies, close to 29% (see Figure 14).

Figure 14

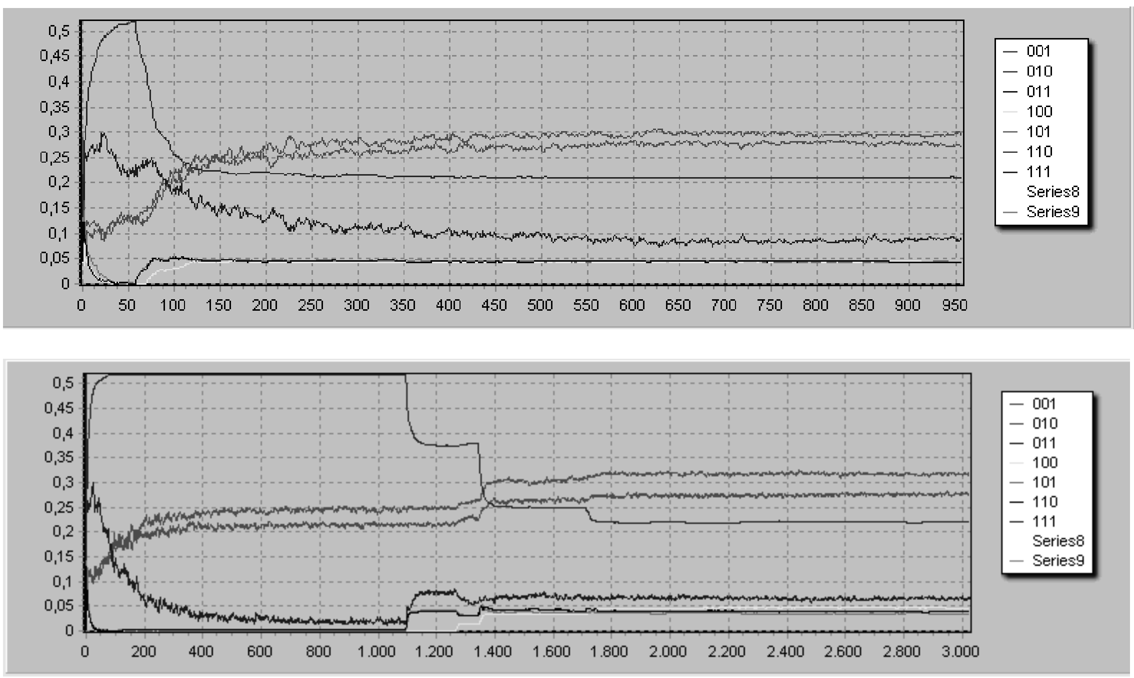
Evolution for λ_1=0.001, α=0, T=0.4 and 0.75



If T gets closer to T=1, the same sort of instability appears, although reaching a maximum around 51% of type-7 companies (well below the 100% attained before), eventually stabilizing at around 22% (see Figure 15). Note that in this case the (1,1,1) profile is not the one with the largest share of the whole population.

Figure 15

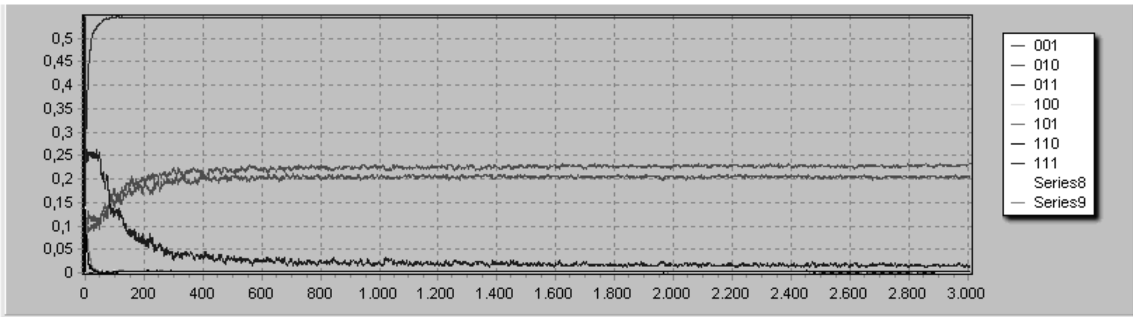
Evolution of company profiles for λ_1=0.001, α=0, T=0.85 and 0.99



Only for T=1 does the proportion of (1,1,1)s dominate in a stable manner, although it does not reach 100%, but rather 54%.

Figure 16

Evolution of company profiles for λ_1=0.001, α=0, and T=1



c) Interpretation

If the changes in parameter values are not large, the behavior does not change significantly, allowing us to conclude that the model is robust, in a way that will facilitate future research. Also, the parameters that define the environment make up what may be understood as a "baseline" for the *future potential* of the economy, a sort of benchmark against which managers cannot "fight." This can be understood as the underlying culture or *social ethos*, which can only be modified through more fundamental action (e.g., generating a social environment in which unity is appreciated).

4. Conclusions

The model we have presented attempts to explain, using simulation techniques, the aggregate behavior of a population of firms in terms of their managers' motivations and willingness to sacrifice short-term measurable results for qualitative variables that affect the future. The key elements of our model are bounded rationality, *satisficing* behavior, and a learning process that can change the nature and behavior of firms. Although the model is still in the development stage, it provides a structured setting in which these issues – which are often discussed informally – can be rigorously analyzed.

An important characteristic of our approach is the feasibility – even easiness – of modeling a complicated process of enterprise evolution based on management attitudes and values. A fairly simple and parsimonious description of reality leads to emergent behavior which is not obvious at all.[18]

The model includes the (almost) minimum number of features that characterize real-life enterprises, going far beyond the stylized versions of economics-based models. Up to now, most modifications of maximizing behavior have been introduced in a piecemeal fashion, as addenda to the maximizing manager, who is almost always lurking in the background. We have shown that features such as learning, bounded rationality, concern for the welfare of others,

[18] In light of the work of the Santa Fe Institute (see, for example, Miller and Page, 2007), one would expect from our simple assumptions the appearance of significant emerging properties. This is in fact the case, as we have seen in Section 3.

uncertainty, and so on can be analyzed and modeled simultaneously. No harm arises from it and the explanatory power of the model increases noticeably.

We would like to point out the importance of bounded rationally for our results. Without it, the optimal behavior of managers would quickly converge to type-7 companies, which would consistently dominate the others. Bounded rationality does away with this, since the manager is satisfied with the first project that exceeds the threshold, making it reasonable for companies to undertake projects other than (1,1,1).[19] Diversity is good, and in our model it emerges from the bounded rationality feature.

Managers' uncertain knowledge about their company type may have a "catastrophic" effect on their company's evolution, in the sense that a large change may arise from a small modification in the parameters. The reason is simple but interesting. The manager has a prior on the company type. Unless the prior is very sharp around the true value, the distribution gives weight to the other types. Assume you have a type-7 company. We argue that these companies can be very unstable whenever management has inaccurate knowledge of their true state. As managers estimate company type by computing the expectation over the prior, the expected company type will come to less than 7. This leads to the selection of other than type-7 projects, which, in turn, gives a positive probability of losing attributes. And if you lose attributes, it will be difficult to recover them, leading to a decrease in the number of type-7 companies, which reflects what happens in real life when managers have a distorted perception of the state of their company. In practice, managers who have a diffuse knowledge about their company make poor decisions. And obviously, everything will be much worse if they consider only the efficiency attribute, ignoring attractiveness and unity.

Finally, it is worth investing in learning about one's own company profile. Assume that, at a given stage, companies of type-7 abound. By the "imitation effect," I would like to be like the leaders. But, if I want to carry on being a type-7 company, I must select type-7 projects. A type-7 company doing a type-7 project has a probability of success equal to one, and will continue to have a (1,1,1) profile. Assume that my preferences are for type-7 companies but my company is not type-7. What happens? By imitation I will tend to select (1,1,1) projects and so will set myself up for failure, which may lead to a downgrade in company type. The widespread tendency to "follow the leaders" entails the risk of overreaching, unless managers have an accurate assessment of their company profile.

Elusive concepts such as attractiveness and unity are difficult to measure objectively. Estimating them is therefore the responsibility of general management. The tendency to delegate this task to the HR department isolates general management and reduces the chances of a correct diagnosis, thus increasing risks.

One possible difficulty with the model stems from the fact that, in its current form, it is not easy to anticipate behavior for values of the parameters in reasonable domains. The only way to learn about behavior is by running the model and observing the outcome. In our further work we will try to explain observed behavior, building on the fact that the dynamic evolution of the model is controlled by a Markov chain, a class of well known processes. We also intend to add some of the enhancements suggested in previous sections.

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[19] Under some conditions a majority of firms become type-7 (which is obviously the ideal situation). But we have seen that learning can be dysfunctional: after the proportion of (1,1,1)s reaches 100%, it can decrease substantially as time goes by.

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