A System Dynamics approach to the analysis of the intra-organisational ecology theory

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Abstract

This paper describes how System Dynamics simulation has been used to interpret, test and refine a theoretical framework grounded on a case study. The case analised is Burgelman's account of Intel strategic reorientation which led to the development of the intra-organisational ecology theory of strategy-making. The article explains how System Dynamics simulation has been employed and discusses advantages of coupling simulation, case study analysis and theory building.

Introduction

Simulation studies have a long tradition in organisational and strategy research, dating back to the seminal works in the area of the behavioural theory of the firm and organisational decision theory [Cyert, Feigenbaum and March, 1950; Clarkson 1960; Cyert and March, 1963; Cohen, March and Olsen, 1972]. A number of important theoretical pieces in this area are based on simulations studies. This is true for the "Garbage Can" model [Cohen, March and Olsen, 1972] and for the Behavioural Theory of the Firm developed by Cyert and March [1963]. More recently, simulations have characterised studies in organisational evolution and dynamics, and, in particular, inter-organisational evolution [Lomborg, 1996] and intra-organisational evolution [Burgelman and Mittman, 1994], organisational learning [March, 1991] and organisational change [Mezias and Glynn, 1993; Lant and Mezias, 1992; Sastry, 1997].

Modelling and simulation may constitute fundamental elements of a research design. Modelling helps clarify concepts and sharpen the comprehension of a theory. Simulation helps rigorously to deduce consequences from modelled assumptions and to refine hypotheses.

An empirical case, for example, coupled with a simulation study, provides a laboratory to test the coherence of theoretical approaches eventually generated. Alternative hypothetical, though dormant, trajectories can be activated by modifying the underlying modelled assumptions and therefore the computer simulation model can be used as a laboratory [Forrester, 1961] thereby providing an appropriate setting to conduct controlled experiments. History can be re-run, showing how small, *ab-initio* modifications in parameter values can be amplified over time, to yield firms with distinct characteristics. In this light, simulation is a unique methodology to perform this journey backward in history.

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Evolutionary Thought and the Contribution of Burgelman's Model

A rich collection of studies has repeatedly used the ecology variation-selection-retention approach to investigate phenomena in social sciences. Such attempts range from Campbell cultural evolution, later applied to the study of organisational dynamics by Weick [1979], to Nelson and Winter's study of firms' capability evolution [1982] to, finally, Hannan and Freeman's population ecology approach to explain organisational change [1977, 1984, 1989]. One of such attempts is Burgelman's theory of corporate's strategy as an emergent process resulting from the evolution of an ecology of strategic initiatives that compete for scarce resources [1991]. According to this view, front-line managers might generate variation in strategic behaviour by delineating autonomous strategic initiatives that are outside the current concept of strategy. Decision-making in organisations' structural contexts provide internal competitive environments where strategic initiatives are selected. The result of such selection is retained through change in top management strategic intent that both influences the selection mechanisms crystallised into the structural context and inspires strategic initiatives that are in line, or induced, by such strategic context. Changes in the core features of firms are possible when autonomous initiatives find their way in the organisation by avoiding the pressure of the official resource allocation rule which characterises a firm's selection mechanism. In this process, top managers have a crucial role in fostering variation by facilitating the flow of resources towards autonomous initiatives on their embryonic stage. This piece of work opened a promising thread of study providing a framework to interpret the long-standing quandaries in organisational and management studies concerning the relative role of managerial choice and environmental determinism in deciding the trajectory of a firm's evolution. Indeed, Burgelman's approach bridges together two competing views on organisational change in its considering contemporaneously an evolutionary and a teleonomic motor of change [Van de Ven & Scott Poole, 1994].

Important insights into the dynamics of organisational change can therefore extracted as long as it is possible to generate a framework to investigate the relative role played by these two engines.

As Van de Ven and Scott Poole pointed out [1994], a fertile approach would consider the feedback characteristics of the interaction of different motors of change. Such analysis, could explain why, given an exogenous disturbances, some organisations develop evolutionary trajectories of change thereby discovering new and eventually unintended paths while others show dynamic behaviours which are resilient to disturbances and remain close to the original trajectory.

USE OF SIMULATION TO TEST AND REFINE A GROUNDED THEORY

Modelling of a theory

The process of modelling a theory has at least two advantages. First, modelling helps to transform verbal statements and phrases into equations which can be easily communicated and eventually argued against. Second, the equation-format provides a common language to facilitate the integration of hypotheses grounded on field studies and those emerging from relevant literature.

In the following, a description is reported of how a simulation study enhanced the comprehension of Burgelman's intra-organisational ecology theory. The process which allowed to capture Burgelman's theory into a simulation model, partly inspired

by Sastry's approach [1997], started from a textual analysis of interpretation of strategic reorientation of INTEL [Burgelman, 1991]. The simulation model, extensively described elsewhere [Mollona & Noda, 1999], allowed to move towards a deeper comprehension of the theory.

Modelling retention processes

A fundamental idea emerging from Burgelman's article concerns the role played by retention processes and inertia. Future decisions are strongly biased by decision-makers' ex-post rationalisation of past experience. As Burgelman points out, strategy is embodied in "…oral and written statements regarding the technical/economics as well as cultural factors - such as key values and company traditions - perceived to be associated with past success." [Burgelman, 1991, p:243].

In this light, the idea of *information feedback system* and the distinction between stock- and flow-variables, at the heart of System Dynamics modelling, was particularly suited to describe and conceptualise retention processes. The identification of stock-variables as the results of organisational retention processes forced a clear definition of the locus where retention process could be observed within the organisation.

Thus, strategy was described as a set of resource-stocks in which, as a consequence of top managers' ex-post rationalisation from past actions, information accumulates. These resource-stocks, which crystallise the history of the organisation, do not change instantaneously, rather evolve incrementally as the activity of the organisation unfolds. In the model, a choice had to be made on which resource-stocks to include in order to capture the retained strategic context. The choice made led to the inclusion in the model of two stocks.

The first resource-stock is *aspiration-level* (*AL*). This stock variable accumulates perceived information concerning past performances in the core business. Indeed, historical performances contribute to shape the perceived character of the organisation and are the base to formulate aspiration levels and organisational goals [Cyert & March, 1963]. In the model, the retention process is formulated by computing the weighted average of the variables *AL* and a firm's *earnings_in_core_activity* (e_c) with the time constant τ_{AL} being the weighting factor:

$$AL_t = AL_{t_0} + \int_{t_0}^{t} \dot{AL} \cdot dt \qquad (1)$$

$$\text{and } \frac{dAL}{dt} = \dot{AL} = \frac{(e_c - AL)}{\tau_{AL}}, \qquad (2)$$

where τ_{AL} is the *time_to_update_ aspiration_levels.*

The second resource-stock is the *perceived_need_to_change_strategy* (*PNCS*). Such a resource-stock embodies the tension accumulated in the organisation which leads top managers to experiment with new courses of action and, consequently, to redistribute resources in the organisation. Here, the stock-and-flow modelling language allowed to operationalise the idea that "[c]orporate management's manipulations of the structural context seemed to be guided primarily by strategic concerns at their level, reflecting emphasis on either expansion of mainstream business or diversification, depending on perceptions at different times of the prospects of current mainstream business" [Burgelman, 1983a; p:240].

Thus, *PNCS* represents the accumulation, or retention, of past information concerning the difference between *aspiration_level* (*AL*) and actual earnings in a firm's core activity (e_c). This difference, in the model, is represented by a variable called *perceived_gap_in_core_activity_performances* (pgp_c). The retention process is modelled as the weighted average between new information (value of pgp_c) and old information (value of *PNCS*). The weighting factor is the time constant τ_P (*delay_to_change_perception*) which represents the delay in search action. The time constant determines the pace of the retention process and, therefore, indicates the cognitive delays in perceiving the need to intervene in the structural context.
Again, the stock-and-flow formulation in equations 4 and 5 contributes to give life and motion to the hypothesis that strategy "…is rooted in organizational experience and learning, [and] top managers are reluctant to make frequent changes in it."[Burgelman, 1991; p:251]. Delays can be generally associated with disagreement on both the need to change the strategy and the direction which strategic reorientation should take. As Burgelman reports from Intel's exit from the DRAM business, while "… some managers sensed that the existing organizational strategy was no longer adequate […] there were competing views about what the new organizational strategy should be.". Moreover, "There was still an important group of managers who believed the DRAM's were critically important to Intel." Equation 5, for example, shows that the concept of *delay* cam be operationalised and, through simulation, consequences on organisational behaviour of delays of different size can be explored.

$$pgp_c = \frac{e_c - AL}{|AL|} \tag{3}$$

$$PNCS_t = PNCS_{t0} + \int_{t_0}^{t} \dot{PNCS} \cdot dt \tag{4}$$

$$\text{and } \frac{dPNCS}{dt} = \dot{PNCS} = \frac{(pgp_c - PNCS)}{\tau_P}, \tag{5}$$

Another area where retention can be observed deals with the evolution of a firm's structural context. The structural context of an organisation encompasses "…administrative […] and cultural […] mechanisms. Administrative mechanisms include, among others, strategic planning and control systems, approaches to measuring and rewarding managers, and rules governing resource allocation. Cultural mechanisms include, among others, socialization rituals and behavioral norms (do's and don'ts)" [Burgelman, 1991; p:244].
Focusing on the rules governing resource allocation, the analysis of Burgelman's article suggests that a firm's resource allocation pattern does not change instantaneously. Rather, the INTEL case suggests that the structural context gradually and incrementally switched resource allocation to the business that maximised margins of activity. In that case, "…important amounts of resources continued to flow to…" the core business [Burgelman, 1991; p:245].
Such an inertia might be due to the need to modify entrenched perceptions concerning activities whose track-records and historical data have been accumulated and to the political power accrued to the champions of initiatives which have a history of success in the organisation.

These considerations led to the creation of the variable *routine_resource_allocation_rule* R_r to represent the retention of accumulated information concerning past resource allocation decisions.

$$R_{r_t} = R_{r_{t_0}} + \int_{t_0}^{t} \dot{R}_r \cdot dt \qquad (6)$$

$$\text{where } \dot{R}_r = \frac{R_p - R_r}{\tau_R}. \qquad (7)$$

Therefore, the *routine_resource_allocation_rule*, (R_r) is the delayed version of the new proposed resource allocation developed on the base of actual performances of initiatives (R_o), and the routine resource allocation rule (R_r). The weighting factor, is the time constant τ_R which determines the inertia with which the allocation routine is updated.

Three steps to test and refine a theory

A major insight originated from the field-study concerns the idea that strategic and organisational change at INTEL emerged as the result of '…the way in which selection processes were allowed to work themselves out.' [Burgelman, 1991,:252] in an '…atmosphere in which strategic ideas can be freely championed…' [Burgelman, 1991,:252].
From this hypothesis it emerges that a necessary condition for firms to reorient their strategy is that top managers are able to contemporaneously create an organisational atmosphere which favour an entrepreneurial spirit and, on the other hand, and maintain the rigour of intra-organisational selection processes.
To what extent this is true? In other words, how can we isolate the effect of top management capability to stimulate autonomous experimentation from the effectiveness of resource allocation systems to select profitable initiatives? How can we test relative weights of these two effects which are deeply different in their nature?
A way to perform this test is to find similar organisations facing the same environmental shift in which we can observe different top management's capabilities combined with different types of selection processes. To find such a research setting is very difficult. Yet, simulation studies can provide a support.

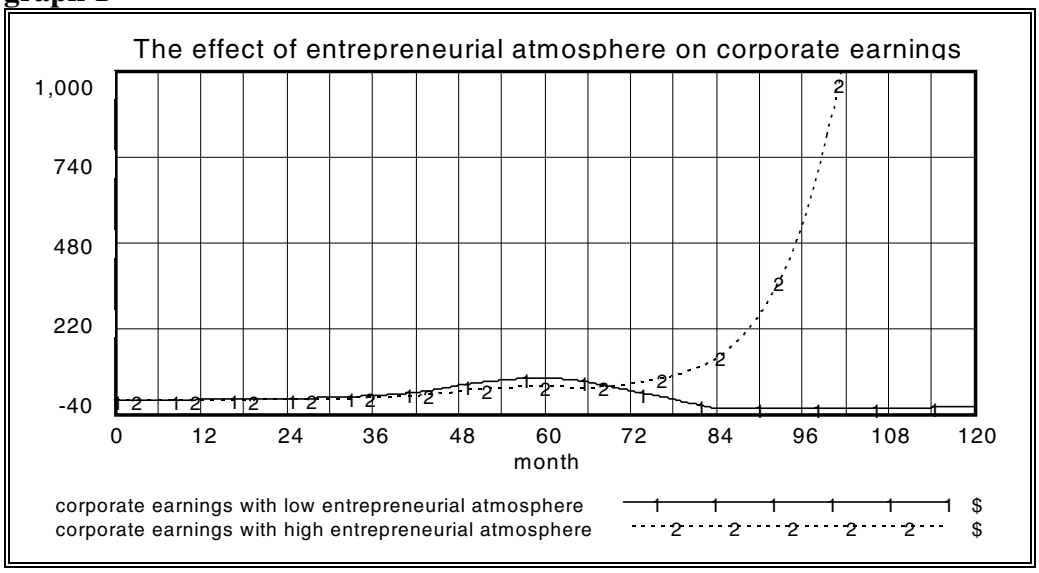
Search for necessary conditions

A way to proceed, for example, is to create a null hypothesis advocating that INTEL, or, in general, an identical firm, with theoretically perfect selection mechanisms may adapt without top management effect on corporate entrepreneurship and observe whether such an a hypothesis can be falsified. This falsification would strengthen the hypothesis that top management capability to govern corporate context by regulating organisational atmosphere is a necessary condition for a firm to survive strategic reorientation.
H_o: INTEL could have adapted to environmental shifts simply relying on a rigorous resource allocation system able to immediately recognise and favour the most profitable strategic initiative without top management intervention to facilitate birth and survival of entrepreneurial initiatives.

To set up this test, a simulation model is created which a firm crystallises the characteristics described in the INTEL case. The firm is modelled with a rigorous financially-oriented resource allocation mechanism that allocates resources to the most profitable strategic initiative. The model is run with different parameters encapsulating different managerial capability to create entrepreneurial atmosphere. To falsify the null hypothesis H_o it is necessary that, given identical environmental scenarios, the simulation experiment produces contemporaneously successful adaptation of the firm with entrepreneurial atmosphere and failure in the adaptation of the other firm.

The behaviour reported in graph 1 is obtained using a scenario reproducing a sudden drop in profitability in the industry where the simulated firm operates, and a rise of profitability in a new industry. The simulation demonstrates that the capability of top management to keep a sufficient critical mass of resources devoted to strategic experimentation is a necessary condition to maintain a window of opportunity to adapt to sudden shifts in the environment. Given a sufficiently rapid environmental shift, simulation shows that firms cannot adapt simply relying upon internal selection mechanisms which shift resources to profitable new strategic initiatives. These latter may be able to demonstrate their profitability only with a time delay when a sufficient critical mass of resource has been allocated.

graph 1



The sufficient condition

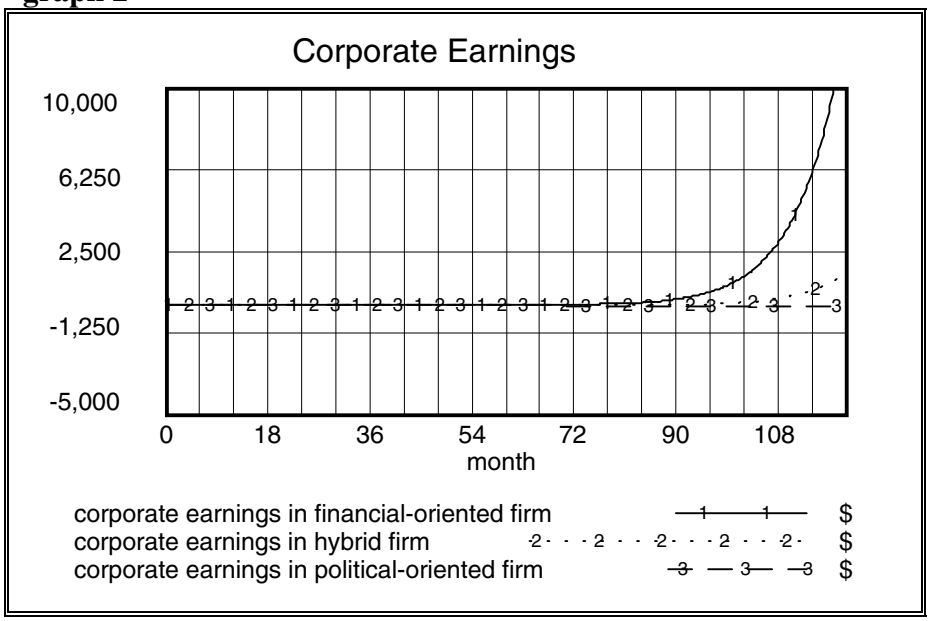
Another issue emerging in testing the power of the intra-organisational theory to explain the INTEL case is the question concerning the extent to which top management's capability to stimulate entrepreneurial atmosphere was alone a sufficient condition to assure successful adaptation. In other words, with simulation is possible to activate different historical trajectories to see whether, with different resource allocation mechanisms, INTEL would have adapted.

To explore such an hypothesis, again, it is possible to construct a null hypothesis such as:

H_o :Top management's capability to stimulate corporate entrepreneurship was a sufficient condition, independently of the characteristics of the selection mechanism, to successfully manage strategic reorientation at INTEL.

To test this hypothesis, beside the financial routine which allocates resources to the initiative which maximise margin-per-wafer, two additional resource allocation routines were modelled, to mimic selection processes with different characteristics. The objective was to re-run INTEL history and see whether, with similar environmental conditions and similar entrepreneurial atmosphere, adaptation performances change depending on the type of selection mechanism.
Thus, a second routine, named the *political rule*, assumes that accumulated political power in the organisation strongly drives resource allocation. The formulation of the *political rule* was inspired by studies of the role of power in behavioural decision-making in organisations [Pfeffer, 1981]. A third rule is named *hybrid* because merges aspects of political and financial routines. The rule simply allocates resources in proportion to the ratios of the earnings of the strategic initiatives.
Results of the simulation, reported in graph 2 falsifies H_o by clearly showing that adaptation performances dramatically changes depending on the type of structural context. The graph shows that, with identical entrepreneurial atmosphere, financial firms successfully adapt to the evolving environment; hybrid firms adapt showing much lower performances and political firms fail to adapt to the environmental change.

graph 2



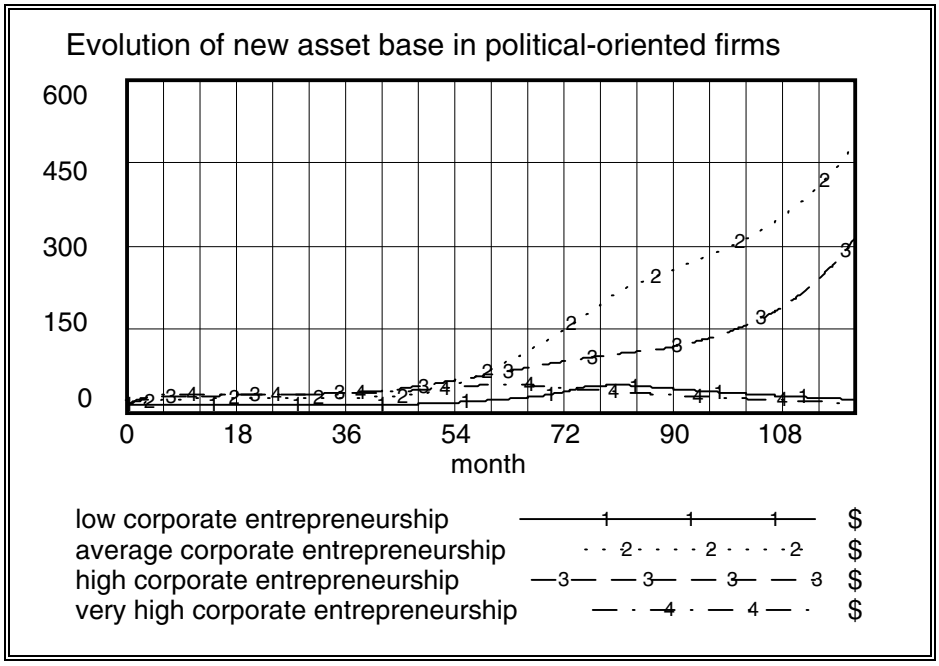
Exploring alternative futures

Another question which may arise from INTEL case concerns its normative power. Burgelman's conceptual framework explains how INTEL was able to reorient its

activity and survive an environmental shift by manoeuvring rigour in selecting strategic initiatives and corporate atmosphere. Was the INTEL case the result of luck in balancing these two dimensions? Is it possible to imagine that small differences in the morphology of its structural context or in the emphasis on internal entrepreneurship would have produced different results? In such a case, how different the situation should have been at INTEL to originate alternative histories? Is it possible to find a reliable connection among, magnitude of entrepreneurial atmosphere, morphology of structural context and organisational emerging behaviour? The problem with field studies is that it is not possible to know what would have happened if corporate atmosphere of the morphology of structural context had been slightly different; in other words, it is hard to speculate on the robustness of the theory.

Assumed that it is possible to crystallise an explanatory theoretical model into a mathematical model, a simulation study might constitute a powerful tool when coupled with a field study. Indeed, by running a simulation under different hypotheses concerning, for example, corporate atmosphere and organisational morphology it is possible to explore alternative futures and to deduce robust explanations. On these lines, it was possible to define thresholds beyond which entrepreneurial atmosphere becomes dangerous for firms' survival and to speculate on preferable associations of organisational morphologies and top management's intervention. For example, graph 3 below shows one of the test conducted on the robustness of the theoretical framework extracted from the INTEL field-study. By varying corporate entrepreneurship, in political firms, adaptation capabilities are modified. In particular, the graph shows how with computer simulation it is possible to refine the Burgelman's theory by explaining how corporate entrepreneurship positively affects adaptation and survival when constrained within a specified range.

graph 3



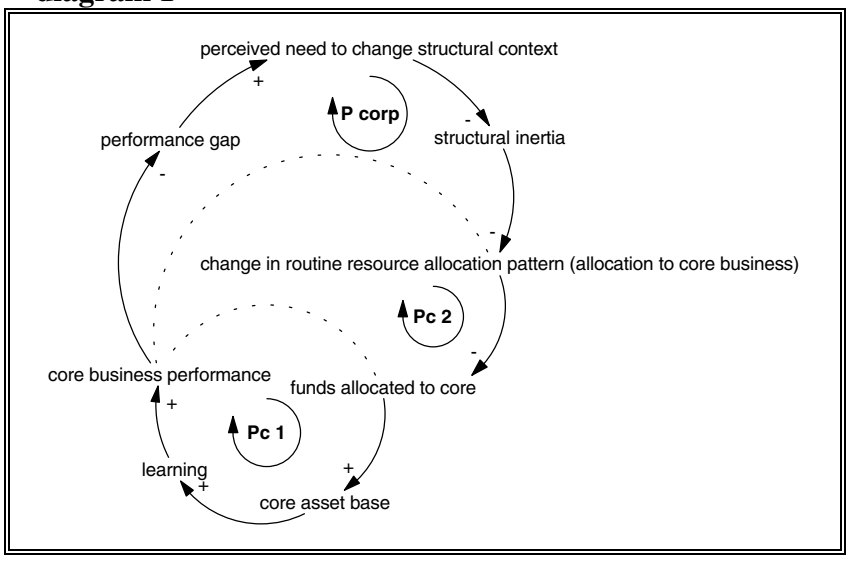
Enhance Structural Explanation with Feedback Concepts

Another way to interpret the fundamental insight emerging from Burgelman's article concerns the role of top managers in governing the interaction of variation-increasing and – decreasing mechanisms [Burgelman 1991:254]. The former stimulating the emergence of new, entrepreneurial strategic initiatives, the latter hindering the birth and development of new strategic initiatives. A question, however, emerges on how to concretise these concepts. In field-studies, in order to explore the role of variation-increasing or –decreasing mechanisms, where should we look? How to define the boundaries of the set of decisions, actions and processes which configure a variation-increasing or –decreasing mechanism?

In this case the feedback concepts provided useful tools to build hypotheses on how variation-increasing or –decreasing mechanisms moulds a firm's strategic behaviour. These mechanisms can be represented as recurring feedback structures in which a set of variables and processes are inter-nested. The dynamic behaviour of such structures and their effect on a firm's strategic behaviour can be deduced through simulation to generate hypotheses which can then be tested in the field-work.

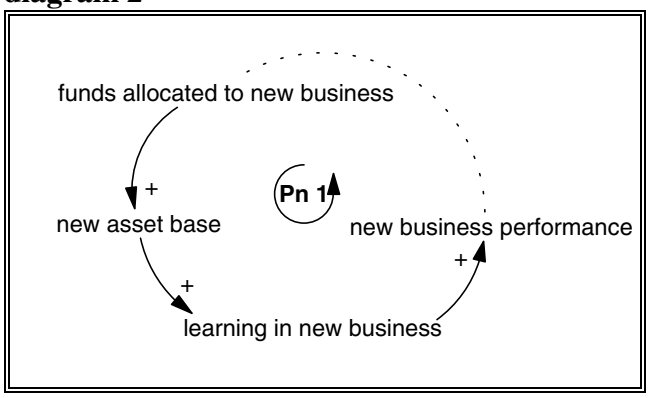
For example, in diagram 1, inertia building is explained by the feedback structure constituted by three positive feedback loops while corporate renewal is related to the power of the positive feedback in diagram 2. Different behaviours of firms in terms of inertia creation or strategic renewal can be expected by analysing the relative strength of the positive feedbacks in the two diagrams. In this case, *relative strength* is not a nebulous concept, rather it can be connected to the magnitude of the variables embedded in the feedbacks described. Looking diagrams 1 and 2, for example, the hypothesis can be tested that the degree at which people learn in the core and new activity defines the strength of positive feedback which increase respectively the power of variation-reducing and -increasing mechanisms in organisations.

diagram 1



In the INTEL case, feedback concepts facilitated the conceptualisation of the idea of variation-increasing or –decreasing mechanisms. In general, *feedback* can be considered as an *auxiliary* concepts, that links structural explanations and observed behaviours and supports field enquiry by incrementally illuminating the territory to be investigated. Simple diagrams like, for example 1 or 2, may constitute building blocks for theory building, or elementary hypotheses orienting field research.

diagram 2



CONCLUSIOSN: VALUED ADDED FROM SIMULATION

The insights gained in the process of testing Burgelman's theory, suggested a way in which simulation could support the field enquiry.

It is widely recognised that in-depth field study is a research design particularly suitable for theory building and hypothesis generation [Eisenhardt, 1989; Leonard-Barton, 1990; Yin, 1989; Noda, 1994]. However, this methodology also suffers from the limitations of a low internal validity [Leonard-Barton,1990.

Field cases are retrospective studies. Retrospective studies explain, *ex-post* how a set of variables interacted to drive, for example, the aggregate observed behaviour of an organisation. However, it could become troublesome to ascertain the extent to which the theoretical explanatory model, and the observed behaviour are linked. This difficulty is explained by the fact that retrospective studies are not particularly efficient in connecting causes and effects [Leonard-Barton, 1990].

If, for example, we are aware that two variables affect the observed behaviour, given the complex web of interactions in which these variables are embedded, it might be hard to determine their relative strengths. It might be the case that the influence of one of these two variables is insignificant, and could be omitted from the analysis to satisfy the criterion of parsimony for a good theory [Eisenhardt, 1990]. To investigate further the importance of that variable, an experiment could be run to detect what happens if the variable is omitted. Indeed, the value of experiments in theory-building has been overwhelmingly stressed [Kaplan, 1964; Yin, 1989]. But how is it possible to conduct experiments using retrospective field studies?

Conducting experiments using retrospective field research is not impossible but certainly not easy. For example, to conduct an experiment concerning the role of a variable in affecting behaviour, two identical organisations which differ only in the variable analysed would be required. Situations of this kind are not readily available. For example, some longitudinal *event* studies have compared *polar cases* - that is, cases of organisations that have shown opposite behaviours in responding to an identical exogenous stimulus-, explaining the different unfolding of their histories, starting from particular event, as the result of different initial conditions [Noda, 1994]. Still, it remains very hard to assess the relative weight of the variables in influencing behaviour, or to connect the structure of causal relationships among variables to the observed behaviour. Yet, the theoretical model arising from the field study could be captured in a simulation model. In this way, the link between the structure of causal relationships among variables, and the behaviour generated, could be effectively

explored. The validation of the simulation model entails a rigorous test for internal validity of the theory embodied in such a model.
Moreover, as previously suggested, computer models provide laboratories to conduct the experiments necessary to grind and refine the theory. For example, sensitivity analysis can be conducted to scrutinise the relative strengths of variables in influencing behaviour.
Some variables, previously regarded as important might turn out to be unimportant, while others formerly deemed inessential, might prove fundamental under certain circumstances.
Simulating the model in extreme conditions, it is possible to perform *boundary experiments* [Kaplan, 1964] to establish the robustness of the theory. Extreme conditions might include both the assumption of unusual initial values for some variables in the model, or exogenous perturbation of the model, mimicking apparently bizarre or extraordinary scenarios.
Associated with a simulation study, the field study is not more a retrospective photograph of what has happened, but rather becomes a live picture illustrating what could have happened in different circumstances. By running a simulation under various circumstances it is possible to propitiate the emergence of counterintuitive, apparently paradoxical, behaviours. Davis [1971] suggests that an hypothesis is *interesting* if it induces the revision of an established characterisation of a single phenomenon or of a relation among phenomena. The clarification of unexpected behaviours, using simulation, often gives birth to such *interesting* hypotheses.
In the foregoing it has been argued that by capturing in a simulation model the rich but static description emerging from a field research, the researcher enhances his theory-building capabilities. It is important to remark that System Dynamics-based simulation studies add another advantage to those already described. System Dynamics simulation studies not only supports the process of testing a theory by capturing in a mathematical model and simulating the theory, in addition, by connecting observed variables and explanations by the means of the concept of *feedback* provides an environment to build and test structural theories of behaviour.

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