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Representing change: a system model of organizational inertia and capabilities as dynamic accumulation processes

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Abstract

Using system dynamics models and methods, in this paper we suggest a feedback representation of the ecological theory of organizational inertia and change. The paper pursues two main objectives related to the representation and specification of organizational theories. The first is to identify and specify dynamic elements that are left implicit in the original theoretical narrative. The second objective is to explore conceptual connections between core features of ecological and evolutionary theories of organizations that are typically believed to lead to incommensurable empirical models. We perform a series of simple simulation experiments to explore the behavioral consequences of our representations and identify issues that future research on dynamics of organizations may help to clarify. The main insight offered by our model-based exploration is that organizational inertia—defined as the tendency of formal organizations to resist change—and organizational capabilities—defined as the ability of organizations to innovate and reconfigure their internal resources—should be represented as paired concepts, each understandable only in terms of the other.

Keywords: Simulation; Inertia; Organizational theory; Capabilities

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1. Introduction

Assumptions about how structural inertia and organizational capabilities jointly shape the evolutionary dynamics of corporations and other institutions are frequently taken as primitive terms in empirical studies. Limited research is available that has examined these assumptions directly by representing inertia and capabilities, and adaptation and selection, as fundamentally interdependent dynamic processes [24,29].

Ecological studies of how organizations fail to match the requirements of a changing environment, or to keep up with fundamental transformations in patterns of resource availability, typically start by assuming that organizations are relatively inert, i.e., that they can react to perceived needs for change only with delay [4]. The general objective of these studies is to discover empirical regularities in the relationship between organizational age, size, change attempts and failure within organizational populations and communities [9]. In ecological theories, individual organizations are typically identified as the fundamental units of selection [1,17].

Evolutionary studies of how organizations achieve and sustain competitive advantage emphasize the role of firm-specific capabilities and assets as determinants of organizational performance [48–51]. The general objective of the studies within this perspective is to explain how "[C]ombinations of competencies and resources can be developed, deployed and protected" by individual organizations [50, p. 510]. According to evolutionary perspectives on organizational change and learning, organizations are only carriers of competencies that are embedded in specific routines [1]. Therefore routines—rather than entire organizations—are considered as the appropriate units of selection [29,30,35].

Although the core concerns addressed by these mutually contentious perspectives on organizations are different, we believe there are also areas of substantial overlap that could be usefully explored. Perhaps the most obvious example of such overlap relates to the role played by routines in organizational evolution, performance and survival. In ecological theories, routines are never represented explicitly, and are frequently treated as an epiphenomenon of organizational aging processes [16]. In such theories routines enter the picture indirectly through their stabilizing effect on organizational structure and their implications for reliability and accountability—two prime indicators of organizational performance [17,18]. In evolutionary theories, however, routines are essentially a set of organizational capabilities—a body of knowledge about how to do things. In an evolutionary perspective, routines are seen as the "[B]uilding blocks of organizational capabilities" [52, p. 148], and therefore as fundamental sources of competitive advantage.

According to ecological theories of organizations, successful reproducibility of structure and routinization of action make organizations reliable, progressively less attentive to change opportunities, and less responsive to change attempts [4,17]. According to evolutionary theories, on the other hand, replication and routinization of successful courses of action induce processes of resource accumulation, competence building and learning [35,40].

Given these unresolved contrasts, a series of fundamental questions remain unanswered about the structural conditions under which successful resource accumulation strategies generate organizational inertia, induce core rigidities, or create dynamic capabilities [11,12,23,33].

Against the background of this general discussion, in this paper we try to develop specific connections between processes of accumulation of organizational capabilities and organizational inertia in the context of a feedback representation of a model of change inspired by ecological theories of organizations. We take the theory of structural inertia proposed by Hannan and Freeman [18] as our starting point to develop a dynamic feedback model of organizational inertia and change. We use system dynamics (SD) methods to simulate the model, test its internal consistency, and explore the full dynamic implications of a theory that relates the dynamics of organizational inertia to the accumulation of organizational capabilities.

In the paper we pursue two main objectives, both related to the representation of processes of organizational change rather than to their direct analysis. The first is to identify and represent dynamic elements that are left implicit in the original theory of structural inertia. The second objective is to explore conceptual connections between core features of ecological and evolutionary theories of organizations that are typically believed to lead to incommensurable empirical models. While not an explicit objective, the paper can also be taken as an illustration of the value of SD models and simulation methods for building theories in the context of a central debate in current organizational research. More specifically, the paper could be viewed as a contribution to the small but growing literature on the simulation of second-order models in organization science [26,42,45,46,53]. First-order models are specifications of empirical processes developed for the main purpose of theory-testing. Second-order models, of the kind discussed in this paper, are abstract representations based on a plausible reconstruction (or integration) of an underlying theoretical narrative, as an aid to the process of theory-building [5,16,19,26–28,32,37,43].

2. Theories and models

2.1. A feedback perspective on organizational inertia and change

Starting from the notion of organizations as change-resistant complex systems for which structural change is at least as risky as inaction, the theory of structural inertia originally proposed by Hannan and Freeman [18], provides a well-structured framework for modeling processes of organizational change. The theory identifies reliability and accountability as the primary sources of survival advantage for modern complex organizations. Reliability means that organizations are rewarded for reducing the variability of the products or services supplied, and for fulfilling customers' expectations in terms of quality, timing and prices. Accountability means that organizations are rewarded for their ability to document how their resources are allocated, and for convincing members, investors and clients of the procedural rationality of the decisions behind specific outcomes. Reliability and accountability are high when organizational goals are institutionalized and activities routinized, but institutionalization and routinization also generate inertial pressures because they encourage replication and exploitation of existing competencies [17].

According to Hannan and Freeman [18] structural inertia is not constant over the organizational life-course, but varies systematically with age and size. Specifically, organizational reliability and accountability are assumed to increase monotonically with size and age. Given that resistance to change also moves in the same direction of reliability and accountability over time, it follows that the probability of change decreases as organizations grow older and—presumably—bigger. Fig. 1, taken from Kelly and Amburgey [21], illustrates the basic logic behind the original theory of structural inertia.

The theory of structural inertia can be seen as a dynamic theory with multiple feedback loops that are both explicit as well as implicit in the original formulation. On the one hand, the presence of multiple feedbacks is fully consistent with the process view of organizational change underlying the theory but, on the other hand, the sequential version of the model used in empirical studies (and summarized in Fig. 1) does not adequately capture the complexity of the relationship between organizational inertia, change and survival implied by the theory.

The causal loop diagram in Fig. 2 connects three of the central concepts in the theory of structural inertia: inertia, performance reliability and change attempts. Inertia affects change attempts negatively. Change attempts decrease reliability because they disrupt established systems of roles and routines, and induce changes in the structure of external networks in which organizations are embedded [2].

Finally, due to the high degree of replicability and routinization needed to stabilize performance over time [17], reliability increases organizational inertia. In keeping with the theory, this first loop implies that a positive feedback process is at work to increase the level of organizational inertia over time. This is indicated by the "+" symbol placed in the center of the circle diagram. According to the theory, structural inertia reduces the number of change attempts, and this will result in higher reliability, i.e., improved ability to reproduce past behavior. But reproducibility induces further increases in inertia. The dynamic behavior generated by the positive feedback process represented by this first loop is exponential growth.

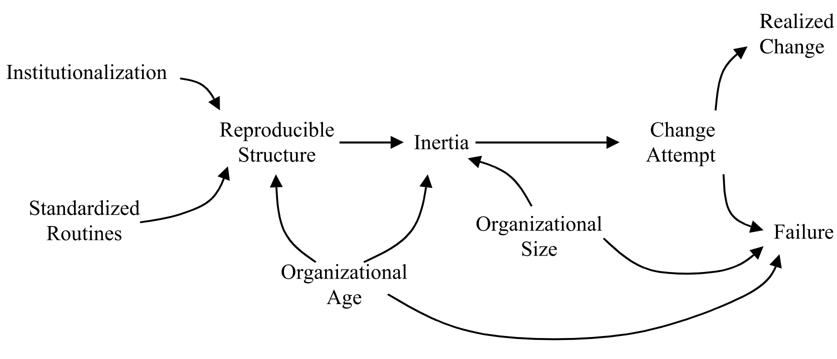


Fig. 1. The ecological model of organizational inertia and change (adapted from [21]).

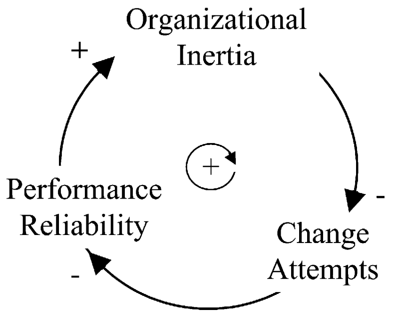


Fig. 2. Accumulation of inertia as a positive feedback process (reinforcing loop).

What are the limiting factors that prevent organizational inertia from increasing indefinitely as organizations grow larger and older? It is not easy to find an explicit answer to this question in the ecological literature on organizational change, according to which inertia apparently tends to grow indefinitely. The causal loop diagram reported in Fig. 3 illustrates a negative feedback process that may possibly limit the accumulation of structural inertia over time. According to the diagram, as inertia increases the likelihood of successful change becomes smaller. In turn, prolonged periods of stasis increase the pressure for change in the organization. As pressure for change increases, it is reasonable to expect that at least some new change attempts will be made. According to the theory, repeated attempts at changing organizational structures and processes decrease reliability and reset the internal organizational "age clock". The negative feedback behind this balancing process is represented by the "−" symbol placed in the center of the corresponding circle diagram.

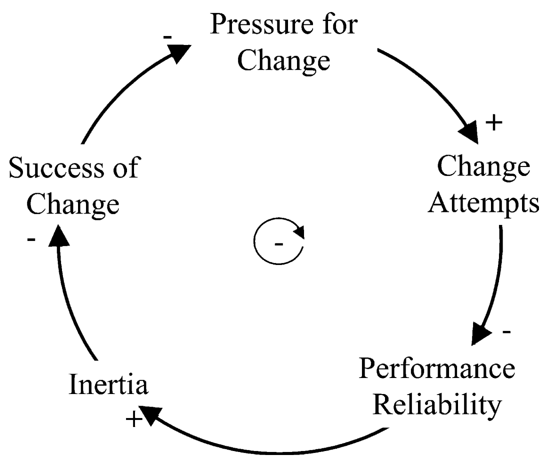


Fig. 3. Change as a negative feedback process (balancing loop).

2.2. The evolutionary dynamics of routines and capabilities

In its original formulation, and as we have represented it, the theory of structural inertia has two main counter-intuitive implications. The first is that the same processes that give organizations a survival advantage also make them more resistant to change. It follows that selection tends to favor organizations that are relatively inert, i.e., whose structure is reproducible through appropriate action routines. This conclusion is clearly at odds with the suggestions offered by textbook views of organizational change according to which flexibility—rather than inertia—is the key to organizational performance and long-term survival. The second implication is that organizational change is risky in and for itself because it disrupts the routines in which organizational memory and competencies are stored [35], and calls into question the (internal and external) bases of institutionalization and legitimation [17,47]. As a consequence, organizations in the process of fundamental transformation are "between a rock and a hard place" in the sense that change processes may increase organizational failure rates independent of their content, i.e., of whatever organizational characteristics are being changed [2,20]. To the extent that young organizations are exposed to a "liability of newness"—the tendency of organizational failure rates to be higher in the early stages of organizational life and to decline with age [14]—major structural changes imply that established organizations may once again be exposed to the risks of failure that are typical of young organizations. For example, as major change episodes occur, the organization may once again experience the need to establish a framework of trust within which strangers can cooperate and agree on the appropriate sanctions for opportunistic behavior, and suffer once again from the lack of agreed-upon solutions to routine problems [47]. In this sense, organizational change is said to "reset the clock" that regulates the vital dynamics of individual organizations and increase—at least temporarily, the hazards of failure [2,47].

These fundamental insights offered by the ecological theory of structural inertia identify routines as central elements of organizational structure without defining them explicitly. But what exactly are "routines"? In the words of Levitt and March, routines can be defined broadly as: "[T]he forms, rules, procedures and conventions, strategies and technologies around which organizations are constructed and through which they operate" [25, p. 320]. Therefore the notion of routine represents an important opportunity for linking ecological and evolutionary theories of organizational change. In ecological theories, routines are frequently discussed as sources of structural inertia [17, p. 76], but their dynamics are never explicitly represented. In particular, by emphasizing routines as the basis of structural reproducibility, ecological theories of organizations seem to give insufficient attention to the fact that routines are also the building blocks of organizational capabilities [52]. But where do routines come from and how are they related to capabilities? In the words of Dosi et al. [12, p. 2]: "To be capable of something is to have a generally reliable capacity to bring that thing about as a result of intended action. Capabilities fill the gap between intention and outcome". In our view, this notion of "reliable capacity" is exactly what links organizational capabilities to routines, and hence to organizational inertia.

In an evolutionary perspective, variations are introduced when performance fails to meet expectations or performance goals [1]. A gap between expected and actual performance triggers processes of exploration [29] and problemistic search [10]. When this happens, the pressure for change in organizations increases. Pressure for change introduces variations though change attempts. Unsuccessful variations are selected out. Successful variations are retained and are, more or less, slowly turned into performance programs—or routines—that can be invoked when needed [31,35]. Capabilities emerge out of the repeated execution of routines—or performance programs [35,50]. How rapidly (or slowly) processes of learning convert routines into capabilities depends on organizational inertia. The feedback process implied by this narrative is summarized in Fig. 4.

This representation allows us to relate structural inertia—defined as the tendency of organizations to resist change—and the ability of organizations to evolve new capabilities through the iteration of successful performance programs. As Fig. 5

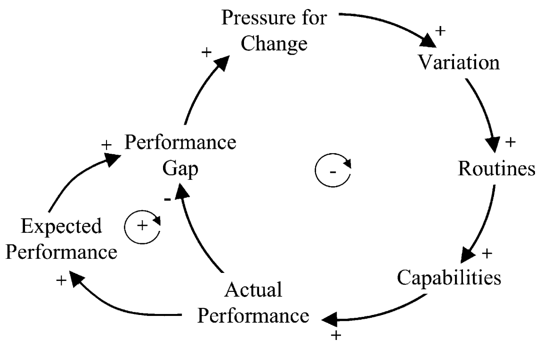


Fig. 4. The feedback structure of organizational capabilities and performance.

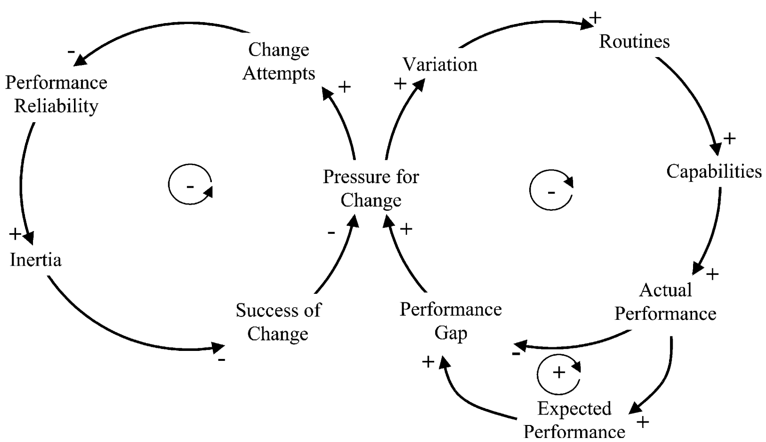


Fig. 5. Inertia and capabilities as coupled feedback loops.

illustrates, pressure for change provides the conceptual link between structural inertia and the evolution of new capabilities.

2.3. Model structure

In this section we present a formal reconstruction that integrates some of the main ideas of ecological and evolutionary theories of organization. The resulting model allows us to represent the connection between—and in fact the duality of evolutionary processes of learning and capability formation, and the accumulation of structural inertia in organizations. In the model-building process we emphasize the generic structural elements that are present in the theoretical narrative, as opposed to elements that are idiosyncratic to specific organizational and institutional contexts—and that can be understood only through systematic comparative research.

The model consists of three interdependent macro-sectors as summarized in Fig. 6. In keeping with the original formulation of the theory, the *organizational inertia* sector models resistance to change as a function of organizational size, age, capabilities and an organization-specific threshold for change. The *organizational performance and change* sector models the relation between performance (defined in terms of desired levels of organizational reliability) capabilities, and managerial change attempts. Finally, the *organizational capabilities* sector tracks the dynamics of routines represented as a three-stage evolutionary mechanism of variation, selec-

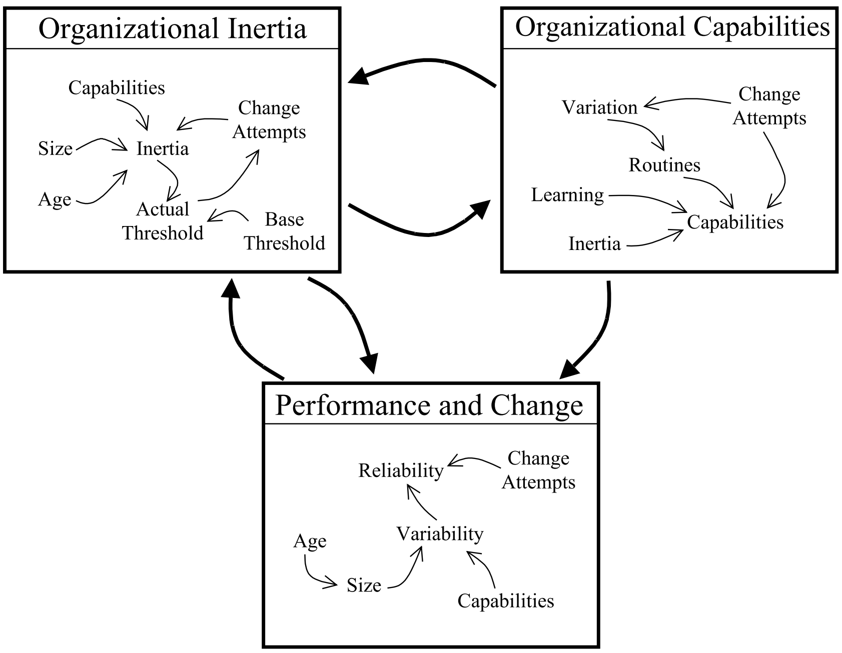


Fig. 6. Macro-sectors of the model.

tion and retention. Change attempts produce variations that are converted into performance programs through a selection mechanism. The iteration of performance programs converts routines into capabilities through a process of learning. By reducing the rate of learning, organizational inertia slows down the formation of new capabilities, which in turn affects performance.

After this general overview, we are now ready to represent the micro-structure of the model. In the remainder of this section, we try to do so by presenting theoretical foundations and evidence for the hypothesized micro-structural relations with each model equation. Our strategy is to keep notation as much as possible intuitive with the development of a minimal amount of formalism. The discussion is organized around the three macro-sectors of the model identified above.

Representing organizational inertia. We represent structural inertia (I) as a stock (or accumulator) variable that integrates the corresponding net flow, defined as the difference between increase in inertia ($I^{(+)}$) and decrease in inertia ($I^{(-)}$).

$$I_t = \int_{t_0}^{t} \left[I^{(+)}(s) - I^{(-)}(s)\right] \mathrm{d}s + I(t_0) \tag{1}$$

Following the original formulation of the theory [18], structural inertia is affected by organizational age, size (S) and experience (C). To represent these concepts we specify functional relations (which might be linear or nonlinear) between increase in inertia, age, size and capabilities: [2]

$$I_t^{(+)} = I_t * f_1(S_t) * f_2(\text{age}) * f_3(C_t) + \mu \tag{2}$$

where the functional relations f_1, f_2, f_3, specify the effect of size, age and capabilities, respectively, on the increase in inertia (as described in Appendix A). Finally, we assume that inertia will increase by a small amount (μ) every year, regardless of the effects of the three constructs mentioned above.

We assume that change attempts are intendedly adaptive and have the basic objective of decreasing structural inertia, i.e., making the organization more responsive to changes in whatever area management considers relevant. In practice this goal may or may not be achieved depending on how effective the change attempts are. We model decrease in inertia as a random variable which represents how successful a change attempt is in reducing inertia. When a change attempt is initiated, the random variable determines how much inertia decreases. This might range from zero (i.e., change attempts have no implications for inertia) to a significant decrease in the current level of inertia. The decrease in inertia is specified as:

$$I_t^{(-)} = \begin{cases} 0 & \text{if } \mathrm{CA}_t \leqslant 0 \\ I_t \ * \pi & \text{if } \mathrm{CA}_t > 0 \end{cases} \tag{3}$$

[2] Note that we are simulating a continuous model and not a discrete model. We use a standard fourth-order Runge–Kutta integration method which allows us to specify the model in the way it is presented here. In a discrete model the equations here would be simultaneous, however, that is not the case in a continuous model.

where CA is a change attempt made by the organization and π is the stochastic variable determining the actual effect of the change attempt on the level of inertia. This formulation makes the decrease of inertia a function of the level of organizational inertia present when change attempts are initiated.

Change attempts (CA) are triggered by the accumulation of the pressure for change (PC). When the pressure for change becomes bigger than the actual threshold (AT), change attempts will be observed (i.e., CA takes on a value of 1). Therefore

$$\mathrm{CA}_t = \begin{cases} 0 & \text{if } \mathrm{PC}_t < \mathrm{AT}_t \\ 1 & \text{if } \mathrm{PC}_t \geqslant \mathrm{AT}_t \end{cases} \tag{4}$$

The actual threshold for change (AT) is a function of a baseline threshold (BT) level and the level of inertia in the organization.

$$\mathrm{AT}_t = \mathrm{BT}_t * f_4(I_t) \tag{5}$$

the BT can be interpreted as the minimum level that pressure for change (PC) must reach in order to trigger change attempts. As inertia increases, the threshold for change also increases because the organization becomes more resistant to change. Pressure for change cumulates over time as the actual level of performance diverges from the expected level of performance expressed in terms of reliability. Change attempts then diminish the pressure for change that is represented as:

$$\mathrm{PC}_t = \int_{t_0}^{t} \left[\mathrm{PC}^{(+)}(s) - \mathrm{PC}^{(-)}(s)\right]\mathrm{d}s + \mathrm{PC}(t_0) \tag{6}$$

where $\mathrm{PC}^{(+)}$ stands for "increase in pressure for change" and $\mathrm{PC}^{(-)}$ stands for "decrease in pressure for change". The increase in pressure for change is modeled as a function of expected reliability (ER) and reliability (R) (see definition below). We assume pressure for change increases as a function of the gap between expected reliability and reliability. Any difference between the expected and actual reliability will accumulate into additional units in pressure for change. Of course, if actual performance is better than expected, then no additional pressure for change is recorded. This is captured by the Max operator, included in following equation:

$$\mathrm{PC}_t^{(+)} = \mathrm{Max}(0, \mathrm{ER}_t - R_t) \tag{7}$$

Decrease in pressure for change ($\mathrm{PC}^{(-)}$) is formulated in the same way as decrease in inertia ($I^{(-)}$). If change attempts take, pressure for change decreases. The actual magnitude of this decrease is a function of how successful the change attempt is, and this is captured by the random component ζ included in the equation that regulates the decrease in pressure for change:

$$\mathrm{PC}_t^{(-)} = \begin{cases} 0 & \text{if } \mathrm{CA}_t \leqslant 0 \\ \mathrm{PC}_t * \zeta & \text{if } \mathrm{CA}_t > 0 \end{cases} \tag{8}$$

Representing organizational performance and change. Reliability is a complex construct, presented in the original formulation of the theory as the joint consequences of routinization, formalization, and institutionalization [18]. To represent the concept of reliability more directly, we simply model it as the inverse of variability, which itself is a function of the organizations capabilities (C) and organizational size (OS), plus an exogenous baseline variability level that is always present in organizations.

$$R_t = \int_{t_0}^{t} \left[R^{(+)}(s) - R^{(-)}(s)\right] \mathrm{d}s + R(t_0) \tag{9}$$

where $R^{(+)}$ (increase in reliability) and $R^{(-)}$ (decrease in reliability) are, respectively, the inflow and outflow whose net effect is integrated in the stock "reliability".

As the organization grows older, gains experience and becomes larger, the initial variability in production activities, quality and administrative behavior decreases due to routinization and learning. Increase in reliability is given as:

$$R_t^{(+)} = \frac{1}{v_t} - R_t \tag{10}$$

where v represents "organizational variability", in terms of products, quality and routines. In Eq. (10), v is defined in the following way:

$$v = BV * f_5(\text{size}) * f_6(C) \tag{11}$$

where BV is the baseline variability, corresponding to a normal level of variability. The two functions f_4 and f_5 represent the influences of size and capabilities respectively on variability (see Appendix A for the necessary details).

The decrease in reliability is defined as a threshold function, in the same spirit of Eqs. (4) and (8), and therefore as:

$$R_t^{(-)} = \begin{cases} 0 & \text{if } \mathrm{CA}_t < \phi \\ R_t * \lambda & \text{if } \mathrm{CA}_t \geqslant \varphi \end{cases} \tag{12}$$

where ϕ is the threshold variable that determines the point above which change attempts begin to decrease organizational reliability. Another constant (λ) controls the actual decrease in reliability.

Empirical studies have documented a systematic connection between organizational size and age. In keeping with the original theory we define organizational size as a monotonically increasing function of age [18]. However, we allow for a wide range of different assumptions about the functional form of the relationship, which could be formalized to capture specific effects related to processes of organizational learning. Size is therefore:

$$S(t) = \int_{t_0}^{t} [S(s) * f_7(s)] \mathrm{d}s + S(t_0) \tag{13}$$

We formulate expected reliability (ER) as a function of reliability. The reason is that reliability improves faster through the early periods where there is relatively little accumulated experience. How much the expected improvement in reliability will be depends on a trend observed from previous periods and on an explicit managerial goal. We model expected reliability in the following way:

$$\mathrm{ER}_t = R_t + \mathrm{TR}_t + \mathrm{SR}_t \tag{14}$$

where R is reliability, TR is the trend in reliability and SR the "stretch" in reliability (representing the managerial goal). The trend in reliability is formulated as a first-order exponential smoothing of reliability, so that a heavier weight is put on the most recent improvements in reliability. This formulation is similar to an adaptive expectations mechanism, so that:

$$\mathrm{TR} = R_t \frac{R_t - \mathrm{AR}_t}{\mathrm{AR}_t * \tau} \tag{15}$$

$$\mathrm{AR}(t) = \int_{t_0}^{t} \left[\frac{R(s) - \mathrm{AR}(s)}{\tau} \right] \mathrm{d}s + \mathrm{AR}(t_0) \tag{16}$$

where AR is the average reliability and τ is the time over which the trend is observed. The stretch in reliability can be seen as a proxy for the expectations of a steady increase in performance from period to period. In practice, the magnitude of the stretch may be influenced by a number of factors related—for example—to the opinion of investment analysts, expectations of stockholders, and the structure of managerial incentives. Here we model stretch in reliability simply as a fractional improvement over the level of reliability in the previous years, in the following way:

$$\mathrm{SR}_t = R_t * \sigma \tag{17}$$

where σ is the fraction of yearly improvement.

Representing organizational capabilities. Capabilities (C) accumulate over time from two main sources, routines that become institutionalized, and repeated use of existing capabilities. Capabilities are lost during reorganization and change. This can be formalized in the following way:

$$C_t = \int_{t_0}^{t} [\mathrm{LR}(s) - \mathrm{EC}(s)] \mathrm{d}s + C(t_0) \tag{18}$$

where LR is the learning rate and EC is the decrease in capabilities. The erosion in capabilities can be represented as:

$$\mathrm{EC}_t = \begin{cases} 0 & \text{if } \mathrm{CA}_t < \psi \\ C_t\omega & \text{if } \mathrm{CA}_t \geqslant \psi \end{cases} \tag{19}$$

where CA denotes the change attempts described above, ω and ψ are constants that control the level of decrease in capabilities caused by a major change attempt, and the size of the change attempt that is needed before any decrease in capabilities takes place.

The learning rate (LR) is influenced by the number of routines currently in use. The greater is the number of routines in use, the larger is the pool of potential capabilities. How fast potential routines can be turned into capabilities depends on the level of inertia. The higher is the level of organizational inertia, the slower is the creation of new capabilities. An organization with low inertia will be faster to turn routines into new capabilities so that

$$\mathrm{LR}_t = \frac{\mathrm{NR}_t}{I_t} \tag{20}$$

where NR represents new routines, and I is inertia as described previously. The dynamics of routines is regulated by a basic evolutionary mechanism. New routines are viewed as variations, some of which will be selected out and some of which will be retained and converted into capabilities in the following way:

$$\mathrm{NR}_t = \int_{t_0}^{t} [\mathrm{RR}(s) - \mathrm{LR}(s)]\mathrm{d}s + \mathrm{NR}(t_0) \tag{21}$$

where RR is the retention rate and LR is the learning rate. The retention rate is given as the fraction of new practices (routines) that are not selected out, and is expressed as:

$$\mathrm{RR}_t = \frac{V_t \beta}{\delta} \tag{22}$$

where V is variation, β is the fraction of the variation converted into routines, and δ is the time it takes to select and convert variation into new routines. "Variation" originates from the new practices and experiments introduced in the organization and is described as:

$$V_t = \int_{t_0}^{t} [\mathrm{EP}(s) - \mathrm{RR}(s) - \mathrm{VSO}(s)]\mathrm{d}s + V(t_0) \tag{23}$$

where EP is the amount of exploration going on in one time period, VSO is variation selected out, i.e. not adopted by the organization, and RR is the retention rate defined before. The amount of variation selected out is a fraction of the total variation so that:

$$\mathrm{VSO}_t = \frac{V_t(1-\beta)}{\delta} \tag{24}$$

where—as defined earlier—δ is the time necessary to form an opinion about the adaptive value of a new variation. The fraction of variation selected out is the part not adopted by the organization $(1-\beta)$. Finally, exploration (EP) is defined as

$$\mathrm{EP}_t = \mathrm{CA}_t \alpha \tag{25}$$

The amount of exploration depends on change attempts. A change attempt will trigger activities of exploration for new ways of doing things. This activity will eventually produce new routines though variations (V). The amount of new variation that a change attempt generates depends on a random element α.

3. Methods

3.1. Simulating organization theories

In this paper we explore some of the implications of our qualitative arguments using computer simulation. A number of claims may be made about the value of computer-based simulation for understanding the dynamics of organizational and social systems [19,26]. Perhaps the strongest of these claims is that simulation models can be used for theory discovery and hypothesis generation [8,41]. The specific advantages of model-driven experimentation is the possibility of examining the dynamics of a system of interconnected statements and to study its long-term implications in terms of the phenomena of interest.

An effective way of using computer simulation as an aid to qualitative reasoning is by designing and running a series of virtual experiments. A virtual experiment is an experiment in which a simulation model is used as the observation-generating mechanism. When standard principles of good experimental design are followed and all the model assumptions are made sufficiently explicit, a useful way of interpreting the findings of a series of virtual experiments is as a set of testable hypotheses and conjectures that are consistent with the underlying process being modeled. These hypotheses can then be examined using data from actual experiments, quasi-experiments, field studies, or archival sources [41].

3.2. Numerical values, functional forms and auxiliary assumptions

To set the models in motion and to make the simulation results easily replicable, we need to assign numerical values to all the parameters, initialize all the state variables, and select appropriate forms for those functional relations about which there is no clear theoretical indication. As we point out in the next section, the model that we derived is a model of a theory rather than a model of an empirical process. As a consequence we cannot rely on historical figures for model initialization and calibration. This does not mean—of course—that numerical values can be chosen randomly. Dimensional consistency of the model requires that the range of possible numerical values that we can assign to variables becomes progressively smaller as the model increases in size (i.e., as we add more structural equations). In Appendix B we list all the values of the constants, and initial values of the stocks that we used to simulate the model. Appendix B also provides additional information on the probability distributions that we used for random number generation. The set of values that we report represents one among the (possibly) many that satisfy dimensional consistency criteria.

The theory of structural inertia is our main source of assumptions for the shape of structural relations. Unfortunately the theory does not specify all the necessary relations and—frequently—simply assumes linear relations. Hence we had to add assumptions where the theory would not provide sufficient details. As we mentioned, the numeric values of these qualitative relations have to be calibrated so that they are consistent with the other numeric values in the model. Of course, many other functional relationships could be possible, and one of the arguments in favor of our modeling effort is that by using the graphical converters reported in Appendix A, we are able to provide a well-structured context for a detailed, and relatively straightforward, sensitivity analysis exercise that may be performed in a future study.

The results that we report are obtained by numerical integration using the fourth-order Runge–Kutta method with a fixed step, as implemented in *Powersim 2.5*—a software package designed for SD simulation [39]. The same software was also used to define the stochastic components of the models via internal random-number generation. After verifying that our models are reasonably insensitive to the choice of integration method and simulation step—and in order to keep numerical integration errors sufficiently small—we selected a relatively small simulation time-step ($\mathrm{d}t = 0.125$).

3.3. Validation and interpretation of second-order models

As we have mentioned, in this paper we are building a "second-order model", that is a *model of a theoretical narrative*, rather than a *model of a historically determined process*. Our models face validation problems that are similar to those faced by the logical reconstruction models of Péli [36], and relatively distant from those faced by the "history friendly models" of Malerba et al. [28]. The quality and validity of second-order models depend more on the type of questions that they make possible and the quality of inquiry they promote, than on the answers they provide or their ability to track historical data [44]. As a consequence conventional statistical approaches to validity are not directly applicable to second-order models [22,45]. More sophisticated approaches to validation that seek to establish multiple points of contact between the model and the real system [13] are likely to be similarly unsatisfying when the 'real system' takes the form of a complex theoretical narrative. Because second-order models invariably require changes in the formal constraints on the description language used to express a theoretical narrative [32,37,38], model validation in these cases is typically accomplished on a "link-by-link" basis, by checking the formal and substantial correspondence between different symbolic representations and the underlying theoretical narrative [46]. When correspondences cannot be uniquely determined, detailed partial model testing [34] or symbolic representations that allow nonmonotonic arguments [38] become necessary. After addressing these basic concerns of internal validity and correspondence between a theoretical narrative and its reconstruction, the validation process of a second-order model does not differ much from that of any other kind of empirical model [26,32]. Specifically, a second-order model should be evaluated on the basis of the clarity of its stated purposes and its comparability to models suggested by alternative theories [7,15].

4. Model behavior and analysis

Fig. 7 shows the simulation results of the baseline model. In Fig. 7a we can observe how Inertia is slowly building up over time. Small fluctuations in inertia correspond to marginally successful change attempts, originated by increases in the pressure for change. Fig. 7b shows the behavior of both the pressure for change, as well as the actual threshold for change. Change attempts (the solid line in Fig. 7b) are triggered when pressure for change reaches the critical threshold for change (the dotted line in Fig. 7b). The direct effect of a change attempt is to release some pressure and to reduce the level of the stock pressure for change. How often change

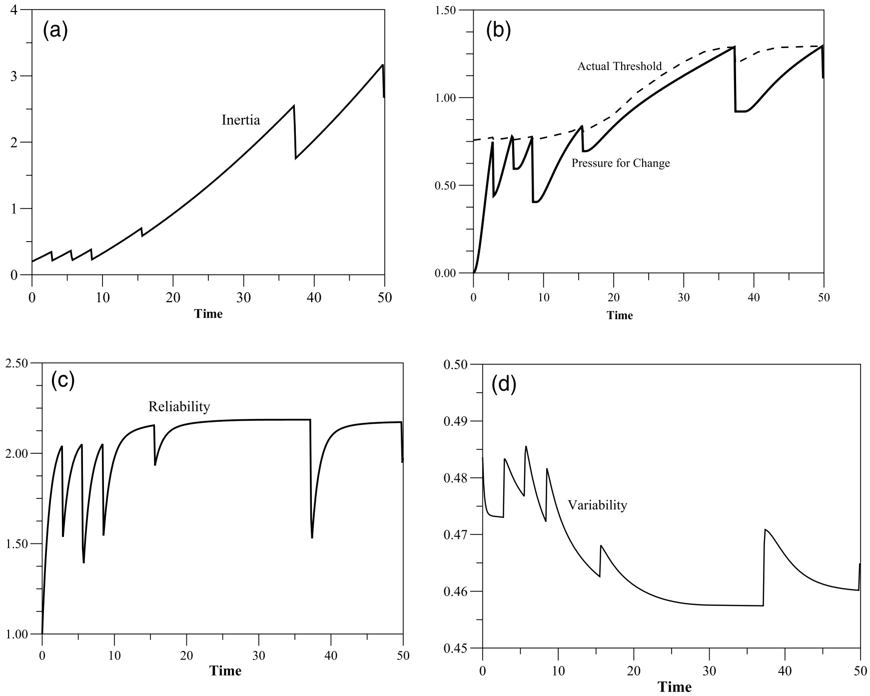


Fig. 7. Base line runs.

attempts take place—or if indeed they take place at all—depends on the speed of accumulation of pressure for change relative to the increase in the actual threshold for change. The actual threshold is mainly driven by the accumulation of inertia and the value of the BT.

When inertia accumulates faster than pressure for change, no change attempts take place. On the other hand, if pressure for change accumulates faster than inertia, change will gain momentum and there will be a constant stream of change attempts. As one would expect, in Fig. 7c we can observe that each change attempt is also causing a decline in reliability. The increase in reliability is mainly driven by changes in variability as specified in Eq. (10). Fig. 7d shows how variability changes over time as a consequence of the various interruptions caused by change attempts. Overall, Fig. 7 illustrates the dynamic interdependence of reliability and inertia in organizations.

Fig. 8 illustrates the initial building up of capabilities and the associated accumulation of variations and routines—the main drivers of organizational capabilities. Starting from Fig. 8a we can observe how, as change attempts disrupt the normal working routines, the organization begins an exploration process leading to an accumulation of a number of possible new variations (i.e., alternative ways of doing things). The amount of variation induced by an individual change attempt, depends on the value assumed by the random variable α in Eq. (25). Some of the variation will be selected out. The remaining variation will be converted into new routines, as we

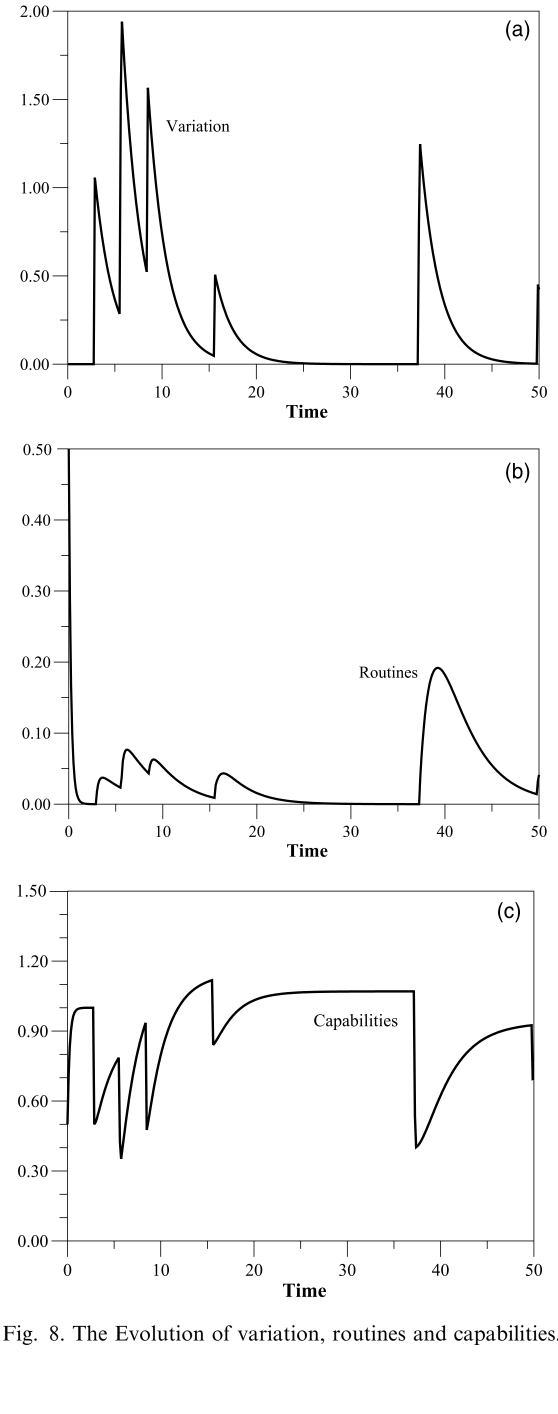


Fig. 8. The Evolution of variation, routines and capabilities.

can observe in Fig. 8b. Over time, routines will then be converted into new capabilities. The speed of the conversion of routines into capabilities is determined by the level of organizational inertia. The more inert the organization is, the slower the conversion of routines into capabilities is likely to be. This also implies that at times where change attempts take place (and succeed in reducing the level of organizational inertia) there will be a greater chance of new capabilities being established (as we can observe in Fig. 8c). But capabilities are also lost following change attempts. Fig. 8c shows how a sharp drop in capabilities is followed by a relatively slower process of reconstruction. The accumulation of new capabilities is rapid at first, but as inertia increases and the set of possible new routines is reduced, the rate of increase slows down, until it stops, causing organizational capabilities to stabilize.

Fig. 9 shows the evolution of the model over a longer period of time. We can observe how inertia increases and then begins to fluctuate between 2 and 6 (Fig. 9a). As we might expect, inertia accumulates in the first stage of the process (until around time $= 100$) interrupted only by minor change attempts (manifesting themselves as small declines in inertia). After the first 100 time periods and until the end (time $= 200$) we can observe three major change attempts which drive down inertia significantly, as well as a number of smaller—less successful—change attempts with little or no effect on the accumulation of inertia. However, due to the size and age of the organization, inertia builds up relatively fast after a decline. In Fig. 9b, change attempts are clearly detectable in the decrease in capabilities. There are periods in which there appears to be a stable set of capabilities developing in the organization (e.g., from time $= 15$–40) interrupted by periods characterized by abrupt change. This process/behavior has many characteristics in common with the punctuated equilibrium model of organizational change [43]. How long the stable intervals are is determined by the interaction between Pressure for change, inertia and capabilities as we can observe in Fig. 10.

To probe further the connection between inertia and capabilities, we ran a number of simulations where we varied the BT, i.e., the constant that acts as a multiplier of inertia to generate the actual threshold for change. If this constant is relatively small, pressure for change accumulates relatively fast and change attempt will be observed earlier in the process. By the same reasoning, if the BT is relatively large it will take longer for pressure to cumulate and generate change attempts. The only difference in the simulations in Fig. 10 is the level of the BT (and the results can be compared to the base case in Figs. 7–9, where BT $= 1.00$).

As expected in the case of BT $= 0.25$ (in Fig. 10) we see that the level of inertia is very low throughout the entire period, with a high number of change attempts taking place (as illustrated by the decrease in inertia). This is also reflected in the evolution of capabilities in the corresponding panel of Fig. 10. Capabilities are fluctuating widely over the period because an organization with no inertia is unable to maintain a constant set of capabilities.

As we increase BT to 0.75 we can observe a modest amount of inertia accumulating in the system; even this relatively small increase in Inertia has an immediate effect

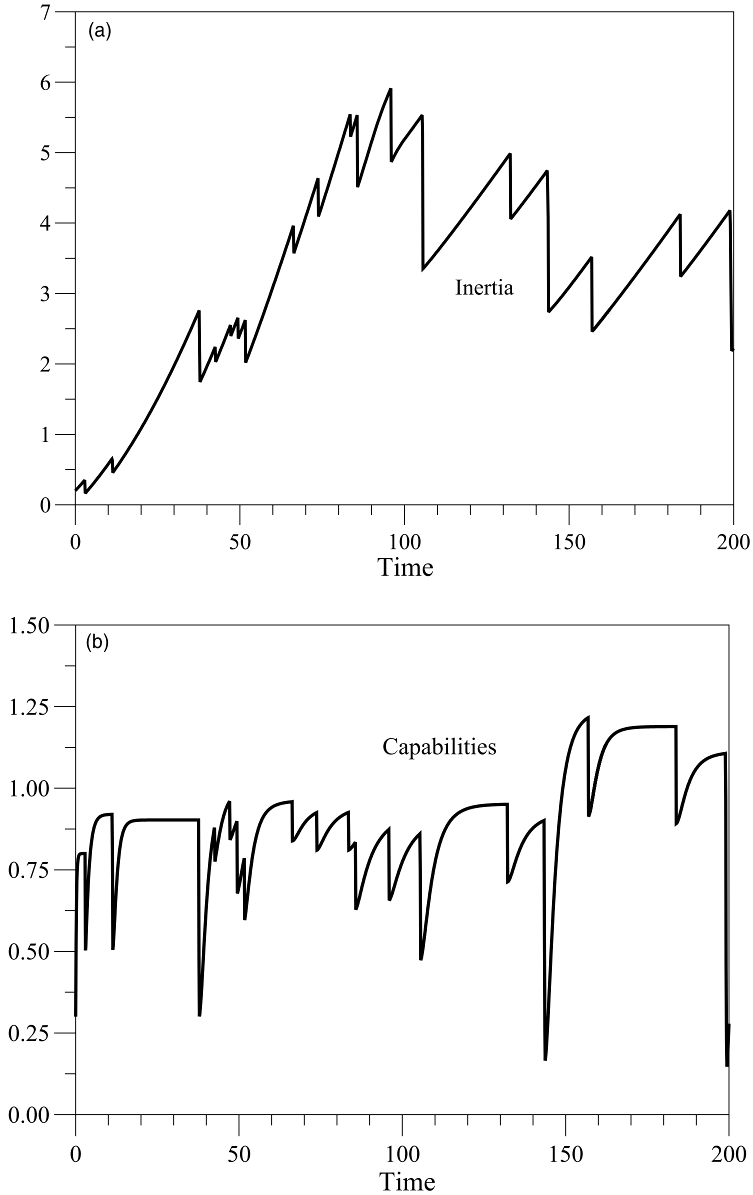


Fig. 9. Example of long-term development of inertia and capabilities.

on the evolution of capabilities. We begin to observe longer periods where a stable set of capabilities is followed by periods of change, although more pronounced than was the case in the previous experiments. As we further increase BT to 1.25, we can

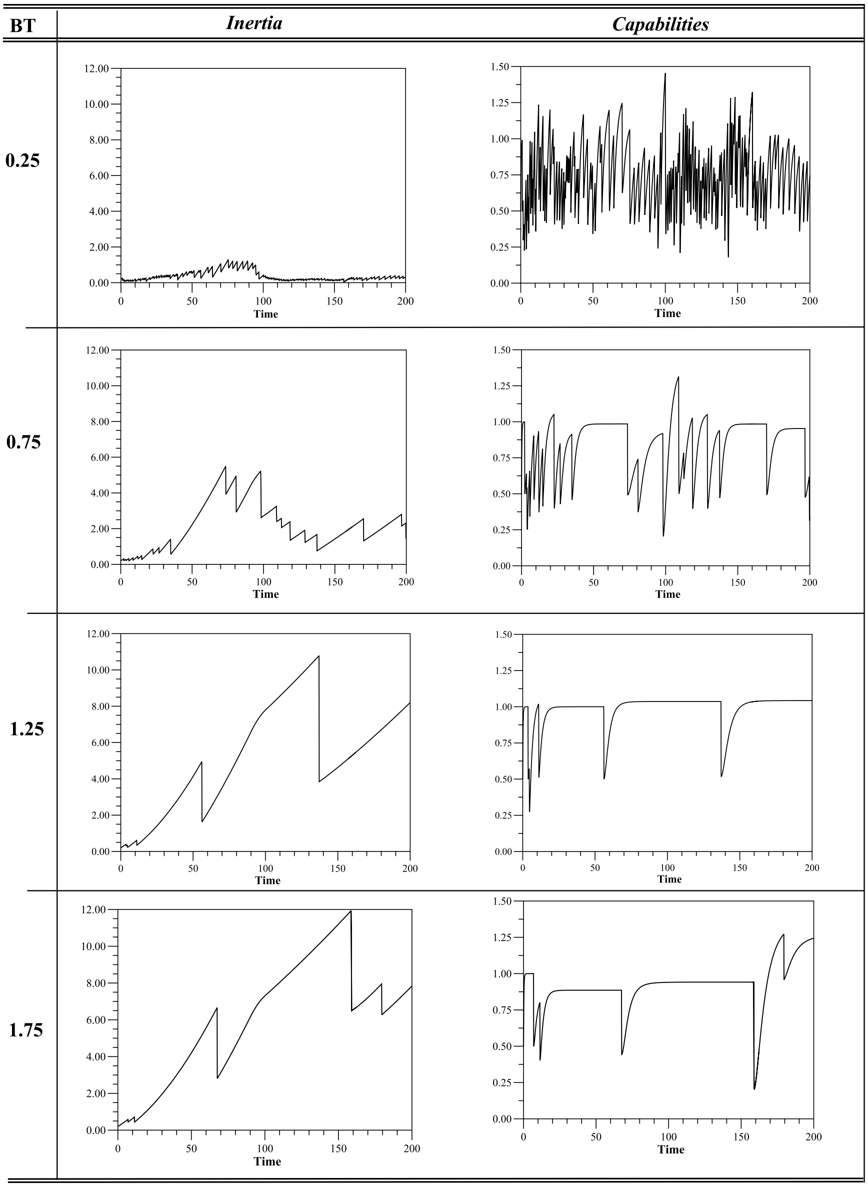


Fig. 10. The evolution of inertia and capabilities as a function of BT for inertia.

begin to see a much more substantial accumulation of inertia in the organization (by more than a factor of 2 compared to the case of BT = 0.75, and by a factor 10 from the case of BT = 0.25). Due to the relative rare change attempts taking place, capabilities remain constant for longer periods of time (up to 80 time periods). As we can observe in the last case with BT = 1.75, we see a (small) additional increase in inertia and a level and stability of capabilities which are about the same as in the case of BT = 1.25.

In summary, the simulations show the presence of a relatively large increase in the stability of capabilities when we move from a very low level of inertia in the organization to a relatively modest level (BT = 0.75), while the advantage of moving from a value of BT = 1.25–1.75 is almost undetectable. One possible implication of these observations is that it might be desirable for the organization to have a level of inertia generated by a BT value of between 0.75 and 1.25. The exact value might depend on organizational and industry specific variables. Another way of expressing this is to say that there is an "optimal" level of inertia, which is above the lowest attainable level.

5. Discussion and conclusions

As Bothner and White recently put it [6, p. 206]: "simulation models are always formulated as mechanisms for simplifying the moving parts of a social process down to it core features. Such endeavors succeed when, in reducing the real world complexity, they nearly inviolate the established facts and yield surprising insights for further exploration". In this paper we emphasized the "moving parts" of an idealized organizational system as representing the dynamic duality between organizational inertia and the evolution of capabilities. This remains a crucial—if contentious—area for contemporary organizational research because different assumptions about the dynamics of organizational inertia and change lead to very different views of the organizational world. According to one view, as organizations grow old and large they also accumulate competencies, resources and knowledge that can be deployed to sustain and improve their competitive advantage. An alternative view suggests that—as organizations grow old and large—they become progressively more vulnerable to processes of self-reproduction that dissipate resources and decrease their ability to respond adequately to the challenges of innovation and change posed by new rivals [9]. Which of these two views is more realistic depends on assumptions about *organizational inertia*, i.e., about the relative speed (and cost) at which established routines can be changed to address current needs and demands. For this reasons the notion of structural inertia is central to our understanding of organizational dynamics. But routines—defined by Nelson and Winter [35, p. 15]) as: "relatively constant dispositions and strategic heuristics"—are also central in evolutionary theories of organizations because they provide the basis for the development of concrete organizational capabilities. Taking this observation as our starting point, in this work we explored the possibility of representing organizational inertia and capabilities as dynamic accumulation processes in the context of a unified model.

We built our efforts on the fragment of population ecology theories of organizations that more directly deals with organizational inertia and change, and reformulated some of the central assumptions and propositions in System Dynamics terms.

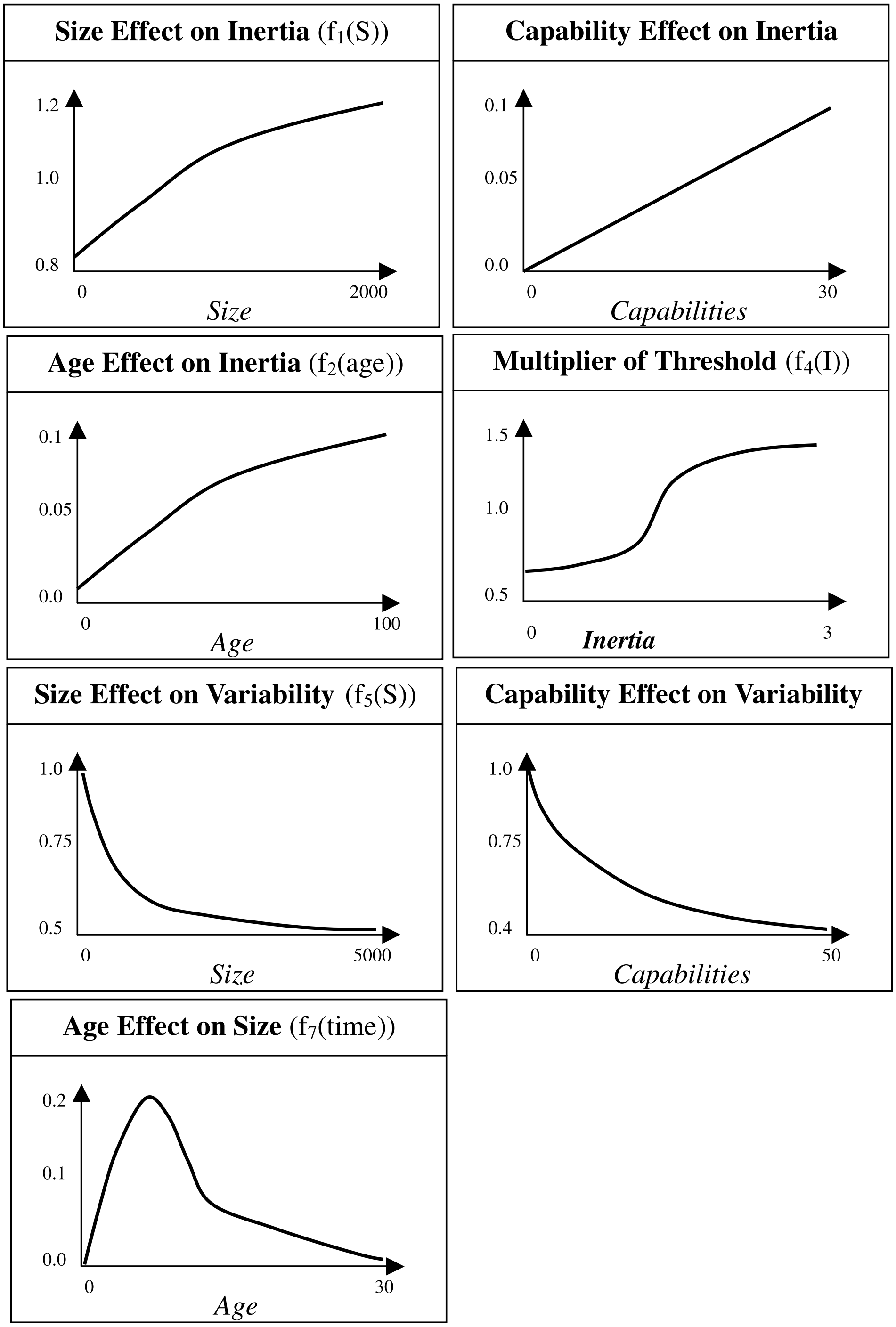
We selected this specific theory of organizations because the clarity of its original formulation makes it particularly suitable to formalization. One of the main motivations for translating the ecological theory of structural inertia into a System Dynamics model was that empirical studies that have attempted to test the theory directly have been forced to ignore the complex feedback structure linking individual propositions for the purpose of specifying estimable statistical models. Perhaps the main motivation for the modeling exercise that we presented was our conviction that this "single proposition" approach to organizational research greatly reduces the complexity—and intellectual value of theoretical narratives developed to account for relevant features of the organizational world. By using simulation methods we could exploit the rich dynamic feedback structure implicit in the original formulation to test its internal consistency, and explore the link between organizational inertia, the value of organizational experience and change.

Our current modeling efforts suffer from two main sets of limitations. The first is related to the fact that we presented a "model of a model", rather than a model of a specific organizational situation, or an empirically defined organizational problem. As a consequence the model reflects and—in a way—accentuates the simplification of the underlying theoretical narrative, and at no point do we pursue the objective of improving its realism. A common criticism of "models of models", i.e., of more or less rational reconstructions of theoretical narratives, is that they do not so much reproduce the original theory as they reinvent it. This poses delicate problems of model validation [3,53]. A related problem typical of this kind of "second-order model" is that many elements of model specification may look arbitrary because organizational theories tend not to be developed in explicit dynamic terms and rarely specify exact functional forms that conceptual associations among variables ought to assume (i.e., they tend to lack a clear reference mode) [53].

The second set of limitations concerns issues of model validation, i.e., the assessment of the extent to which the range of dynamic behaviors produced by the model is consistent with what we know about actual organizations. When modeling empirically observed processes, the problem of model validation is typically addressed by analyzing the extent to which the dynamic behavior of the model reproduces history. Clearly, second-order models cannot be validated by direct comparison with history. Hence, we cannot claim that were able to reproduce specific processes of organizational survival and transformation. More work—and much bigger models—are needed before we can extend the basic feedback representation of the theory of structural inertia presented in this paper to include elements of realism grounded in a detailed understanding of specific organizational situations. This is likely to be the future direction that this type of research will take as we continue to explore new ways of designing models capable of capturing and representing the full dynamics implied by complex theoretical narratives.

Appendix A

The functional relationships assumed in the model are indicated below.


Size Effect on Inertia (f1(S))
1.2
1.0
0.8
0
2000
Size
Capability Effect on Inertia
0.1
0.05
0.0
0
30
Capabilities
Age Effect on Inertia (f2(age))
0.1
0.05
0.0
0
100
Age
Multiplier of Threshold (f4(I))
1.5
1.0
0.5
0
Inertia
3
Size Effect on Variability (f5(S))
1.0
0.75
0.5
0
5000
Size
Capability Effect on Variability
1.0
0.75
0.4
0
50
Capabilities
Age Effect on Size (f7(time))
0.2
0.1
0.0
0
30
Age

Appendix B

This appendix provides all the numerical values used in the baseline case. The variables are grouped by sector and denoted by the type of variable.

Sector	Variable	Type	Value
Inertia	Inertia	Initial value	0.50
Inertia	Constant increase of inertia (μ)	Constant	0.05
Inertia	Decrease in inertia (π)	Stochastic variable	Normal distribution mean = 2.4, S.D. = 2.0
Inertia	Basic threshold (BT)	Constant	1.00
Inertia	Pressure for change (PC)	Initial value	0.00
Inertia	Decrease in pressure for change (ζ)	Stochastic variable	Normal distribution mean = 3.6, S.D. = 5.0
P&C	Reliability (R)	Initial value	1.00
P&C	Base variability	Constant	1.00
P&C	Decrease in reliability (λ)	Constant	3.00
P&C	Reliability threshold value (ϕ)	Constant	0.60
P&C	Size	Initial value	10
P&C	Average reliability	Initial value	1.00
P&C	Time to average reliability (τ)	Constant	3.00
P&C	Yearly Improvement (σ)	Constant	0.05
Capabilities	Capabilities (C)	Initial value	0.50
Capabilities	Threshold for cap. erosion (ψ)	Constant	0.50
Capabilities	Decrease in capabilities (ω)	Constant	6.00
Capabilities	Routines (NR)	Initial value	0.50
Capabilities	Variation (V)	Initial value	0.00
Capabilities	Fraction to routines (β)	Constant	0.40
Capabilities	Variation conversion time (δ)	Constant	1.00
Capabilities	Exploration generation (α)	Stochastic variable	Normal distribution mean = 012.0, S.D. = 2.0

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