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Chance and necessity revisited: A reassessment of path dependence, and its implications for organization studies*

Abstract: *This paper has three objectives. First, to provide a clear and distinctive definition of path dependence as well as to unpack its antecedents and implications in order to outline its strong theoretical interest. Second, to reassess the empirical scope of path dependence in the light of recent controversies, by delineating the epistemological limitations that prevent the theory from fruitfully informing the empirical sphere. In particular, three issues are identified that preclude path dependence from consensually connecting theory and observations: i) its reliance on the contingency assumption, ii) its claim that contingent events matter "in the long run" and iii) its ambiguous relationship to suboptimality. The third objective of this paper is to suggest methodological ways to overcome these limitations and to present a simple simulation that illustrates how path dependence can be integrated in organization and management research in a useful and epistemologically sustainable manner. Notably, the simulation shows that path dependence can help scholars to generate new hypotheses about the evolution of organizational capabilities.*

Keywords: *path dependence, contingency, suboptimality, epistemology, capabilities*

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Introduction

The claim that 'history matters' has become a necessary prolegomena for many social scientists interested in explaining a given course of events. That the past influences the future, however, is a trivial statement. Path dependence represents an opportunity to connect historical sequences in a more formal way (David, 2001). But despite recent efforts to clarify the concept, no consensual definition of path dependence has emerged yet (Djelic & Quack, 2007; Page, 2006; Sydow *et al.*, 2005)[1]. Its ambiguous theoretical substance paves the way for controversy when confronted with empirical observations. In particular, it is still contested whether the QWERTY and VHS case studies constitute acceptable empirical evidence for path dependence (Ekelund & Tollison, 1997; Liebowitz & Margolis, 1990, 1995).

The issue at stake is twofold. First, as theorists of social phenomena, scholars ought to provide a sounder conceptual basis for path dependence. This notion needs to gain thickness in order to become clearly distinct from other constructs (e.g., increasing returns, suboptimality, market failure) or causal mechanisms (e.g., first mover advantage, structural inertia, institutional persistence). Second, as empirical researchers, scholars should define the conditions under which observable phenomena can be said to verify path dependence. In particular, when alternative explanations are suitable to account for the same observations, scholars should assess if path dependence provides the most accurate account.

This paper will hopefully contribute to advance path dependence research in both directions. Section 1 identifies the theoretical building blocks that can shape a distinctive definition of path dependence and unpacks some necessary or sufficient antecedents and implications of the concept. Section 2 examines from an epistemological standpoint to which extent path dependence can account for empirical observations. It is assumed for the sake of the discussion that some observations allow scholars to either confirm or disconfirm the hypothesized mechanisms of path dependence. This will lead me to assess the empirical limitations of path dependence, particularly in the light of the QWERTY and VHS controversies. Since the two first sections address issues at the theoretical and epistemological levels, they are of interest for social scientists working on path dependence, whatever their field of specialization. The last section derives methodological implications from this fresh look at path dependence, which I will illustrate from my own perspective – that of a student of organizations. The end of the paper will present a simple simulation model that applies some

[1] "path dependency […] has a number of different meanings, but a common thread is a critical perspective on traditional efficiency arguments" (Djelic & Quack, 2007:163); "[path dependence] encompasses almost any process in which someone can find or claim evidence of increasing returns" (Page, 2006:87); "organization research […] refers to this concept only in a rather loose or simply metaphorical way" (Sydow *et al.*,2005:4).

results of this inquiry to one of the most lively and promising lines of research in organization and management sciences, the dynamic resource-based view (Helfat & Peteraf, 2003; Helfat *et al.*, 2007; Teece *et al.*, 1997). This choice seems appropriate because resource accumulation and capability formation are often described in terms of choice and chance (Barney, 1986, 2001; Makadok & Barney, 2001), which are notions central to path dependence studies. As a matter of fact, the evolution of capabilities is closely associated with path dependence in the literature (e.g, Schreyögg & Kliesh-Eberl, 2007; Teece *et al.*, 1997).

This critical reassessment of path dependence aims at three objectives: 1) to outline the theoretical interest of path dependence while delineating its empirical limitations (epistemological contribution); 2) to suggest ways to overcome these limitations in empirical research (methodological contribution) and 3) to further the dynamic RBV research agenda by discussing the implications of a simple simulation that integrates elements of path dependence studies in a fruitful and epistemologically sustainable manner (theoretical contribution).

1 – Defining path dependence “thickly”

A definition of path dependence needs precision and distinctiveness, otherwise “the notion of path dependency would not be much more than a metaphor highlighting nothing other than a social truism” (Sydow *et al.*, 2005:18) – namely, the fact that history matters. This definition will be useful to differentiate between path dependence and other loosely-related constructs.

Contingency

Path dependence refers to a property of dynamic processes whose evolution exhibits contingency (David, 1985). The term ‘contingency’ has got several layers. In a seminal paper, Arthur (1989) argues that path dependent processes are contingent in the sense that their final outcomes depend on earlier events that partly occurred randomly. Thus contingency entails three components: history-dependence, uncertainty and lack of necessity (e.g., presence of “chance”). These dimensions of contingency reasonably describe the nature of socially embedded decision making. Consequently, a considerable amount of historical sequences are potentially part of the path dependence research agenda, in several disciplines belonging to social sciences[2].

[2] For instance, this includes studies of technological evolution (Arthur, 1989; Cowan, 1990), institutional change (Goldstone, 1998; Mahoney, 2000; North, 1990), political choices (Pierson, 2000; Thelen, 1999), state policies (Cowan & Gunby, 1996), or organizational capabilities (Schreyögg & Kliesh-Eberl, 2007; Teece *et al.*, 1997).

Chaos, randomness and path dependence

The literature has stressed that informal definitions of path dependence often lead to confusing or even contradictory statements (David, 2001). Path dependence involves some kind of chance or randomness. Unlike chaos theory, it is concerned with stochastic processes: path dependence is not about a hypersensitivity to initial conditions[3]. Some trajectories, once entered, influence with probability one the future distribution of outcomes. Such a distribution is not random; it is merely subject to modifications between the starting point and the outcome of the process. Path dependence, although a property of stochastic processes, is therefore not a synonym for randomness.

Put simply, a *path dependent process* is one whose outcome distribution changes over time as the process unfolds. Stated formally, path dependence is a property of a non-ergodic Markov chain, which has at least two possible equilibria that are selected contingently somewhere along the path (see Appendix A for a formal development). Notably, the early history of the process does not necessarily matter more than its recent history (Page, 2006). Path dependent processes are such that, for any set of initial conditions I, the probability of any outcome O conditioned by I verifies: $\forall(O,I)$, $P(O|I)<1$. Hereafter, this relationship is referred to as a *theorem of path dependence*. Notably, this theorem and its assumptions can be applied to the evolution of living species: random events (e.g., genetic mutations) occur at every stage of the evolution, thereby modifying the future probability of outcomes (e.g., expression of a given trait). To a large extent, the evolution of living species is non-reversible: once a path has developed, there is no turning back because of the speciation process.

Path dependence, increasing returns, lock-in and suboptimality

It can be shown formally that neither increasing returns nor network externalities are necessary conditions for path dependence to occur: the mere presence of sunk costs or asynchronic decision making suffice in leading to path dependent outcomes (Balmann *et al.*, 1996). For instance, when sunk investments have been previously made in a given productive activity, it is attractive for an agent to acquire skills related to it, even when other activities could be more profitable *per se*. Similarly, asynchronic decision making induces complementarities between knowledge and assets, whose evolution might become path dependent. Vested interests as well may lead decision makers to rationally pursue a given path because of past decisions, even though more globally efficient options are currently available

[3] "Path dependence is a property of a system such that the outcome of a period of time is not determined by any particular set of *initial conditions*" (Goldstone, 1998:834).

(Altman, 2000). Constant or decreasing returns may yield path dependent outcomes when alternative options are eliminated along the path. Page (2006) provides formal evidence that the history of a decision process only matters when at least one negative externality exists among available options. Only a negative externality directly "compromises optimality" (Page, 2006:109).

A path dependent outcome can only exist if there is at least one other outcome which could have been reached – but which was not due to contingency. Formally, this reflects the non-ergodicity of the Markov chain: at least two locally stable equilibria exist from which the process cannot escape endogenously. While path dependence logically implies lock-in, lock-in might also occur without path dependence. For example, Arthur's famous payoff tableau does not involve non-ergodicity but does illustrate lock-in (Arthur, 1989:119). Nevertheless, lock-in is not a synonym of inefficiency, market failure or suboptimality. A process may well get locked-in an optimal region of equilibrium if contingency decided so (David, 2001).

Why then is path dependence so often associated with suboptimality (Liebowitz & Margolis, 1990, 1995)? The reason for this resides in the role endorsed by path dependence in a struggle over paradigms. David (2001) presents path dependence as a core concept of "historical economics", which he describes as a paradigm challenging the neoclassical school of thought. In order to show that historical economics is able to succeed where neoclassical economics failed, path dependence should manage to explain more than the paradigm it aspires to outperform. Practically, this means that historical economics based on path dependence should preferably be applied to cases which do not fit in the neoclassical optimization framework (e.g., suboptimal equilibria), while in fact there is absolutely no incompatibility between path dependence and optimality.

The logic of path dependent explanations in social sciences

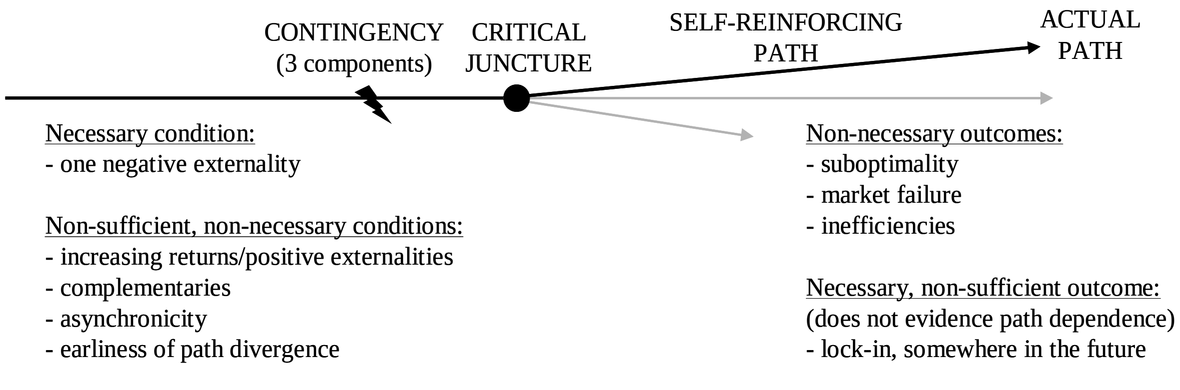
Social scientists with different backgrounds share a set of common explanatory mechanisms about path dependence. The story goes that "insignificant events" (Arthur, 1989:116), "small or contingent events" (Pierson, 2000:251) or "chance elements" (David, 1985:332) have a durable influence on the selection of a given equilibrium among the possible ones. Once a path is contingently selected, it is pursued because of its increasing attractiveness relative to others. Self-reinforcement then locks the process into a locally stable equilibrium. Only exogenous shocks can get the system to shake free of its own history (David, 1994, 2001).

The stability of the argument across disciplines is motivated by logical consistency. Contingent events must be found at the origin of a path dependent process for two reasons.

They first guarantee that multiple paths can potentially be pursued. Were contingency absent, decisions makers would choose what appears to be the best option among those that are available *ex ante*, and no new or unexpected path would be created. Contingent events at the beginning of a sequence also ensure that what initiates the path and what reproduces it later on (e.g., complementarities) are distinct mechanisms. If the same causal force explained both the creation and the reproduction of the path, path dependence would add nothing to traditional systemic explanations (Schwartz, 2004). For instance, if QWERTY was initially adopted because it maximized the early adopters' utility compared with other keyboards *even before any self-reinforcing mechanism started to operate*, we would conclude that QWERTY always was the best keyboard. Positive feedbacks or increasing returns, by implying that alternative paths become less and less attractive with time, explain why actors are not enticed to explore other options[4]. Therefore, contingency and a self-reinforcing mechanism are two necessary building blocks of path dependence in social sciences.

This section developed a formal definition of path dependence, distinguished the concept from loosely-related ones and outlined how social scientists usually exploit the logic of path dependence. Important results are summarized in Table 1 below.

Table 1: The logic of path dependence and some of its important properties



[4] Path dependence predicts the reproduction of a given pattern without specifying why it becomes relatively more attractive than others. Sydow *et al.* (2005) identify several mechanisms that can account for this self-reinforcement: economies of scale/scope, externalities, learning effects, social expectations/coordination effects, cognitive/sunk cost traps, escalating commitment. Schwartz (2004) doubts that it is helpful to conflate distinct causal mechanisms into a single label ("self-reinforcement") on the ground that their predictions share the idea that something is being reproduced. This can be misleading, as in Zukowski (2004:956), who concludes about Poland's assumed path dependent development "that in a narrow sense, Poland's historical sequence cannot be interpreted in terms of path dependence, but it rather represents a classic case of institutional persistence".

2 – Dealing with path dependence empirically

The formal definition of path dependence provides scholars interested in historical causality with a sound theoretical basis (see Appendix A). It helps social scientists to acknowledge the role of chance (De Rond & Thietart, 2007) when studying various sequences of phenomena, such as technological or institutional trajectories. It highlights the importance of gathering relevant information before committing resources to a project (Liebowitz & Margolis, 1995; David 2001). It also underlines the fact that our decisions may have a long-term impact at a scale much broader than was expected *ex ante*. Finally, it encourages both scholars and social actors to complement teleological thinking with historical awareness.

Researchers look beyond the insights generated by a theory; they ask for empirical evidence that such insights are relevant. The move from theoretical path dependence to the empirical sphere is not an easy one (Foray, 1997). Controversies about the QWERTY and VHS cases have not been resolved yet (Liebowitz & Margolis, 1990, 1995; Schwartz, 2004). To understand why, this section draws on epistemology to address three issues that have prevented path dependence from consensually advancing empirical knowledge.

First, empirical support for path dependence requires evidence that paths are selected contingently and not by structural forces (e.g., superior efficiency, information asymmetry), otherwise traditional efficiency-based theories suffice in explaining observations. Second, it needs to be proved that contingent events have consequences in the long run. It they affect future steps of the process without impacting its long run equilibrium, then path dependence can no longer be formally defined as a property of non-ergodic Markov chains. This would imply that lock-in is not anymore a necessary outcome, and path dependence would loose most of its substance. Third, to demonstrate its distinctive explanatory power, path dependence should be able to account for persisting suboptimal situations. As our discussion of the QWERTY and VHS controversies will show, this demands using counterfactual analysis, where hypothetical worlds are compared with the only, actual one we live in.

The following discussion focuses on the conditions under which path dependence can translate into empirical research. With this purpose in mind, it is assumed that at least some observations inform social scientists on the degree of plausibility of path dependence-inspired statements. It is also taken for granted that "consistency, logicality, and clarity are fundamental requirements of scientific justification, regardless of one's personal epistemology" (Péli *et al.*, 1994:571). This merely implies that contradictory statements are to be avoided, as well as false inferences and unclear arguments, whose empirical testability might be reduced.

Evidence for chance

To simplify the following discussion, path dependent processes are modeled as adoption patterns in the broad sense: social actors adopt technologies, institutions, beliefs, theories, or routines, and some of these entities might end up dominating others. Such adoption patterns can be represented as sequences of digits: for instance, when two entities A and B compete for adoption, the sequence "01101100110111100010" means that B was chosen first, then A twice, B again, etc., with 0 and 1 coding respectively for adoptions of B and A. Path dependence needs the intervention of some chance or randomness in the adoption pattern before the paths start to diverge (Arthur, 1989). But how to generate empirical evidence for chance or randomness? Before discussing the inherent difficulties of the task, I need to say a word about the definition of random numbers.

In the early 1960s, Solomonoff, Chaitin and Kolmogorov worked on the notion of randomness in mathematics (Chaitin, 1975; Li & Vitanyi, 1997; Solomonoff, 1960). A synthesis of their works led to a definition of random numbers as series of digits whose complexity is approximately equal to their size in bits[5]. In other words, a random number is one that cannot be generated by an algorithm of a much lower size than the number itself, since the information contained in it cannot be compressed. Consider the two followings series representing patterns of adoption using the notations introduced above[6]:

1) 10010110010011011011
2) 11111111111111111111

Intuitively, the first series appears "more random" than the second. However, both series could be obtained with equal probability by tossing a coin twenty times: from a coin's point of view, both series are equally random. To resolve this paradox, Chaitin (1975) proposes to define randomness objectively, that is, without reference to the mechanism generating the sequence (here, the coin). This implies measuring the quantity of information involved in the sequence itself. To transmit the information contained in the series with a computer, one would write two algorithms: the second series would obtain with a program like "Write '1' 20 times", while the first sequence would require a longer algorithm – for instance, "Write '10010110010011011001'". The size of the latter program is about the same as the size of its

[5] The complexity of a series of digits is the size in bits of the smallest computer program able to generate it.
[6] This example is adapted from Chaitin (1975).

output since the data cannot be compressed. Therefore, according to Chaitin's definition of randomness, our first intuition was correct: the first series is indeed more random than the second one.

Interestingly, in Arthur (1989), lock-in occurs when random events get B's adoptions far enough ahead of A, that is, when something like the second pattern of adoptions presented above obtains early in the process. Put differently, Arthur tends to consider that a series of twenty adoptions of B is the true chance event that triggers path dependence. As the previous example illustrates, this is rather counter-intuitive: repetitive patterns of digits in the second sequence (i.e., the twenty "1") are more likely to have a non-random origin. For instance, the strategic savvy of B's promoters could well explain why B's share eventually rocketed. Since chance is not the most obvious explanation to account for repetitive patterns, the path dependence argument needs indeed some empirical support.

However, Chaitin (1975) asserts that no evidence for randomness can easily be produced. In order to show that a series of digits is random, one would need to prove that no program of a complexity smaller than that of the series exists that could generate it. According to Chaitin, Gödel's incompleteness theorem contains the rationale for why such evidence is often impossible to produce. Any formal system consisting of a formal language and a set of inference rules can be associated with a given degree of complexity. The more complex the system, the more complex the information derivable from it (e.g., theorems and their proofs). As a consequence, complex proofs can not be established within simple systems: the information they contain is considered uncompressible and thus appears random (see Appendix B). This inherent limitation of formal systems leaves informal theoretical systems like those employed in social sciences in an even more difficult position when it comes to proving randomness or chance.

The chancy character of an adoption pattern is therefore unlikely to ever be empirically evidenced. While chance remains a reasonable assumption in formal models where A and B only differ in their payoff structure (e.g., in Arthur, 1989), in real-world situations (e.g., in the QWERTY case), decision makers adopt A or B based on their preferences and the perceived properties of A and B. A causal link is likely to exist between the choice to adopt a technology, for instance, and its idiosyncratic properties (e.g., design, technical specifications, brand reputation). Thus in empirical studies, the chance argument is no more provable than in formal models but it is much less realistic, since social actors do not behave randomly. In other words, the verifiability of empirical path dependence remains a serious issue.

Falsifying chance

The chance argument is unverifiable in non-trivial cases. But can one falsify it? To do so, one needs to think of a possible world where the adoption pattern is not random. Since social actors are very likely to behave in a non-random manner, scholars need to consider properties of A and B that could significantly influence their choices.

In Arthur's (1989) model of adoption under increasing returns, lock-in occurs when contingent events push the adoption of technology B far enough ahead of A. Increasing returns render B so much more attractive than A that even those who have a natural preference for A will eventually adopt B. Now, what if the early adoptions of B are not due to chance? What if B managed to get an early advantage because it convinced its prospects to make their purchase earlier than A's prospects? The time pattern of a firm's sales is usually not considered a small chance event by managers, since generating income right now is always better than generating it in the future. Were one to prove that B got ahead because its promoters acted more strategically, then the role chance would become negligible[7].

One may wonder how it can empirically be proved that B's early advantage is due to something else than chance (e.g., more efficient promotion). To formalize this discussion, I introduce simple notions of predicate logic. Such formalization has proved useful in the past for social scientists interested in assessing the consistency, logicality and clarity of theoretical arguments (Péli *et al.*, 1994). In the following, A and B stand for two entities competing for adoption (e.g., technologies, institutions, policies) and whose payoff structures are hard to compare early in the process[8]. Social actors are assumed to be purposive: they do not adopt A or B randomly but because of their respective properties, which include anything that characterizes them. Imagine A and B technologies; their relevant properties could be price, design, consumer service, geographical location of outlets, training required to use them, and so forth. In order to disconfirm empirically the path dependent explanation based on contingency, one needs to show that B has got at least one property that differs from A's which could explain why B got ahead. A and B certainly differ in at least one of their respective properties: if they did not, then A and B would not be distinct. This is a simple application of Leibniz's law of the identity of indiscernibles (Hacking, 1975; Leibniz, 1686/2000), which states that no two distinct entities have got exactly the same properties[9].

[7] The argument can be extended to situations where recent (and not early) history determines the final outcome.
[8] Otherwise there would be no indeterminacy of outcome (no path dependence), since the better option would always be chosen by early adopters. This path *in*dependent process may anyway generate lock-in (Arthur ,1989).
[9] The principle of the identity of indiscernibles is uncontroversial for macro entities with many distinctive features (Forrest, 2006). A short introduction to logical language can be found in Péli *et al.* (1994: Appendix).

Using the notation of predicate logic, A and B representing alternative options and P any property characterizing them, the argument can be written:

$$\forall P[PA \leftrightarrow PB] \rightarrow A=B$$
$$\underline{A \neq B \qquad\qquad\qquad}$$
$$\therefore \exists P[(PA \wedge \sim PB) \vee (\sim PA \wedge PB)]$$

(if for any property P, A and B have P, then A and B are identical; A and B are distinct; therefore, there exists at least one property P that A and B do not simultaneously have)

Differences exist between A and B that could capture variance in adoption trends – and thereby avoid the controversial reliance on chance to account for historical causality. Yet, relating actors' preferences and property differences to the adoption pattern is a considerable challenge: extensive data about the adopters' and promoters' motivations needs to be gathered and analyzed. A way to do so is to regress the speed of adoption on every relevant property difference identified by adopters. Had A and B exactly the same properties but design, one could still argue that B was more fashionable, existed in a wider variety of colors, was more ergonomic, and so forth. Any combination of property differences could also be investigated as a cause for early adoption; this means considering potential interaction effects between the independent variables of the regression model. As a matter of fact, a lot of alternative hypotheses can be formulated to account for B's early advantage. Nevertheless, the quantity of information required to test them is likely to exceed by far the quantity of information available in existing historical accounts about the case under scrutiny[10]. And since most historical trajectories are unique, econometrics may be of little help to identify generalizable results in empirical cases of path dependence.

Many non-contingent factors can explain the shape of adoption patterns. Path dependence is falsifiable discursively, but gathering data supporting explanations not based on chance appears very difficult when unique historical trajectories are at stake. To rely on chance-based explanations is to take the risk of constructing a theoretical edifice on very weak foundations, for chance cannot be evidenced. As I will now discuss, this paradox lays foundations for controversy when it comes to testing path dependence empirically.

Back to QWERTY and VHS

Path dependence has a strong theoretical interest. Nevertheless, the chance argument in which it is grounded, although acceptable in formal models, raises serious epistemological issues in the empirical sphere. As a consequence, empirical studies in path dependence are bound to be

[10] With only 5 potentially relevant differences between A and B, one needs to construct 15 independent variables to include 2-variable interaction effects in the model. The regression of the speed of adoption S on property differences $P_1,\ldots,P_n$ is written: $S = \Sigma\beta_k P_k + \Sigma\Sigma\beta_{i,j}P_iP_j + \varepsilon$, with $k \in \{1,\ldots,n\}$, $i \in \{1,\ldots,n\text{-}1\}$, $j \in \{i+1,\ldots,n\}$.

controversial. From the previous discussion one can predict that: 1) scholars who reject path dependence will try to account for adoption patterns by looking at the ignored property differences between A and B; 2) in most cases, they will use available historical data to fuel controversy; 3) most controversies are likely to remain unresolved, but their intensity will decrease with the amount of unexploited historical data.

The QWERTY and VHS controversies illustrate that well. David (1985) attributes the dominance of the QWERTY keyboard to path dependence, reporting that a better competing standard (DSK) is available (David 1985:332). Liebowitz & Margolis (1990) strongly criticize the empirical evidence considered by David. They find that past studies comparing QWERTY and DSK along the dimension of typing speed provide only weak, and sometimes biased results. They introduce properties other than typing speed that seriously question DSK's superiority, like ergonomic characteristics or the competing firms' marketing abilities.

The VHS controversy follows a similar path. Arthur (1990:92) remarks the similarity of VHS and Beta along three properties (price, time of market entry and initial market shares), from which he infers that the final victory of VHS can only be explained by a contingent initial lead amplified by increasing returns. Liebowitz & Margolis (1995:222) contest Arthur's example by considering a fourth property that could account for the domination of VHS, namely its longer recording time, particularly valued by consumers in the 1970s. Had they not mentioned recording time discrepancies between VHS and Beta, they could have advanced that a "large part of the VHS advantage came from the sheer ability to deliver more VHS machines than Beta producers could make early on in the competition" (Cusumano *et al.*, 1992:47). Or they could have reported any other property difference which possibly explains the outcome. Since historical data is never exhaustive, whatever the proponents of the controversy reply to each other, it is often a matter of belief to agree with them or not. Despite all the efforts by Arthur, David and others, Ekelund & Tollison (1997 : 387) assert that, so far, "there are no *real* world examples of path dependence".

Evidence for the long term impact of history: how long is the "the long run"?

Another issue that severely constrains the empirical scope of path dependent explanations is the idea that history matters "in the long run". In the long run, VHS will be replaced by another recording system (e.g., DVD) and QWERTY keyboards substituted for something else (e.g., voice recognition systems). Empirically, each pair of competing entities has an idiosyncratic, *ex post* determination of "the long run", since the moment when lock-in occurs is unpredictable *ex ante* due to contingency.

Interestingly, Page (2006) formally distinguishes outcome-dependent from equilibrium-dependent processes. The outcome of a process at time *t+1* might depend on past states while the long run equilibrium does not. But does such a distinction make sense in empirical cases? For instance, one could reframe the VHS vs. Betamax controversy in an equilibrium-*in*dependent way: whether VHS or Beta was chosen in the past does not actually matter, since nowadays everyone is locked in using DVDs. The difficulty to give sound empirical content to path dependence partly comes from the fact that, while some mathematical processes do converge to uncontroversial stable equilibria, real history does not. If the long-run is identified *ex post* (e.g., after lock-in has been observed empirically), the prediction that path dependence implies lock-in suffers from a lack of falsifiability. Indeed, how can we think of a world where lock-in does not occur when we do not know when it is supposed to occur?

Evidence for suboptimality: if only the past had been different.

More than three centuries ago, Leibniz meant to establish logically that we live in the best of all possible worlds (Leibniz, 1686/2000). Using only slightly different arguments, advocates of path dependence maintain nowadays that we do not. If the past had been different, we could all be better off right now (e.g., nobody would use QWERTY keyboards). Arguably, both Leibniz and the advocates of path dependence fail to establish their point logically.

The theorem of path dependence asserts that the past shapes the present stochastically ($\forall$(O, I), Pr(O | I)<1). Thus, at the present time, no one can determine what today would look like had the past been different, since the dice of contingency would need to be rolled again from that point in the past onwards. Therefore, no given outcome in a path dependent process cannot be caused deterministically by the occurrence of a particular event in the past. Let us analyze the previous statement with the language of propositional logic; O_A means that "A is the outcome of the process", I_A that "choice A was made in the past" and C that "contingent events reinforced the choice made in the past". Path dependence means that:

$$I_A \wedge C \rightarrow O_A$$

$$\sim O_A \rightarrow \sim I_A \vee \sim C$$

(If A was chosen and contingent events reinforced this choice, then A is the outcome; by contraposition, if A isn't the outcome, then <u>*either*</u> *A was not chosen in the past* <u>*or*</u> *contingent events made the path diverge)*

In particular, if the so-called optimal outcome did not occur, one cannot infer that a different choice in the past would have made it occur (with probability one). A different past does not necessarily imply a different future, since contingent events may modify the path taken (cf. Appendix C). When a standard B is preferred to A, the income it generates leads to further investment in B's quality. But what if A had been chosen in the past? Would it have improved as much as B – or more, or less? Since there is no way to know, path dependence is not in a position to empirically verify suboptimality. It follows that no particular event in the past can be identified that would give an 'optimal' outcome in the future (with probability one). Hence, the proposition that "the current situation is not optimal" is at best misleading; the strongest claim one can make is that we could have been better off today with a probability strictly comprised between zero and one. This implies in turn that, with a non-zero probability, we are currently living in the best of all possible worlds (cf. Appendix C).

3 – A possible future for path dependence

Path dependence raises essential questions for social scientists. However, the empirical literature on path dependence has yet failed to address major issues, namely 1) how to verify or falsify the contingency argument of path dependent explanations?, 2) how to define at what point in time history matters? and 3) how to consistently integrate path dependence and claims about suboptimality? The previous discussion did not intend to reject path dependence as a scientific construct but to recognize its theoretical interest while evidencing its strong empirical limitations. This section opens with suggestions about designing research on path dependence while avoiding empirical deadlocks. I then illustrate my argument by presenting a simple application of path dependence in organization and management studies.

Back to the future: a suggested direction for path dependence research

The complexity of empirical observations can arbitrarily be made greater by considering additional properties of a given system, in order to falsify path dependent arguments. The latter rely on the assumption that random shocks matter in the long run; yet, randomness cannot be verified and "the long run" often needs an *ad hoc* definition to fit the observations.

The theoretical substance of path dependence would prove more fruitful and less controversial in situations where: 1) the complexity of the observed system can be circumscribed so that only a limited amount of properties are relevant for study, 2) the chance argument is not used as a patch for lacking data but is indeed a credible assumption and 3) the long run equilibrium is not defined *ex post* to fit with the theory. One can think at least of two research methodologies that meet those criteria: computer simulation and lab experiments. Simulation and experimental designs basically allow researchers to reduce considerably the complexity of the studied phenomenon (Mezias & Eisner, 1997; Webster & Sell, 2007). The finite amount of variables in a computer simulation and the possibility to control for most undesired noises in a lab experiment are two interesting features of such designs, which render falsification a feasible task. Also, randomness is modeled in an acceptable manner using generators of pseudo-random numbers or random sampling techniques. Early choices are not assumed *ex post* to have happened by chance, but are actually modeled as the outcome of random events. Using such designs, scholars can tell what is attributable to chance and what is not, since all relevant variables can be tracked at each step of the process. The impact of chance can be estimated by re-running the simulation (with a different random seed) or replicating the experiment (with different subjects). Moreover, random shocks need not be modeled as equilibrium selection mechanisms, as is often the case in empirical path dependence studies, but instead represent what in the simulation or experiment has not been controlled for, thus providing insights about how to improve theory in the future. Finally, since the parameters of simulations and experiments are chosen *ex ante* by the researcher, the time boundaries of such designs are less subject to *ad hoc* definitions based on *a posteriori* observations. Those parameters can be modified in future replications in order to compare different paths whose outcome can be known (and not only assumed); this provides sufficient support for claims about which path is the optimal one among those tested.

Simulations and experiments are research settings that address all of the epistemological issues discussed earlier in the paper: they make non-metaphorical path dependence more readily applicable. As exemplified hereafter, modeling path dependence with such methodologies help scholars to generate new hypotheses in their area of specialization. As a student of organizations, I will now develop an illustration of such possibilities in the field of organization science.

A simple simulation of the path-dependent evolution of organizational capabilities

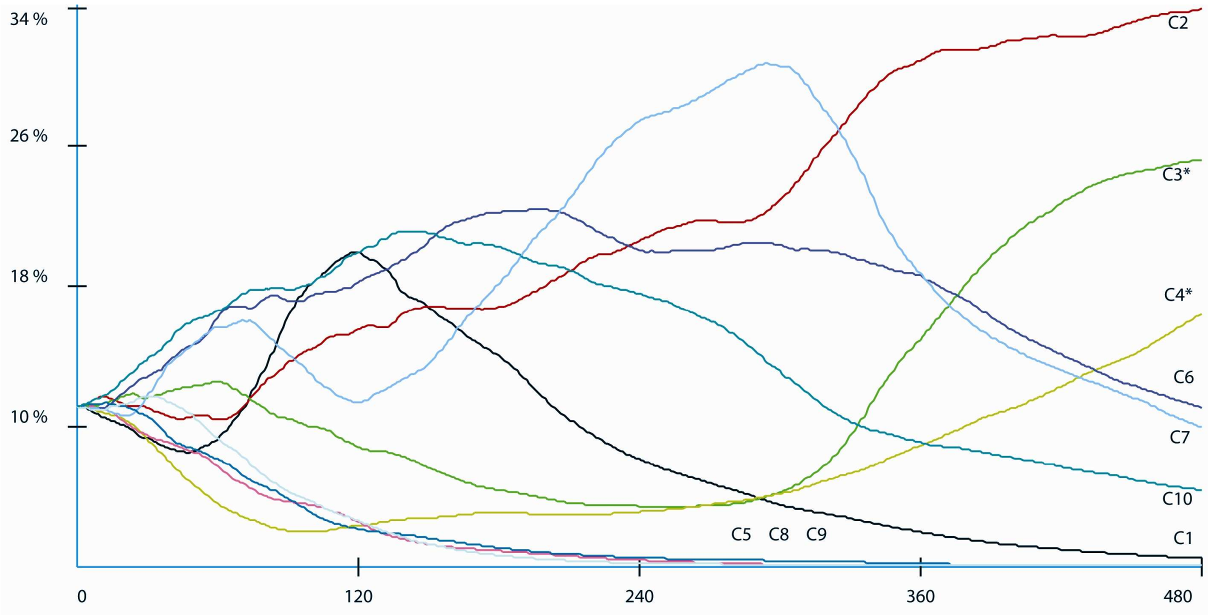
A (dynamic) capability is defined as an organization's "ability to integrate, build and reconfigure […] competencies to address rapidly changing environments" (Teece *et al.*, 1997:516). In organization and management sciences, the evolution of organizational capabilities is often said to be path dependent (Eisenhardt & Martin, 2000; Helfat & Peteraf, 2003; Schreyögg & Kliesch-Eberl, 2007; Teece *et al.*, 1997). Sydow *et al.* (2005) regret that the latter term is often used too broadly and can describe almost any organizational process[11].

[11] Teece *et al.* (1997:522-3) write that "path dependenc[e] recognizes that 'history matters'[…]. Thus a firm's previous investments and its repertoire of routines (its 'history') constrain its future behaviour". The existence of such inter-temporal dependencies is indeed a property of most social processes.

As a response, they offer a modified definition of path dependence by relaxing some assumptions that are often not consistent with the ontology of organizational processes (e.g., randomness). In this section a different but complementary approach is explored, since path dependence is maintained within its original assumptions. The advantage is twofold: first, some substantial properties of path dependence still obtain (e.g., lock-in as a necessary outcome); second, the concept remains narrow enough to avoid the risk of conflating different theories into a single one (Schwartz, 2004).

Organization and management scholars are confronted with a paradox: they usually assume that purposive action drives organizational life, whereas path dependence theory insists on chance. In *ex post* historical accounts of path dependence (e.g., QWERTY), the explanation goes as follows: since the outcome is deemed suboptimal (we are using the 'wrong' keyboard), the process must have been path dependent; therefore, contingent events must have occurred earlier. Previous sections emphasized the limitations of this explanation: it compares an actual outcome with a virtual one; it assumes a necessary relationship between path dependence and suboptimality; it infers the existence of early contingency when alternative explanations seem more appropriate; more importantly, it does not provide evidence that any of those statements hold true. By contrast, in the following simulation, randomness lays at the foundation of the model, so that core assumptions of path dependence are verified; what matters hereafter is the kind of outcomes that such a process can yield.

Without relying explicitly on path dependence in the model, Zott (2003) studied in a simulation the impact of three properties of capabilities (time, cost and learning of resource deployment) on intra-industry performance differentials. He observes that path dependencies are associated with learning but do not always obtain. Accordingly, in the following simple simulation, an emphasis is put on learning to increase the likelihood of path dependence. No particular hypothesis is formulated *ex ante* since the objective is to show how the observation of simulated path dependence can help scholars to generate testable hypotheses. An organization is represented as a bundle of 10 capabilities, which are internally supported by managers based on their past performance. A capability with above (below) average performance at period t leads to increasing (decreasing) support at period $t+1$. Managerial support includes anything that fosters capability development (e.g., resource allocation, attention devoted, degree of priority attributed). The performance of a capability in $t+1$ depends on three factors: that achieved in t, random shocks, and scale/scope economies. Learning operates at a constant rate to accelerate the process. Thus, the more support a capability receives, the more likely it will receive further support. The following graph displays the path dependent evolution of the intensity of managerial support received by the ten capabilities over 480 time periods (see Appendix D for more information):



Graph 1: Evolution of the intensity of managerial support for the 10 capabilities

Two important observations can be made: 1) it is not the early history that determines the outcome at period 480 (C6, C7 and C10 had an early advantage); 2) lock-in has not occured yet at period 480 in this simulation: the moment of its occurrence depends on the random seed (it is unpredictable *ex ante*). Late lock-in can be explained by the fact that only few capabilities have completely lost managerial support after period 360 (C5, C8 and C9), which leaves enough alternative capabilities available to buffer random shocks without sticking to one single path. Interestingly, two capabilities identified with '*' in the graph seem 'dormant' until period 280, a moment after which their performance increases dramatically[12]. Had the organization got rid of C3 and C4 earlier, the overall ability to face subsequent environmental pressures could have been damaged, particularly in high-velocity environments (Henderson & Stern, 2004). Internal selection events at the capability level thus seem to matter[13]. Therefore,

> *Hyp. 1: The more internal selection events occur in an organization (at the capability level), the faster its evolution can lead to lock-in in the presence of path dependence.*

[12] Dormant capabilities are those kept within an organization despite relatively poor (although stable) performance, which embody a potential for subsequent evolution in the shape of learning and routines.
[13] While Henderson & Stern (2004) regard internal selection events at the product level (e.g., managers select out a product because of its poor performance), this section implements the concept at the capability level.

The development of new capabilities is likely to counteract this tendency by providing the organization with new options, which represent alternative paths. Thus,

> *Hyp. 2: The more an organization develops new capabilities, the slower its evolution can lead to lock-in in the presence of path dependence.*

As this paper showed, however, lock-in does not imply suboptimality. But lock-in implies that very few alternatives remain viable for adoption. In high-velocity environments (Eisenhardt & Bourgeois, 1988) where organizations are confronted with considerable pressures toward change, lock-in might become an issue whatever the equilibrium:

> *Hyp. 3: The higher the velocity of the environment, the more damaging lock-in can be.*

When change is required, an organization with dormant capabilities possesses a catalog of alternative paths that can ease its evolution:

> *Hyp. 4: In high-velocity environments, the more dormant capabilities an organization possesses, the easier it will be for it to implement change.*

This hypothesis is consistent with the proposition that capabilities should be monitored reflexively “in order to check their ongoing workability in the light of a potentially changing unpredictable environment” (Schreyögg & Kliesch-Eberl, 2007:930). It complements this suggestion by insisting on the fact that unpredictable changes are more likely to be dealt with when a variety of dormant capabilities are present within the firm, *caeteris paribus*. Dormant capabilities also qualify the dichotomous view introduced by Eisenhardt & Martin (2000). According to this view, stable environments are associated with robust, highly codified and detailed capabilities, whereas in high-velocity contexts the latter are simple, fragile and semistructured. Dormant capabilities have the potential to represent a third way by hinting at the existence of underperforming building blocks of routines that can suddenly revive under new environmental conditions. Apple’s early growth was based on innovation capabilities and a “freewheeling corporate culture” (Sull, 1999) that attracted creative engineers. When the industry for home computers became mature, cost cutting and discipline became necessary ingredients to fuel a sustained performance, but they ran counter corporate routines and this curbed Apple’s growth in the late 1990s. Only a few years later did this dormant capability of cheerful creativity translated into a booming growth when Apple entered a new environment with the iPod. Thus, the identification of dormant capabilities within the firm should not lead automatically to divestiture, but requires an assessment of which strategic moves (e.g., diversification) could place them in a position to revive organizational performance.

Conclusion and discussion

By providing a distinctive definition of path dependence, this paper was able to investigate the conditions under which the concept can advance knowledge. A (stochastic) path dependent process was defined as one whose outcome distribution changes over time as the process unfolds. At least one negative externality is observed in path dependent processes, possibly coupled with some self-reinforcing mechanism. Suboptimality, market failure or inefficiency are constructs only loosely related to path dependence, while lock-in is a necessary outcome of it, although one cannot predict when it will occur.

Attempts to apply path dependence empirically have failed so far to address three major epistemological issues, namely 1) how to verify or falsify the contingency argument of path dependent explanations?, 2) how to define at what point in time history matters? and 3) how to evidence suboptimality without contradicting the core theorem of path dependence (i.e., $\forall(O, I)$, $P(O|I)<1$)? As long as suboptimality remains an unproved possibility, path dependence should not be conceived of as a theory challenging neoclassical thought – it actually does not need such a confrontation to prove fruitful for social scientists.

I suggested that the use of computer simulations and lab experiments could be a way to overcome the empirical limitations of path dependence and develop its full potential while avoiding confusion and pointless controversies. Indeed, the ontology of a theoretical framework needs to fit that of the reality it intends to analyze (Lawson, 1998). I showed how a simulation modeling the path dependent evolution of organizational capabilities could help to generate new hypotheses for organization and management scientists. The simulation, although very simple, led to the identification of a specific type of capabilities – dormant capabilities – which could ease organizational change and prevent a decrease in performance under specific conditions. In particular, the presence of dormant capabilities could be a factor delaying the occurrence of organizational lock-in since they embody a repository of knowledge that could be leveraged profitably in a different environment. The hypotheses developed display similarities with the literature on coevolution and organizational ecology, which gives a flavor of the integrative potential of path dependence-inspired research, both theoretically and in simulation or experimental designs.

More essentially, this paper was an attempt at shifting scholars' attitude toward path dependence. Path dependence is a *property* of certain processes; it does not predict anything *per se* – only that lock-in will obtain at some point in the future, under certain assumptions. One of these assumptions is the presence of random shocks. Only when contingency includes a component of randomness can path dependence be taken as a distinctive analytical framework. Yet contingency should not become a theoretical shortcut: chance or randomness are not proxies for purposive behavior and will never be, especially since no accurate prediction will ever be derived from assumptions like "people behave randomly" or "people are sometimes lucky, sometimes not". Besides, when theories with similar complexity and explanatory power are competing, it seems reasonable to adopt the one that involves the smaller amount of chance in its assumptions and causal mechanisms. Its external validity is likely to be greater since its predictions will depend less on a particular, contingent context. The challenge for scholars, therefore, is to move away from methodologies based on *ex post* accounts of historical sequences *assumed* to be path-dependent, to research designs where processes are modeled *ex ante* as path dependent in order to derive *empirically testable* hypotheses and develop theories with *predictive power*. In sum, the view of path dependence offered here calls for a radically different approach to the concept.

This paper contributed epistemologically to our understanding of how path dependence can become a building-block for the advancement of knowledge in social sciences; it suggested methodological ways of overcoming the empirical limitations of path dependence and proposed a simulation as an illustration in the field of organization and management sciences. Hypotheses were formulated that shed new light on organizational capabilities by conceptualizing them as alternative paths in a process leading to lock-in. This theoretical contribution requires further development and empirical testing in the future.

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APPENDIX A: Non-ergodic Markov chains

A stochastic process consisting of a sequence of random variables $\{X_n, n=0,1,2,\ldots\}$ with a finite or countable number of possible values and that has, for any state *i*, a fixed probability P_{ij} that it will next be in *j* is called a *Markov chain*.
Any Markov chain verifies the Markov property which states that the future state only depends on the present state:

$$\Pr(X_{n+1} = x \mid X_n = x_n, \ldots, X_1 = x_1) = \Pr(X_{n+1} = x \mid X_n = x_n)$$

- A Markov chain is *irreducible* if all states communicate with each other.
- State *i* has *period* d if $P_{ii}^{\,n} = 0$ whenever n is divisible by d and d is the greatest integer with this property. A state is said to be *aperiodic* when it has a period of 1.
- State *i* is *recurrent* if with certainty a process starting at *j* will eventually return; it is *positive recurrent* if the expected number of transitions needed to return is non-null and finite.
- An irreducible aperiodic Markov chain with only positive recurrent states is said to be *ergodic* (Ross, 1996:ch.4). It has a stationary distribution, i.e. one that verifies, for all *n*:

$$\Pr(X_{n+1} = x \mid X_n = y) = \Pr(X_n = x \mid X_{n-1} = y)$$

When a Markov chain is ergodic, it is possible to reach a given state from any other state through a certain sequence of events.
As a consequence, a Markov chain is *non-ergodic* if: i] there exist states that are not reachable from others (non-irreducibility), ii] there exist states that are never reachable in a given amount of steps (non-aperiodicity) or iii] there exist states that are reachable with probability one only after zero or an infinite number of transitions (non-positive recurrence).

APPENDIX B: Evidence for chance – a development

For logical and epistemological reasons, the random character of complex patterns cannot be verified, even in formal systems (Chaitin, 1974). Gödel established in 1931 that no formal system can endogenously produce the evidence for every true theorem derived from it. Consider the proposition: “this statement is unprovable”, which is a provable proposition only if it false. Since false propositions cannot be proved, it means that there exists at least one proposition whose truth is unprovable, which implies that the formal system within which propositions are produced is incomplete.
Similarly, if we ask a computer to find a series of binary digits that can be proved to be of a complexity greater than the number of bits in the program itself, the computer returns a number that the program should not be able to calculate, because it cannot be proved that a number is of a complexity greater than that of the program generating it. Since the complexity of a random number is approximately equal to its size, like in the first series p.8, this implies that no program can prove the randomness of a number more complex that the program itself. Consequently there exist an infinite amount of random numbers that cannot be proved to be random, whatever the complexity of the system at stake.

APPENDIX C: Formal developments about suboptimality

The claim: "if the past had been different, we would be better off" contradicts the theorem of path dependence:

- a different past does not necessarily imply a different future, since contingent events may modify the path taken.
- if a different past meant a different future, then holding the past constant the future would not change: the alternative outcome B could not occur knowing that I_A did. Therefore, $Pr(O_B \mid I_A) = 0$, which implies that $Pr(O_A \mid I_A) = 1$, a statement that contradicts the theorem of path dependence ($\forall(O,I)$, $Pr(O \mid I)<1$).
- this can be generalized to processes with *n* possible outcomes by writing O_B as $O_1 \vee O_2 \vee \ldots \vee O_{n-1}$.

The claim: "we might be living in the best of all possible worlds" does not contradict the theorem :

- the current outcome O belongs to the set of all possible outcomes S. Assume O is the optimal outcome (whatever the criteria for optimality). Thus $O \in S$, $\forall x \in S$, $O>x$.
- Let us posit the existence of Q, a better outcome than O ($O < Q$). Yet, we cannot prove that $Q \in S$, since there is no deterministic relationship between the past states and the possible outcomes. Therefore, the probability that we live in the best of all possible worlds is non-zero.

APPENDIX D: Generating hypotheses with LSD

The simulation has been conducted using Laboratory for Simulation Development (LSD), a program developed by Marco Valente.

Scale/scope economies work in the simulation as a self-reinforcing mechanism. They create the necessary negative externality that leads to path dependence: they render other capabilities less and less attractive compared with the self-reinforcing one. Random shocks represent the events that may affect managerial support to a capability: shifting stakeholder preferences, internal power relationships, legal changes in the environment, evolution of competitive structure. It need not be assumed that such events occur randomly in the real world, although they do in the simulation.

```
MODELBEGIN
EQUATION("Performance")
/* An organization is represented as a bundle of 10 capabilities receiving different levels of
managerial support.
Capability performance[t]= Performance[t-1] + Scale/Scope economies + Random shocks */

v[0]=V("ShockIntensity"); //parameter allowing to modify the intensity of the random shock
v[1]=VL("Performance",1);
v[2]=V("Learning");
v[3]=VL("share",1); // amount of support received as a share of the total
v[5]=RND;
v[4]=v[1]+v[2]*v[3]+(v[5]-0.5)*v[0]; //learning*share represents scale/scope economies
RESULT(v[4])
```

```
EQUATION("AvPerf")
v[3]=0,v[2]=0;
CYCLE(cur,"Capability")
 {v[0]=VLS(cur,"Support",1);
  v[1]=VS(cur,"Performance");
  v[2]=v[2]+v[0]*v[1];
  v[3]=v[3]+v[0];}
RESULT(v[2]/v[3]);

EQUATION("share")
v[0]=V("Support");
v[1]=V("TotSupport");
RESULT(v[0]/v[1]);

EQUATION("Support")
/* Amount of support[t]=Support[t-1](1+SpeedChange(Performance[t]-
AvPerformance[t])/AvPerformance[t]). That is, more support is allocated when the Capability
has an above average Performance and decreases otherwise. The speed of change is set by
SpeedChange.*/
v[0]=V("Performance");
v[1]=VL("Support",1);
v[2]=V("SpeedChange");
v[3]=V("AvPerf");
RESULT(v[1]*(1+v[2]*(v[0]-v[3])/v[3]))

EQUATION("TotSupport")
v[0]=0;
CYCLE(cur,"Capability")
v[0]=v[0]+VS(cur,"Support");
RESULT(v[0])
MODELEND
```

<u>*Parameters:*</u>

- 480 time periods (if each represents one month, the simulation models 40 years of organizational life).
- *SpeedChange*, *Learning* and *ShockIntensity* are parameterized in order to keep the evolution steady and incremental. For instance, random shocks at each period can modify performance by, at max, ± 3 %.
- Initial values concerning managerial support and performance are identical across capabilities in order to control strictly for initial asymmetries. The results remain stable, though, when asymmetrical values are computed as initial conditions.