

Three Facets of Organizational Adaptation: Selection, Variety, and Plasticity

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### Abstract

When considering the adaptive dynamics of organizations, it is important to account for the full ecology of organizational adaptation, including not only the possibility of learning and adaptation of a given behavior, but the internal selection over some population of routines and behaviors as well. In developing such a conceptual framework, it is necessary to distinguish between the underlying stable roots of behavior, which we term a genotype, and the possibly adaptive expression of those genetic roots, which we term the phenotype. Selection occurs over expressed behavior. As a result, plasticity, the capacity to adapt behavior, poses a tradeoff as it both offers the possibility of adaptive learning, but at the same time mitigates the effectiveness of selection processes to identify more or less superior genetic roots of behavior. These issues are explored in the context of a computational model which examines the interrelationship among processes of variation and selection, and plasticity.

The question of organizational adaptation is one of the most central lines of inquiry within the management literature. The reasons for this are quite fundamental. First, there is the argument emanating from Simon (1956) that in the presence of bounded rationality, search is a central mechanism by which intelligent action is identified. Second, organizations operate in environments that themselves are dynamic and, as a result, the problem of intelligent action is not something that can be resolved once and for all, but must be continually reconsidered. Building on these motivations, discussions of learning and adaptation have a long tradition (<u>Argote, 1999</u>; <u>Argyris, 1982</u>; <u>Cyert & March, 1963</u>; Hedberg, Bystrom, & Starbuck, 1976; Huber, 1991; Levitt & March, 1988; March & Olsen, 1979; March & Simon, 1958). Relatedly, in recent years, a new line of inquiry on dynamic capabilities has been an important focus of attention with the strategy field (Helfat et al., 2007; Teece, Pisano, & Shuen, 1997). While much of this work is situated as an extension of the resource view of the firm (Barney, 1991; Wernerfelt, 1984), other strands take a process perspective and point to the importance of organizational mechanisms in linking and recombining activities within the organization as underlying a firm's dynamic capabilities (Eisenhardt & Martin, 2000). Central to both variants of these discussions of dynamic capabilities is some notion of organizational plasticity, the capacity for an organization to transform its resource and market position to further the pursuit of competitive advantage in a possibly changing environment.

An alternative perspective on organizational adaptation that draws on Campbell's (<u>1965</u>) work points to the process of variation and selection within an organization (<u>Aldrich, 1999</u>; <u>Burgelman, 1991</u>). Critical to a selection based argument is the question

of what constitutes the units of selection (Freeman, 1975). Nelson and Winter (1982) provide what proved to be a fertile answer to this question with their work on organizational routines and the link of these routinized action patterns to the relatively stable heterogeneity in performance across firms. However, subsequent work that closely examines the enactment and re-enactment of routine based behaviors in practice notes a surprising degree of fluidity in what nominally constituted the same action pattern (Birnholtz, Cohen, & Hoch, 2007; Feldman, 2000).

We suggest that this conceptual Gordian knot can be reconciled if we recognize that in the early work of Nelson and Winter (1982) the notion of routine carried both the idea of a gene, an inheritable trait, and phenotype, the behavioral expression of that trait. Once one separates the construct of gene and phenotype, it becomes quite natural to recognize the possibly unique expression of "routine" action. Biological organisms, even if they share identical genetic structure but are subject to distinct environmental circumstances (imagine a plant subject to different degrees of sunlight, water, etc.), will take on distinct phenotypic forms. Adopting this perspective, we suggest that while organizations may possess inheritable traits or genes that pass from one "generation" to the next, such a genetic imprint does not deterministically characterize the organizational form or enacted behaviors. These behaviors may constitute a wide range of organizational practices, ranging from operational activities to high level strategic planning processes. These practices may be more or less codified (<u>Zollo & Winter, 2002</u>) and the coupling between these stable templates and the expression of the practice maybe more or less tight (Jensen & Szulanski, 2007; Winter & Szulanski, 2001). The

more codified bases of these practices can be viewed as reflecting the quasi-genetic quality of routines that Nelson and Winter (1982) speak of, while the fact that realized behavior may be more or loosely coupled to such templates (<u>Birnholtz et al., 2007</u>; <u>Feldman, 2000</u>; Jensen & Szulanski, 2007) is illustrative of the distinction between gene and phenotype that we make here.

Furthermore, not only is there a directional influence from genotype to phenotype, but there is also a reverse causality from selection processes operating on realized phenotypes on the set of surviving genotypes. Consider the implications of this argument for the selectability of the genetic roots of routine behavior. The current basis of routine behavior provides a starting point for a subsequent process of adaptation and learning. Given that it is the learned behavioral patterns that are the basis of selection processes, then genetic bases that offer more or less favorable starting points for a process of adaptation should be differentially selected for. Thus, while the evolutionary process is not Lamarckian in that learned traits or patterns are not themselves inheritable, the learning dynamics importantly underlie the selection process. Within the biology literature, this mechanism is known as the Baldwin effect (<u>Baldwin, 1896</u>) and refers to the capacity of organisms to genetically assimilate across generations traits that prove to be more effective in forming the basis for fitter phenotypes.

This contrast between gene and phenotype is also helpful in conceptualizing what constitutes the plasticity of organizations. In this context, plasticity relates to the adaptation and change of a particular attribute of a behavioral pattern. As typically conceived of in models of search and learning (cf., March, 1991; Levinthal, 1997), this is

represented as a given attribute shifting from one value to another. Thus, the classic process of reinforcement learning that has been the central mechanism considered in the literature on organizational adaptation (Argote, 1999; Levitt & March, 1988) is present at the phenotypic level in terms of expressed behavior. While minimal in this regard, this characterization of plasticity has the attractive analytic property that its value is not presumed. That is, it is an open theoretical and empirical question as to whether varying degrees of plasticity are more or less valuable in enhancing organizational performance over time. In this regard, a distinct dimension of plasticity is the tendency for any change in behavior to be performance enhancing.

This link between plasticity and the selectability of underlying traits points to an important tension that has been absent in discussions of the possible virtues of more or less fungible organizational practices. Flexibility, or plasticity, may impede the intelligent selection among more or less valuable stable traits. As a result, a full treatment of the internal ecology of evolutionary dynamics of organizations must consider this tension.

This issue of the more or less intelligent selection among a set of rules that vary in their plasticity is also intimately related to the issue of the reliable replication of routine behavior emphasized by Nelson and Winter (1982) and elaborated by other scholars (Rivkin, 2001; Szulanski, 1996; Zollo & Winter, 2002). The notion of a routine as having a quasi-genetic quality is critical to Nelson and Winter's theoretical development as it provides a basis by which one can understand the persistence of distinct firm capabilities across time. As Rivkin (2001) demonstrates, the more interconnected the set of behaviors,

the greater the risk of a less than faithful reproduction of those specific behaviors at a later time period. In a similar spirit, Zollo and Winter (2002) point to the important role of the codification of behavior. Keeping to the notion of capabilities as having a gene like quality as posed by Nelson and Winter (1982), our distinction between the phenotype, the expressed behaviors, and the gene, the underlying and stable root of those behaviors, points to an additional threat to replication. If there is considerable play between the set of possible forms (phenotypes) that may emerge from a given genetic basis, then one might observe quite a range in behaviors over time even if the "genetic" basis of that behavior remained constant. There are ways in which the possibility of a broad range of possible actions may be quite functional. The particular form that emerges may reflect the specific contingencies that the organization faces or even may represent improved practices in a fixed context. At the same time, this flexibility increases the risk that a particular expressed behavior will not be successfully re-enacted, even if desired.

Thus, quite apart from any direct cost of investing in a dynamic capability (Helfat et al, 2007), plasticity may reduce the quality of the stable, quasi-genetic traits that underlie an organization's behavior. Further, while not incorporating an explicit, direct cost of plasticity, we do allow for the fact that change efforts may not, in all instances, be performance enhancing and incorporate a parameter, which we term plasticity capability, that allows us to explore settings in which change in behaviors tends to yield an improvement versus settings in which change is, on average, neutral with respect to performance.

Thus, plasticity has possible benefits in terms of the possibility of addressing particular and changed circumstances, but it also entails possible costs in terms of reduced selectability of the underlying traits and less reliably reproduced action patterns. Plasticity can be viewed a kind of minimal, 0<sup>th</sup> order, dynamic capability (Collis, 1994). Clearly, in the absence of plasticity there is no possibility of changed behavior. Certainly, the discussion of dynamic capabilities points to the capacity of some organizations to more effectively transform their resources and capabilities in response to, and even in anticipation of, possibly changed circumstances (Eisenhardt & Martin, 2000; Helfat et al., 2007; Teece et al., 1997). At the same time, scholars (cf., Helfat et al., 2007) have been careful to note that dynamic capabilities should not be viewed in an axiomatic manner as leading to enhanced organizational performance. In this regard, we consider not only the possibility of change, plasticity, but also the likelihood that any such change effort will be performance enhancing.

Further, it is important to note that variability in behavior is not simply a function of the plasticity of a given set of behaviors, but also in the variation in behaviors within the organization. Most models of organizational learning examine a path-dependent, reinforcement learning process of a single pattern of behavior (Lant & Mezias, 1992; Levinthal, 1997). As suggested by the work of March (1991) and central to the arguments of Campbell (Baum & Singh, 1994; Campbell, 1965), variability within the organization is also a critical form of variation. Such mechanisms can only be accounted for in models that incorporate structures and conceptualizations that allow for some

process of intra-organizational selection among an intra-organizational population of behaviors.

While only engaging in the question of dynamic capabilities in a highly stylized manner of considering actions that are more or less flexible, and in that sense dynamic, we wish to explore some of these tradeoffs, or implicit costs of flexibility. Further, viewing the organization as a complex, adaptive system points to the fact that it is the adaptability of the entity as a whole that is critical and that it can be problematic to isolate a particular behavior or capability and interpret the implications of the possible adaptability of this particular element for the organization as a whole. Indeed, this contrast is a central finding in March's (1991) model of exploration and exploitation. While fast learning enhances the performance of the individual actor, an organization composed of a population of fast learners yields lower overall organizational performance. In this sense, it is important to recognize that our focus should not be on the question of what might constitute more or less dynamic capabilities per se, but to what might constitute the properties of more or less dynamic organizations.<sup>1</sup>

As illustrated by Figure 1, we suggest that it is important consider all three facets of organizational adaptation and, importantly their interrelationship. Clearly elements of these ideas of intra-organizational selection, variety, and plasticity have been considered previously in the literature, though not always with these labels. For instance, the socialization process modeled by March (1991) in terms of actors' beliefs or culture by

<sup>1</sup> Of course, at a higher level of analysis of organization populations, there is a separate question of the adaptiveness of economic systems and whether that is enhanced by adaptation and resource allocation at the level of individual organizations, or by the rise and decline of individual organizations.

Carroll and Harrison (1993) effectively act as a selection process with certain beliefs and values reinforced and others diminished. Selection is also effectively represented by the decision rule, or "temperature" in a bandit model (Posen & Levinthal, 2012) where the likelihood of choosing what appears to be the higher performing action is tuned to shift the organization from being relatively exploitive or exploratory in its behavior. The variety present in the organization is importantly a function of its search behavior and whether relatively local or more distant options are considered (Levinthal, 1997; March <u>& Simon, 1958</u>). Variety may also be introduced in a less intentional manner via mutations (Bruderer & Singh, 1996; Davis, Eisenhardt, & Bingham, 2009). The issue of plasticity, under a number of different labels, has been central in the consideration of the question of organizational adaptation. Most commonly this has taken the form of the learning rate in a process of a reinforcement learning (<u>Argote, 1999</u>; <u>Lave & March</u>, <u>1975</u>). However, as Davis et al., (<u>2007</u>) show, the value of flexibility can be considered quite apart from a process of reinforcement learning. As noted earlier, while only capturing a facet of the notion of dynamic capabilities, certainly plasticity is an important, minimal element in that construct.

# Insert Figure 1 about Here

To engage these questions, we develop a stylized model that incorporates elements of intra-organizational selection among action patterns and the degree of plasticity of these action patterns. We find that, as prior literature would suggest (<u>Brown</u>)

& Eisenhardt, 1997; Burns & Stalker, 1961; Helfat et al., 2007; Teece, 2007), that plasticity is more valuable in more dynamic environments. However, in the context of relatively intense internal selection processes, performance is generally enhanced by lower levels of plasticity. Under such settings, effectively selecting out more or less promising genetic bases of behavior among a pool of possibilities yields higher levels of organizational adaptation than allowing for a large measure of plasticity of these behaviors. This result does have an important boundary condition in that with very high levels of effectiveness of phenotypic change in which with great likelihood only performance enhancing changes are enacted, greater levels of plasticity can enhance overall organizational performance.

### MODEL

#### Organizational Practices: Link between Genotypes and Phenotypes

Organizations carry out a wide class of practices, some at a strategic level such as mergers and acquisitions which may shape the very boundaries of the firm, others at a project or business unit level, such as the development of new products or entering new markets, and still others of a more tactical sort, such as carrying out particular policies and procedures. We use the term practices as they can embrace both the fixed, quasigenetic property ascribed to routine-based action and the possibly idiosyncratic behavioral expression of this "genetic" property, possibly responding to the particular circumstances that the actor faces. While the genetic basis of these practices serves as a point of reference for future reproductions, their concrete implementation requires a mix of ad hoc and intentional configuration toward specific purposes in specific circumstances. In other words, we consider as root or genetic behaviors (or hereinafter genotype) the organizational elements in a form that are reproducible over time. This may be in the form of a "decision premise" (Simon, 1947), a "simple rule" (Davis et al., 2009), or an existing pattern of behavior (Cyert & March, 1963; Nelson & Winter, 1982). These stable properties will contain a set of elements that guide behavior, but these elements will generally fail to comprise a complete formalization or reduction to practice.

An organization *i* is thus conceived of as possessing a collection of genotypes, each representing a stable underlying basis of a set of practices.<sup>2</sup> The number of distinct genotypes in each organization is indicated by *W*. An individual genotype *w* of the *i*<sup>th</sup> organization is coded by a binary string of length *N* and is indicated by  $GE_i(w)$  and the organization's collection of genotypic elements by  $GE_i(w)$  [*w*=1,...,*W*].

### Phenotypic Plasticity

From this starting point, a set of phenotypic forms is developed through a process of local adaptation.<sup>3</sup> However, not all the bits of a given phenotype may be subject to such adaptive dynamics. With probability  $p_i$  each bit of a genotypic string  $GE_i(w)$  is

<sup>2</sup> The basic model structure, while novel to the organizations literature (though see Bruderer and Singh, 1996 and Davis, et al., 2009 for broadly related efforts), builds upon a substantial line of work in computational biology (Hinton & Nowlan, 1987; Holland, 1975).

<sup>3</sup> We use the term phenotype to refer to the expression of an individual practice or routine and not to the organizational form as a whole.

specified as being plastic or not. For those attributes which are specified as being nonplastic the associated phenotype  $PE_i(w)$  is held fixed and identical to the parent genotype. At a minimal level, the phenotypic plasticity of the elements that compose the practices characterizes the capacity to adapt associated with a given practice. We model this as the adaptation of a particular attribute of a pattern of behavior.

Specifically, we model this as follows. At the start of the adaptation process, each of the W phenotypes, indicated by  $PE_i(w)$  [w=1,...,W], is generated by cloning the binary string representing each of the *W* genotypes (Mayley, 1996). Subsequent to this, each of the W phenotypes,  $PE_i(w)$  [w=1,...,W], is obtained by performing a series of adaptation trials according to the mechanism described as follow. Similar to Levinthal (1997), a new phenotype  $PE_{i,t+1}(w)$  is obtained by flipping a single one of the plastic elements, or bits of the existing phenotype  $PE_{i,t}(w)$ . With probability equal to the parameter  $p_c$ , which we term plasticity capability, the new value of the element is evaluated and retained if the performance level obtained by the phenotype  $PE_{i,t+1}(w)$  is greater than that associated with the prior phenotype  $PE_{i,t}(w)$ ; alternatively, if the new performance is lower or equal to the starting performance, the change is rejected. In contrast, with probability equal to  $1-p_c$ , the new value is retained without any performance evaluation. The phenotype  $PE_{i,t+1}(w)$  then constitutes a starting point for a subsequent adaptation trial. Therefore, whereas the parameter  $p_l$  captures the tendency of the organization to develop dynamic practices, the parameter  $p_c$  indicates the ability of the organization to evaluate these plastic movements with respect to their performance improvement.

#### Performance Values

Phenotypic performance is denoted by  $F(PE_i(w))$ . The performance of each phenotype *N*-tuple,  $F(PE_i(w))$ , is evaluated in the manner of *NK* fitness landscapes (Kauffman, 1993; Levinthal, 1997), where *N* denotes the number of elements in the string and *K* the level of interdependencies across the *N* elements. More specifically, the performance contribution value of a specific bit depends on the value of bits in *K* other locations. The contribution values associated with each possible combination of the bit's value and the others that affect it are defined by a random number drawn from a uniform distribution [0,1]. The overall performance of a string is then the average of all the contribution values. When *K* equals zero, each element contributes independently to the overall fitness of the string, and the landscape is smooth, whereas when *K*=*N*-1, the fitness landscape is maximally rugged.

*NK* fitness landscapes have been widely adopted in the field of computational biology to model the developmental mechanisms of phenotypic forms from underlying genotypes (Suzuki and Arita, 2007; Mayley, 1996). An alternative to this characterization of the payoff structure that might be used is a single spike payoff as in Bruderer and Singh (1996) or a plateau as in Davis et al. (2009), where some subset of the payoff space receives a positive reward and other regions nothing. The motivation for the use of *NK* structure in the current context is that it is consistent with a process of online learning where the evaluation of modifications of the phenotype is possible. In contrast, in Bruderer and Singh (1996) and Davis et al (2009), trials are offline in that organizations

do not experience the payoff of intermediate phenotypic forms and phenotypic level adaptation is not present.

### Internal Selection Environment

The series of adaptation trials continues until the organization carries out an internal selection event in which a new collection of practices is defined by re-specifying the set of genotypic elements. This new set of genetic elements is referred to as  $GE'_i(w)$  [w=1,...,W]. At each time step, the probability that an internal selection event occurs is equal to  $p_s$ . Higher levels of this parameter define an internal selection environment characterized by relatively frequent selection events and correspondingly less extensive opportunities for phenotypic development.

Internal selection occurs through differential replication of the existing set of genotypes  $GE_i(w)$  [w=1,...,W]. While the performance of the phenotype is the basis for the differential selection among the set of behaviors, it is the genetic roots of that phenotype that is effectively reinforced. That is, genotypes associated with more favorable phenotypic performance are more likely to be replicated. Holland (1975), building on the work of Samuel (1959), has referred to such processes as credit assignment mechanisms. This selection process privileges genotypes associated with superior performance as the basis for replication (Holland, 1975; Mayley, 1996; Suzuki & Arita, 2007).

Given this calculation of phenotypic fitness, a proportionate selection rule is specified based on the relative fitness of the various phenotypes (<u>Holland, 1975; Wilson</u>)

<u>& Bossert, 1971</u>). Accordingly, the probability of a given genotype of the old collection being replicated is equal to the expression:

(1)

While it is standard in the literature on evolutionary biology (Holland, 1975; Wilson and Bossert, 1971) to treat selection as strictly proportional to fitness (i.e., with SP = 1), in the context of a model of intra-organizational selection it is appropriate to allow for more, or possibly less, stringent selection criteria. Indeed, the intensity of internal selection, the degree to which higher performing practices are privileged in the internal selection process, is an important feature of the organizational context influencing the organization's evolutionary dynamics. Within this internal selection environment, the genetic elements that compose the most successful enacted practices diffuse at the level of the internal population (Warglien, 1995). Not only will these patterns of behavior diffuse, but the level of phenotypic plasticity itself changes as behaviors that are more or less plastic are selected for.

Internal selection forces take various forms within the organizations. The policies for the diffusion of the best practices constitute a clarifying example. With the help of tools such as integrated databases and electronic knowledge sharing platforms, organizations attempt to systematize the diffusion of the most successful experiences within their boundaries (Hansen & Haas, 2001) and thereby change the demography of practices within the organization. These activities are often classified under the larger category of knowledge management and constitute what is now a fairly common managerial practice. Another important instantiation of internal selection is present in the

form of capital budgeting processes (<u>Bower, 1970</u>; <u>Burgelman, 1994</u>; <u>Christensen &</u> <u>Bower, 1996</u>) where different initiatives within a firm receive more or less reinforcement.

### Practice Mutation

Change in the demography of practices is driven by a number of forces. First, as just noted, there is the differential selection within the organization over a set of practices. Second, any given practice may take a distinct phenotypic form as a consequence of its expression in a particular set of circumstances to the extent that these practices have plastic elements. Third, there may be some drift or mutation in what we are terming the genetic roots of a given practice. Codified knowledge is not a static property of an organization (Zollo & Winter, 2002) whether through unintended mutation or more deliberate efforts at change. As opposed to phenotypic plasticity, which captures the ability of the organization to adapt phenotypic forms based on their fitness with respect to the external environment, these mutations operate directly on the gene and are not linked with the performance of the associated phenotype. Accordingly, each bit of the newly generated genotypic string is assumed to mutate with a probability,  $p_m$ . After each internal selection event takes place, a set of genotypic elements is specified and a new phase of phenotypic adaptation starts over following the same process described above.

The adaptive process defined in the model is comprised of a hierarchical structure formed by the following two distinct elements: internal selection, which determines the evolution of the genotypic elements, and the phenotypic adaptation process in which the agents enact and refine a phenotypic form from a given genotype. This later process takes place in the periods of time between internal selection events. The phenotypic elements comprise the ecology of practices that are activated, completed, and evaluated over time within the organization (Burgelman, 1994). Episodically these practices are evaluated via a process of internal selection that redefines the organization's population of genotypes. Subsequently, a new set of practices is generated and a new process of phenotypic development begins. As a result, the evolution of the genotype follows a slower adaptive process, which is driven in an indirect fashion from the selection over the enacted phenotypic forms, the set of organizational practices that have been developed.

## Summary of Focal Parameters

In sum, in our analysis, we focus attention on the following focal parameters and contextual setting. First, are a set of parameters that determine the changes in the composition of behaviors. The parameter  $p_l$  reflects the capacity of the organization to change its behaviors by changing the phenotypic expressions of its genotypes. More formally, plasticity references the set of phenotypic elements that are candidates for possible adaptive trials. On the other hand, the parameter  $p_c$  indicates the capacity to evaluate these changes. The parameter,  $p_m$ , refers to the tendency of an organization to randomly mutate its set of genotypes when an internal selection event occurs.

The parameter characterized, *SP*, refers to the exponent on the fitness value in the probability ratio determining the internal selection likelihood (see equation [1]). As noted, it is standard in work on models of population ecology (<u>Wilson & Bossert, 1971</u>) and genetic algorithms (<u>Holland, 1975</u>) to treat selection as being strictly proportional to

relative fitness (i.e., *SP*=1). However, it is reasonable to postulate that organizations, acting with some conscious discrimination among populations of practices, may be more discriminating than a process of pure proportionate selection would suggest. As a consequence, we allow the parameter *(w)*) *SP*, in equation [1], to be taken to a power greater than one, to allow for high levels of internal selection pressure. In addition, for robustness, we investigate the opposing case in which no selection occurs according to which at each internal selection event a perfect replication of the prior collection of genotypes is cloned, regardless of the performance values obtained by each of the related phenotypes.

The configurations of organizations that emerge from the parameters illustrated above are analyzed at different levels of environment dynamism. Change in the environment is modeled as follows. At each step of the simulation, with probability equal to  $p_{dyn}$ , the fitness level associated with each bit that constitutes a phenotype is respecified by drawing a new value from a uniform distribution [0,1].<sup>4</sup> In addition, we examine these evolutionary dynamics in environments of varying complexity (*K*).

# ANALYSIS

The analysis highlights the impact of the critical drives of the evolutionary dynamics of organizations: plasticity, intensity of internal selection, and rates of mutation. In particular, we contrast the case in which organizations are rigid (i.e.  $p_l = 0$ )

<sup>4</sup> Note that all phenotypic elements are subject to this possible change in performance contribution, whether plastic or not.

and a setting in which organizations are maximally capable of phenotypic development  $(p_l = 1)$ . We also vary the tendency of the organizations to engage in a random genetic mutation, examining value of  $p_m$  of 0 and 0.025. Moreover, we also contrast the case of no selection according to which the prior set of genes is perfectly cloned at each internal selection event with the presence of an aggressive internal selection environment (SP=10) and a moderate selection environment (SP=1). Further, we examine these parameters under the two alternative environments: Stable  $(p_{dyn}=0)$  and Dynamic  $(p_{dyn}=0.05)$  and two alternative levels of complexity, *K*, equal to 3 and 9.

Organizations are modeled as being composed of 20 genotypes (W=20) each composed of 20 bits (N=20). At the beginning of the simulation, each organization is seeded with a common level of heterogeneity in genotypes. For each organization, a single random genotype is specified and assigned to 50% of the genotypic strings within the organization and the remaining 50% genetic strings are independently randomly generated. For organizations that exhibit plasticity, each period during the adaptation process one of the plastic elements is chosen at random and a one bit change in this plastic element is evaluated with probability  $p_c$ . If the change is evaluated, a change that improves phenotypic performance is adopted; otherwise, the existing phenotypic form is maintained. With probability equal to 1-  $p_c$ , the one bit change is automatically retained, regardless of its performance level.

The parameter  $p_s$  is calibrated, in a broad sense, and held fixed at the value of 0.2 in the analyses reported here for the following reasons. The parameter  $p_s$  is set so that the model operates intermediate between a pure genetic algorithm (Holland, 1975) and a

typical "hill climbing" mechanism (Levinthal, 1997). Very frequent internal selection events (very high  $p_s$ ) cause the structure to operate more like a pure genetic algorithm in which selection operates directly on genes with little phenotypic development. Indeed, in the limit, the genotypic strings would be not only "starting points" but also "final points" as no phenotypic development would occur. On the other hand, very low levels of  $p_s$ characterize a setting of long periods of pure hill climbing, resulting in a phenotypic search process that identifies a local peak in the fitness landscape and continues to remain there until, with probability  $p_s$ , there is an internal selection event.

The level of initial diversity in the genotype represents a partial substitute for the rate of random mutations in genotypes ( $p_m$ ). Indeed, both these parameters influence the level of variety in the population of genotypes. Given the tendency for some regression to the mean from any initial distribution of diversity, we focus on the parameter  $p_m$ , which determines the ongoing rate of mutation, as a more controlled way to manipulate the level of genotypic diversity. Thus, we keep the initial diversity set at 50% and examine the influence of different values of  $p_m$ .

In a first set of experiments, the parameter indicating the level of plasticity capability,  $p_c$ , is held fixed at an intermediate level (i.e. at 0.5). In Table 1 and Figures 2 and 3 a broad set of experiments is reported in which we contrast configurations of the parameters obtained by tuning plasticity, selection and mutation to low and high levels of the respective parameters as indicated above. Specifically, both in Table 1 and in Figures 2 and 3 the average fitness values over 1000 simulation steps are reported For a sample of 100 independent runs obtained by varying the random seed for each run of the

simulation. Given this sample of 100 organizational histories, also reported in Figures 2 and 3 in addition to the mean value, is the 95% confidence interval level of the range of realized values. For organizations that have plasticity, the fitness registered by the genotypes is also reported as an indicator of the quality of the underlying roots of the organizational practices developed during the adaptation process. Note that for the non-plastic organizations ( $p_1$ =0), the phenotypic performance and the fitness registered by the genotypes are identical, as they do not engage in any phenotypic development activity.

### Insert Table 1 and Figure 2 here

In stable settings (see Table 1 and Figure 2), the existence of an internal selection environment is associated with superior performance, especially when genetic mutation occurs. Indeed, with the presence of internal selection, plasticity plays a detrimental role as, in general, the performance of the plastic organizations tends to be inferior to that of non-plastic organizations both at the level of phenotype and genotype. In contrast, when selection is absent, the plastic organizations display superior phenotypes and equal genotypes with respect to the non-plastic organizations. It is worth noting that in contrast to other analyses based on the *NK* framework (Ethiraj & Levinthal, 2004; Lenox, Rockart, & Lewin, 2010; Levinthal, 1997; Rivkin, 2001; Rivkin & Siggelkow, 2003), the results are not terribly sensitive to the value of *K*. These other studies consider the organization as being composed of a single N-tuple. In contrast, here the organization is

comprises a set of *W* N-tuples that are subject to a process of differential selection as well as the possibility of change at the level of the individual level of behavior. As a result, the aggregate behavior is less subject to the pathology of being trapped by the characteristics of a particular starting point or local peak.

Surprisingly, even in dynamic settings (Table 1 and Figure 3), plasticity plays a detrimental role when present in conjunction with strong internal selection pressure and some level of on-going mutation. When selection and mutation are both present, the contribution to performance generated by the genetic basis of behavior is markedly stronger when plasticity is absent. Thus, while plasticity allows the organization to chase the environmental changes by developing numerous alternative forms, it also leads to the selection of weaker genetic roots. Conversely, when selection occurs solely on the genotypes, as in the case of the non-plastic organizations, the quality of the genes is superior, provided that random genetic mutation is present. In contrast, with moderate levels of internal selection, plasticity is a net contributor to performance, even in the presence of random genetic mutation. Thus, as one might expect, the balance between plasticity and inertia, at least as characterized by adaptive change of the phenotype, shifts towards plasticity in the face of a dynamic environment. However, even in a dynamic environment, the presence of plasticity is not an unambiguous good across all parameter settings.

### Insert Figure 3 about here

To gain more insight on the contingencies regarding the possible beneficial role of plasticity, we engage in additional analyses in which we vary the level of plasticity capability,  $p_c$ , which influences the certitude with which phenotypic change is associated with performance increases. We do so under a setting of a strong internal selection environment and the presence of mutation. Figures 4 and 5 report the performance of non-plastic and plastic organizations and the quality of the genes of the latter in stable and dynamic settings, for a full range of values of  $p_c$ . In contrast, in the earlier analysis  $p_c$  was fixed at an intermediate value of 0.5. The results show that in stable settings only at very high levels of plasticity capability does plasticity enhance organizational performance by facilitating the identification of superior phenotypes. At lower levels, the negative effects of plasticity dominate. Plasticity both works to obscure the effect of differential selection of genes and leads to less reliable expressions of behavior. Therefore, in such settings, it is more effective for the behaviors to remain inert so as to provide a stable and reliable basis for differential selection, especially in complex (high *K*) environments.

In contrast, as  $p_c$  approaches 1 and the plasticity capability is maximal, plasticity allows slight superior phenotypic performance. If, with very high reliability, phenotypic change only occurs in association with performance improvement, then the phenotypic flexibility offered by plasticity becomes a net-plus with respect to observed performance. Indeed, at extreme values of  $p_c$ , we see not only superior phenotypic performance with plasticity, but also that the average values of the genotypes are superior as well. In a stable setting and with  $p_c$  at or near 1, genes that are associated with higher performing phenotypes are identified. As a consequence, over time, the overall quality of the set of genotypes underlying this phenotypic performance improves. This phenomena is known in the biology as the Baldwin effect (Baldwin, 1896) which relates to the fact that the genetic bases for learned characteristics can ultimately be selected for. It is important to note though, as examined below, that this result with respect to the quality of the set of genes is not robust to the context of dynamic environments.

# Insert Figure 4 and 5 here

In more dynamic environments, plasticity can contribute more to phenotypic performance than differential selection and mutation alone, with the threshold on plasticity capability for plasticity to be useful equal to approximately 0.6 for K=3 and roughly 0.85 in the case of K=9. Thus, the results can link with existing arguments regarding the role of plasticity in dynamic environments (Teece et al, 1997; Eisenhardt and Martin, 2000; Helfat, 2007), but at the same time they offer important boundary conditions regarding the level of efficacy of these phenotypic adaptations and the degree of complexity of the problem environment, as characterized by K.

Further, even in such settings, plasticity obscures the differential selection of the genetic basis of behavior. While in a stable setting with high levels of plasticity capability plasticity can actually enhance the quality of the genetic basis of behavioral patterns, this result no longer holds in a dynamic setting. This difference is due to the following

mechanism. In a stable setting, plasticity is limitedly beneficial as the environment is fixed. As a result, selection of plastic phenotypes primarily occurs on phenotypes that are quite close to their starting genes. In dynamic settings when organizations are plastic, plasticity provides some robustness in action in response to environmental changes. However, this same property implies that selection occurs on phenotypes that are often rather far from their starting genotype and, as a result, less favorable genotypes have higher chances to survive the process of internal selection. As a result, we do not observe the effective selection of genes for organizations that exhibit plasticity and, as a further consequence, do not observe the Baldwin effect that is present in a stable environment.

In sum, our simulations show that in an effective selection environment generated by the co-occurrence of strong selection pressure and on-going mutation, that plasticity is not an unabashed good. While plasticity offers the straightforward virtue of allowing for performance enhancing phenotypic changes, this possibility comes at an implicit cost. While no explicit cost is postulated for phenotypic change, greater plasticity creates a looser coupling between expressed behavior, phenotypic performance, and its underlying genetic basis. Plasticity in any given period allows for a superior phenotype to be identified; however, this same process increases the likelihood of inferior genes surviving. Further, plasticity raises the possibility of performance degrading changes from a given genetic starting point, as well as performance enhancing changes. Particularly when the problem environment is complex (high *K*), organizational adaptation via a process of fixed phenotypic forms generated by a diverse population of genotypic bases, with the diversity preserved by an on-going process of mutation, can yield superior results. These tensions are further modified by the degree of dynamicity in the environment, with a more dynamic environment shifting the balance towards plasticity being a desired feature, but the fundamental tensions identified here do not abate or disappear.

### **DISCUSSION AND CONCLUSION**

The image of organizations as being driven by relatively stable routine-driven behavior and being the subject of competitive selection pressure at the population level is a theoretically and empirically powerful perspective. However, it is important to extend our evolutionary models at the organizational level in at least two dimensions. One is to incorporate the fact that considerable heterogeneity is typically present within an individual organization regarding organizational practices. In addition, it is critical in an evolutionary account to distinguish between the genetic encoding associated with a given practice and the expression of that practice in a given context. In at least a stylized manner, the current work has introduced both these elements.

Organizational performance, in a direct sense, is a function of the realized behaviors in which the organization engages. What we term as phenotypic plasticity has the virtue of allowing for a greater range of action. However, we observe that this plasticity diminishes the effectiveness of selecting the underlying genetic roots of these behavioral patterns in dynamic settings. As a result, such organizations rely on an inferior

set of standard practices. Thus, the basis of superior performance entails a tension between plasticity's positive rule in offering near-term flexibility in action and its longterm consequences for the quality of the underlying genetic basis of organizational practices. In a stable environment, the net effect of these forces is to favor intra organizational evolutionary dynamics in which the individual behavior patterns are relatively inert, but there is fairly intense differential selection among them. In dynamic environments, the tradeoff between the flexibility benefits of plasticity and its negative implications for the quality of the genetic basis of behavior shifts, with a shift towards a return to plasticity. However, plasticity yields a net adaptive benefit only under settings in which, with a high level of certitude, these individual changes are performance enhancing.

The question of what constitutes the characteristics of an adaptive organization is quite naturally a central issue for management theorists who strive to understand the possibilities and pathologies of organizational change. In particular, the issue of the plasticity of organizations has surfaced in recent years within the strategy literature in the context of discussions of dynamic capabilities (Teece et al., 1997), stable properties of organizations that facilitate efforts at effective change, as distinct from firm differences in capabilities associated with current performance. Work on dynamic capabilities has help shift the discourse in the strategy field from a focus on the pursuit of sustained competitive advantage in a relatively fixed competitive context to a recognition of the centrality of the adaptive properties of organizations. However, it is important to recognize that organizational adaptation is a collective property. As such, the implication

of the adaptability of any particular facet of organizational behavior is, in general, ambiguous with respect to the adaptiveness of the collective. In this sense, to understand organizational evolution, one should keep the focus on the interrelated attributes of the (possibly) dynamic organization rather than on some specific subset of capabilities.

Internal selection pressure and variance in practices are complementary mechanisms of adaptive dynamics. In contrast, in changing environments, plasticity and internal selection can work at cross-purposes, with the presence of plasticity reducing the effectiveness of the selection process. Organizations are complex systems. Their robustness and adaptability is a function of the interplay of multiple factors guiding their evolutionary dynamics. Plasticity and near-term phenotypic adaptation can come at the cost of less effective selection for stable, quasi-genetic bases of behavior.

In our interest as a field in considering the adaptive benefits of phenotypic plasticity, we have tended to neglect the role that genotypic diversity plays in fostering robustness. The mechanisms of variation-selection-retention put forward by Campbell (1965) do not rely on the adaptability of a particular component of organizational behavior, but rather a basic Darwian process of differential selection. Mechanisms that support an ongoing level of internal variation, such as turnover, slack, and local experimentation, facilitate organizational adaptation in a manner quite distinct from the adaptation of a given practice or behavior.

Beyond the particular results of our model and analysis, we hope the work serves to highlight the importance of engaging the rich internal ecology of organizational evolution and to provide a useful conceptual framework for examining these issues.

Adaptive change in specific behaviors is part of a broader process of organizational adaptation, but only a part. Understanding the mix of such mechanisms with processes of variation and selection is critical for a fuller understanding of the problem of organizational adaptation. While typically as scholars we tend to compartmentalize our efforts into a subset of these mechanisms, either on the one hand processes of adaptive learning with respect to an organizational feature or to conceptions of an internal ecology of variation and differential selection, all three mechanisms play an important, and subtly interrelated role. Thus, all three facets of organizational evolution need to be taken on board for a complete picture of these dynamics.

### References

Aldrich, H. 1999. *Organizations evolving*. Thousand Oaks, CA: Sage Publications Ltd.

- Argote, L. 1999. *Organizational learning: Creating, retaining, and transferring knowledge*: Kluwer Academic Publishers.
- Argyris, C. 1982. *Reasoning, learning, and action: Individual and organizational*: Jossey-Bass San Francisco.
- Baldwin, J. 1896. A new factor in evolution. *The american naturalist*, 30(354): 441-451.
- Barney, J. 1991. Firm Resources and Sustained Competitive Advantage. *Journal of Management*, 17(1): 99-120.
- Baum, J. A. C., & Singh, J. V. 1994. *Evolutionary dynamics of organizations*: Oxford University Press, USA.
- Birnholtz, J., Cohen, M., & Hoch, S. 2007. Organizational character: On the regeneration of camp poplar grove. *Organization Science*, 18(2): 315.
- Bower, J. L. 1970. Managing the Resource Allocation Process: A Study of Corporate Planning and Investment Decision. *Harvard Business School, Boston*.
- Brown, S. L., & Eisenhardt, K. M. 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative science quarterly*: 1-34.
- Bruderer, E., & Singh, J. 1996. Organizational evolution, learning, and selection: A genetic-algorithm-based model. *The Academy of Management Journal*, 39(5): 1322-1349.
- Burgelman, R. 1991. Intraorganizational ecology of strategy making and organizational adaptation: Theory and field research. *Organization Science*, 2(3): 239-262.
- Burgelman, R. 1994. Fading Memories: A Process Theory of Strategic Business Exit in Dynamic Environments. *Administrative Science Quarterly*, 39(1).
- Burns, T., & Stalker, G. M. 1961. *The Management of Innovation*: Tavistock Publications, Ltd.
- Campbell, D. T. 1965. Variation and Selective Retention in Socio-Cultural Evolution. In H. R. Barringer, G. I. Blankstein, & R. W. Mack (Eds.), *Social Change in*

*Developing Areas: A Reinterpretation of Evolutionary Theory*. Cambridge, MA: Schenkman.

- Carroll, G., & Harrison, J. 1993. Evolution among competing organizational forms. *World Futures*, 37: 91-110.
- Christensen, C. M., & Bower, J. L. 1996. Customer power, strategic investment, and the failure of leading firms. *Strategic management journal*, 17(3): 197-218.
- Collis, D. J. 1994. How valuable are dynamic capabilities? *Strategic Management Journal*, 15: 143-151.
- Cyert, R., & March, J. G. 1963. *A Behavioral Theory of the Firm*. Englewood Cliffs, N.J.: Prentice Hall.
- Davis, J., Eisenhardt, K., & Bingham, C. 2007. Developing theory through simulation methods. *Academy of Management Review*, 32(2): 480.
- Davis, J. P., Eisenhardt, K. M., & Bingham, C. B. 2009. Optimal Structure, Market Dynamism, and the Strategy of Simple Rules. *Administrative Science Quarterly*, 54: 413-452.
- Eisenhardt, K., & Martin, J. 2000. Dynamic capabilities: what are they? *Strategic management journal*: 1105-1121.
- Ethiraj, S., & Levinthal, D. 2004. Hoping for A to Z While Rewarding Only A: Complex Organizations and Multiple Goals. *Organization Science*, 20(1): 4-21.
- Feldman, M. 2000. Organizational routines as a source of continuous change. *Organization Science*: 611-629.
- Freeman, J. 1975. The Unit Problem in Organizational Research, *Annual Meeting of the American Sociological Association*. San Francisco.
- Hansen, M., & Haas, M. 2001. Competing for attention in knowledge markets: Electronic document dissemination in a management consulting company. *Administrative Science Quarterly*, 46(1): 1-28.
- Hedberg, B. L. T., Bystrom, P. C., & Starbuck, W. H. 1976. Camping on seesaws: Prescriptions for a self-designing organization. *Administrative Science Quarterly*: 41-65.
- Helfat, C., Finkelstein, S., Mitchell, W., Peteraf, M., Singh, H., Teece, D., & Winter, S. 2007. *Dynamic capabilities*: Blackwell Pub.

- Holland, J. 1975. *Adaptation in natural and artificial systems*: Ann Arbor MI: University of Michigan Press.
- Huber, G. P. 1991. Organizational learning: The contributing processes and the literatures. *Organization science*, 2(1): 88-115.
- Jensen, R. J., & Szulanski, G. 2007. Template use and the effectiveness of knowledge transfer. *Management Science*, 53(11): 1716-1730.
- Kauffman, S. A. 1993. *The Origins of Order: Self-organization and Selection in Evolution*. New York, USA: Oxford University Press.
- Lant, T. K., & Mezias, S. J. 1992. An organizational learning model of convergence and reorientation. *Organization science*, 3(1): 47-71.
- Lave, C. A., & March, J. G. 1975. *An introduction to models in the social sciences*. New York: Harper & Row.
- Lenox, M. J., Rockart, S. F., & Lewin, A. Y. 2010. Does interdependency affect firm and industry profitability? An empirical test. *Strategic Management Journal*, 31(2): 121-139.
- Levinthal, D. A. 1997. Adaptation on rugged landscapes. *Management Science*, 43(7): 934-950.
- Levitt, B., & March, J. 1988. Organizational learning. *Annual review of sociology*, 14(1): 319-338.
- March, J. G., & Olsen, J. P. 1979. *Ambiguity and choice in organizations*: Universitetsforlaget.
- March, J. G., & Simon, H. A. 1958. Organizations. New York: Wiley.
- Mayley, G. 1996. Landscapes, learning costs, and genetic assimilation. *Evolutionary Computation*, 4(3): 213-234.
- Nelson, R. R., & Winter, S. G. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap.
- Posen, H. E., & Levinthal, D. A. 2012. Chasing a moving target: Exploitation and exploration in dynamic environments. *Management Science*, 58(3): 587-601.
- Rivkin, J. W. 2001. Reproducing Knowledge: Replication Without Imitation at Moderate Complexity. *Organization Science*, 12(3): 274.

- Rivkin, J. W., & Siggelkow, N. 2003. Balancing Search and Stability: Interdependencies Among Elements of Organizational Design. *Management Science*, 49(3): 290-311.
- Samuel, A. 1959. Some Studies in Machine Learning Using the Game of Checkers. *IBM Journal of Research Development*, 31: 211-229.
- Simon, H. A. 1947. *Administrative Behavior. A Study of Decision-Making Processes in Administrative Organization*. New York, NY: The Free Press, Macmillan.
- Simon, H. A. 1956. Rational choice and the structure of the environment. *Psychological Review*, 63(2): 129-138.
- Szulanski, G. 1996. Exploring internal stickiness: Impediments to the transfer of best practice within the firm. *Strategic management journal*, 17(WINTER): 27-43.
- Teece, D. J., Pisano, G., & Shuen, A. M. Y. 1997. Dynamic Capabilities and Strategic Management. *Strategic Management Journal*, 18(7): 509-533.
- Teece, D. J. D. 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic management journal*, 28(13): 1319.
- Warglien, M. 1995. Hierarchical selection and organizational adaptation. *Industrial and Corporate Change*, 4(1): 161.
- Wernerfelt, B. 1984. A resource-based view of the firm. *Strategic management journal*: 171-180.
- Wilson, E., & Bossert, W. 1971. *A primer of population biology*. Sunderland, MA: Sinauer Associates.
- Winter, S. G., & Szulanski, G. 2001. Replication as strategy. *Organization science*, 12(6): 730-743.
- Zollo, M., & Winter, S. G. 2002. Deliberate learning and the evolution of dynamic capabilities. *Organization science*: 339-351.

# Figure . Three Facets of Organizational Adaptation



			Random Mutation Probability ( <i>p</i> <sub>m</sub> )						
				No (0)			Yes (0.025)		
Selection Pressure			No (0)	Mod (1)	High (10)	No (0)	Mod (1)	High (10)	
K	Environmental Dynamicity ( $p_{dyn}$ )	Phenotypic Plasticity ( <i>p</i> <sub>1</sub> )							
Low (3)	Stable	NO	0.503	0.563	0.595	0.501	0.569	0.687	
		YES	0.520 <i>0.499</i>	0.543 0.536	0.577 0.585	0.521 0.502	0.549 0.544	0.629 <i>0.682</i>	
	Dynamic	NO	0.500	0.501	0.504	0.5	0.516	0.563	
		YES	0.518 <i>0</i> .5	0.519 <i>0.502</i>	0.519 <i>0.502</i>	0.517 <i>0.499</i>	0.524 <i>0.510</i>	0.546 <i>0.541</i>	
High (9)	Stable	NO	0.501	0.561	0.599	0.498	0.547	0.654	
		YES	0.518 <i>0.495</i>	0.530 <i>0.519</i>	0.550 <i>0.562</i>	0.519 <i>0.499</i>	0.527 <i>0.514</i>	0.576 <i>0.613</i>	
	Dynamic	NO	0.499	0.502	0.504	0.5	0.517	0.569	
		YES	0.518 <i>0.499</i>	0.518 <i>0.498</i>	0.520 <i>0.501</i>	0.519 <i>0.499</i>	0.521 0.504	0.534 0.546	

Table . Average Phenotypic Performance and Quality of the Genotypes

NOTES: The table reports the averages performance of the phenotypes and of the genotypes (in italic). For each configuration, W=20, N=20, plasticity capability  $p_c = 0.5$ ,  $p_s = 0.2$ .



Figure 2. Simulation Results in Stable Settings and K=3 (top panel) and K=9 (bottom panel)

NOTES: The graphs report the averages performance over 100 independent runs. The vertical bars indicate the 95% confidence intervals. On the x-axis "I" indicates an inert organization with absence of plasticity, mutation and selection, "P", "S" and "M" indicate the presence of plasticity ( $p_1$  = 1), selection (*SP*=10) and mutation ( $p_m$ =0,0.025), respectively; /ph and /g indicate the reference to phenotipic and genotypic performance, respectively. For each experiment plasticity ( $p_c$ ) = 0.5.In the graph at the top K is set to 3 whereas the graph at the bottom K is set to 9.



Figure 3. Simulation Results in Dynamic Settings and K=3 (top panel) and K=9 (bottom panel)

NOTES: The graphs report the averages performance over 100 independent runs. The vertical bars indicate the 95% confidence intervals. On the x-axis "I" indicates an inert organization with absence of plasticity, mutation and selection, "P", "S" and "M" indicate the presence of plasticity ( $p_l = 1$ ), selection (*SP*=10) and mutation ( $p_m$ =0,0.025), respectively; /ph and /g indicate the reference to phenotipic and genotypic performance, respectively. For each experiment plasticity capability ( $p_c$ ) = 0.5.In the graph at the top K is set to 3 whereas the graph at the bottom K is set to 9.



#### Figure 4. Performance of Inert and Plastic Organizations at Different Levels of Plasticity Capability in Stable Settings

NOTES: The graph reports the averages performance over 100 independent runs. The vertical bars indicate the 95% confidence intervals. In the left panel the data are set to K=3. In the right panel K=9. Plasticity "No" and "Yes" refer to values of  $p_1$  equal to 0 and 1, respectively. For each data series  $p_m$ =0.025 and SP=10.



#### Figure 5. Performance of Inert and Plastic Organizations at Different Levels of Plasticity Capability in Dynamic Settings

NOTES: The graph reports the averages performance over 100 independent runs. The vertical bars indicate the 95% confidence intervals. In the left panel the data are set to K=3. In the right panel K=9. Plasticity "No" and "Yes" refer to values of  $p_1$  equal to 0 and 1, respectively. For each data series  $p_m$ =0.025 and SP=10.