

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

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Learning and adaptation are a central basis for intelligent and effective organizational action (Argote, 1999; Cyert & March, 1963; Hedberg, Bystrom, & Starbuck, 1976; Huber, 1991; Levitt & March, 1988; March & Olsen, 1979; March & Simon, 1958). While adaptation is typically characterized by processes of reinforcement learning (Levitt & March, 1988), processes of variation and selection within an organization are important mechanisms as well (Campbell, 1965; Aldrich, 1999; Burgelman, 1991), potentially supplementing and interacting with those of reinforcement learning. Indeed, as Anderson (1995: 54) notes, in general processes of selection at one level of analysis can be recast at a higher level of analysis as a process of adaptation.

Not only are adaptation of a particular behavior and selection among behaviors two distinct mechanisms of organizational change, but the interplay between them poses an important tension for the adaptiveness of the organization as a whole. In particular, if differential selection within an organization among routines, projects, or practices plays an important role in enhancing overall organizational adaptation, then the plasticity of these underlying behaviors may in fact be problematic. As Levinthal and Posen (2007) argue, while an organizational trait, such as a search strategy, may be fixed, the resulting behavior that results from that fixed strategy will tend to vary over time. Further, selection processes operate on this realized behavior. From this perspective, greater plasticity is potentially problematic as it creates a loose coupling between what is being selected for, some relatively stable underlying behavioral

template, and the basis of selection, the observed performance associated with the expressed behavior that stems from that template.

As a result, plasticity not only offers potential benefits in terms of the possibility of addressing specific and possibly changed circumstances, but it also entails possible costs in terms of reduced selectability of the underlying traits. Furthermore, plasticity poses the potential liability of the lessening of the reliable reproduction of behaviors.

As an illustrative example of these tensions consider a school system attempting to enact an effective pedagogy. One practice might suggest to the instructor that they should apply the day's social studies readings to a contemporary current event. This approach allows for a great deal of flexibility in meeting student interest and in responding to their current experiences. An alternative approach would be to identify a large set of fairly "scripted" lesson plans and run a set of experimental trials over these alternative plans. The former approach might lead to some engaging and informative class sessions, but is likely to lead a wide range of resulting experiences both with respect to the particular content conveyed and the lessons internalized by the students. Thus, the question as to whether this pedagogical approach is an attractive one becomes a complicated one to answer. Further, successful experiences would not be readily transferred across time, let alone across instructors. In contrast, the later approach would result in some subset of lesson plans as being identified as relatively effective and these lesson plans could be fairly reliably replicated both across time and across instructors. Of course, the relative merit of the two approaches would also depend on the size, diversity, and quality of the initial set of "scripts" or

lesson plans under the later approach and, particularly in the former approach, on the efficacy of the set of instructors.

To engage these questions, we develop a computational model that incorporates elements of intra-organizational selection among action patterns and the degree of plasticity of these action patterns. Plasticity is not treated as inherently beneficial or adverse to the organization. Rather, it is treated as the capacity of the organization to adapt its policies in the face of feedback regarding the relative effectiveness of these actions in a manner standard to models of adaptive learning (Lave & March, 1975). Given a population of heterogeneous rules or routines within the organization, a critical feature of an organization is the nature of the internal selection environment over these practices. We explore how the intensity of these internal selection processes interacts with the degree of plasticity of individual patterns of action, resulting in plasticity having an adaptive or possibly maladaptive role for the organization as a whole.

We find that in the context of relatively intense internal selection pressure, performance may be enhanced by lower levels of plasticity. Under such settings, effectively selecting out more or less promising stable bases of behavior among a pool of possibilities can yield higher levels of organizational adaptation than allowing for a large measure of plasticity of these behaviors. This result does have an important set of boundary conditions. First, with very high levels of effectiveness of adaptive change, that is with great likelihood only performance enhancing changes are enacted, greater levels of plasticity can enhance overall organizational

performance. Further, we find, as prior literature would suggest (Brown & Eisenhardt, 1997; Burns & Stalker, 1961; Helfat et al., 2007; Teece, 2007), that plasticity, other things being equal, is more valuable in more dynamic environments. In addition, as the ‘fodder’ over which selection occurs, in the sense of the number and variety of distinct practices decreases or increases, the boundary condition at which plasticity is or is not beneficial shifts.

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 its plasticity for the adaptability of the organization as a whole. In this sense, the work helps to shift the focus from a consideration of a particular set of “dynamic capabilities” (Eisenhardt & Martin, 2000; Helfat et al., 2007; Teece, Pisano, & Shuen, 1997) to an evaluation of what might constitute the properties of more or less dynamic organizations.

MODEL

Organizational Practices: Link between Templates and Practices

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

operations. We use the term practices as this can embrace both the relatively fixed property ascribed to routine-based action and the possibly idiosyncratic expression of these reoccurring patterns of behavior (Birnholtz, Cohen, & Hoch, 2007; Feldman & Pentland, 2003).

Following Jensen and Szulanski (2007), we use the term template to refer to the underlying basis for expressed behaviors, which may in turn reflect a mix of ad hoc and intentional choices regarding specific purposes in specific circumstances as well as the direct replication of actions indicated in the template itself (Jensen & Szulanski, 2007). This root template may be in the form of a “decision premise” (Simon, 1947), a “simple rule” (Davis et al., 2009), “ostensive routine” (Feldman & Pentland, 2003), or an existing pattern of behavior (Cyert & March, 1963; Nelson & Winter, 1982). These stable properties will tend to contain a set of elements that guide behavior, but these elements will generally fail to comprise a complete formalization or reduction to practice.

Similar to Bruderer and Singh (1996), we represent an organization as possessing a collection of such templates, each representing a stable underlying basis of a set of practices. A specific template at time t is denoted by $X_{w,t}$ with an organization’s full set of W templates denoted by $\{X_{w,t}\}$ where $w=[1,W]$. An individual template of an organization is coded by a binary string of length N and an individual element of that string, i , is denoted by $X_{w,t}(i)$.

Plasticity

From a given template, a set of practices is developed through a process of local adaptation. However, not all the elements of a given template may be subject to such adaptive dynamics. With probability p_l each bit of a template string $X_w(i)$ is specified as being plastic or not. Plasticity is not treated as a time-varying attribute. The likelihood of a particular element of the template being plastic or not is specified with the initial specification of the template. For those attributes which are specified as being non-plastic, the associated practice is held fixed and identical to the underlying template. At a minimal level, the plasticity of the elements that compose the practices characterizes the capacity to adapt associated with a given practice.

We model this structure as follows. At the start of the adaptation process, each of the W practices, indicated by $\{Y_{w,t}\}$, $w=[1,W]$, is generated by cloning the binary string $X_{w,t}$ representing each of the W templates (Mayley, 1996). Subsequent to this, each of the W practices is obtained by performing a series of adaptation trials in a manner similar to Levinthal (1997) in which a new practice $Y_{w,t+1}$ is obtained by flipping one of the plastic elements, $Y_{w,t}(i)$, of the existing practice.

With probability equal to the parameter p_c , which we term plasticity capability, the new practice is evaluated and that element is changed if the performance level obtained by the practice $Y_{w,t+1}$ is greater than that associated with the prior practice $Y_{w,t}$ and rejected if the change would lower performance. In contrast, with probability equal to $1-p_c$, the new element is changed without any performance evaluation.¹ The

¹ More generally, per Knudsen and Levinthal (2007), the likelihood of adopting a performance improving (or diminishing) alternative would be a function of both the capability of the evaluator in evaluating and the magnitude of the performance change.

practice $Y_{w,t+1}$ then constitutes a starting point for a subsequent adaptation trial.

Therefore, whereas the parameter p_l captures the tendency of the organization to change its practices, the parameter p_c indicates the ability of the organization to evaluate these plastic movements with respect to their performance improvement.

Performance Values

The performance associated with a given practice is specified 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 (Mayley, 1996; Suzuki & Arita, 2007), a process akin to the identification of a particular practice from a given template. 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 the NK structure in the current context is that it is consistent with a process of on-line learning in which the evaluation of learning trials, modifications in enacted behavior, is possible. In contrast, in Bruderer and Singh (1996) and Davis et al (2009), trials are off-line in that organizations do not experience the payoff of behaviors that are tried and a process of experiential search is not present.

While interdependencies within elements of a given practice are considered in this manner, the contribution to overall organization performance from the set of practices is treated as simply the average of their individual payoffs. For instance, the success of a particular foreign entry strategy might depend on a subtle configuration of choices about the degree to which the local unit was given autonomy in their marketing efforts, choice of localization of manufacturing, and so on; however, the success of the foreign entry strategy in one context may be largely independent of the strategy in another context. Thus, we model explicitly the possibility of interdependencies within a given practice, but, for simplicity, treat the practices as making independent contributions to organizational performance.² Formally, we represent the performance value of an individual practice as $F(Y_{w,t})$, and organizational performance as $\sum F(Y_{w,t})/W$, averaging over W , the total number of practices within the organization.

² Including interdependencies among practices in some sense creates an extended single practice of the “whole”, that is the performance of the organization would be characterized by a single string of length $N \times W$. Such a structure raises a distinct class of issues of selection and evaluation, issues related to work on modular systems (Ethiraj and Levinthal, 2004) and task division (Rivkin and Siggelkow, 2003).

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 templates. Note that such a selection event does not change the number of practices but may change their composition. 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 experiential learning. We focus on a moderate level of p_s in our subsequent analysis as very low values of p_s , in the limit, approach a process of simple path-dependent adaptation with selection playing a very limited role. Conversely, at very high values of p_s the model approaches a genetic algorithm (Holland, 1975) where selection occurs on the underlying templates and there is little scope for distinct enacted behaviors to emerge. While the extremes of path-dependent learning (Levinthal, 1997) and genetic algorithms (Bruderer & Singh, 1996) are important processes, the joint role of the adaptation of individual practices and selection over these practices is present at intermediate frequency of selection events.

Internal selection occurs through differential replication of the existing set of templates $\{X_{w,t}\}$, $w=[1,W]$. While the performance of the resulting practices is the basis for the differential selection, it is the set of underlying templates for these practices that are effectively reinforced. That is, templates associated with more

favorable 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 templates associated with superior performance as the basis for replication (Holland, 1975; Mayley, 1996; Suzuki & Arita, 2007).

A proportionate selection rule is specified based on the relative fitness of the various practices (Holland, 1975; Wilson & Bossert, 1971). Accordingly, the probability of a given template, $X_{w,t}$, being replicated is set equal to:

$$\frac{F(Y_{w,t})^{SP}}{\sum_w F(Y_{w,t})^{SP}} \quad (1)$$

This replication rule is applied to each of the W templates. So, while the composition of the set of templates may change over time, the number, W , of templates remains constant. Further, it is important to recognize that while the total number of templates is held fixed, the number of distinct templates may change and, indeed, in the limit the organization may, as the result of multiple rounds of selection, have W copies of a single template. While it is standard in the literature on evolutionary biology (Holland, 1975; Wilson & 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 underlying elements that compose the most successful enacted practices diffuse at the level of the internal population (Warglien, 1995).

Internal selection forces take various forms within the organizations. The policies for the diffusion of 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. Another important instantiation of internal selection is present in the form of the capital budgeting processes (Bower, 1970; Burgelman, 1994; Christensen & Bower, 1996) where different divisions or initiatives within a firm receive more or less reinforcement.

Change in Template

Codified knowledge is not a static property of an organization (Zollo & Winter, 2002) whether through unintended mutation or more deliberate efforts at change. We consider both sorts of mechanisms. After each internal selection event takes place, for each of the W templates, each bit of the template is assumed to mutate with a probability p_m .³ In addition, with each internal selection event, some fraction, p_r , of the enacted plastic

³ The net degree of mutation is a joint function of the frequency of selection and the degree of mutation, as characterized by p_m , contingent on a selection effect. Thus, while mutation is linked to selection, its magnitude can be manipulated in the model independently via p_m .

practices are encoded in the underlying template and form the starting point for the identification of subsequent practices.

Full retention of enacted practices not only poses challenges with respect to the encoding of behavior, but also would pose challenges with respect to the adaptive process itself. Consider a template for how a technology firm goes about its product development efforts. The efficacy of these efforts might be judged by the length of time of the development process and the quality of the resulting new product. However, much of what occurred in that development process is likely specific to the context of that particular technology or product. The firm would unlikely to be interested in replicating the exact process in the future as it will be involved in some “next generation” effort. Rather, replication would more likely be with respect to the general guidelines of the development effort (e.g., how the team was staffed in terms of skills and functional background; the nature and timing of the milestones imposed on the team; the nature of the interface/coordination efforts between the development team and other operating units; etc.). In addition, it is worth noting that if the enacted practice in full were retained, this would result in a basic process of path-dependent learning. That is, a set of individual learned behaviors would develop along the lines of Levinthal (1997), with some differential selection among them. In such a setting, the adaptation challenge posed by the potential loose coupling between templates and realized practices would not be present. At the other extreme, if none of the elements of the enacted practice were retained in the new set of templates, then the potential cost of plasticity in terms of the selectability of templates would be amplified.

Environmental Change

Change in the environment is modeled as follows. At each step of the simulation, with probability equal to f_r , the fitness level associated with each bit that constitutes a practice is re-specified by drawing a new value from a uniform distribution [0,1]. Thus, environmental change is distinct from changes in behavior, with environmental change reflecting a change in the payoff associated with a given set of practices as opposed to a change in a practice itself.

In sum, the adaptive process defined in the model is comprised of a hierarchical structure formed by the following two distinct processes: internal selection, which determines the evolution of the underlying templates, and the path-dependent process of experiential learning in which behavior is enacted and refined from a given set of underlying templates. This later process takes place in the periods of time between internal selection events. Episodically, these practices are evaluated via a process of internal selection that redefines the organization's population of templates. Subsequently, a new process of experiential learning begins. As a result, the evolution of the templates follows a slower adaptive process, which is driven by the periodic selection over the enacted practices, while the adaptation of the practices occurs on an ongoing basis.

A suggestive illustration of the adaptive dynamics is provided in Figure 1. Expressed practices are derived from a population of templates. The degree of tight or loose coupling between the set of practices and the underlying template is

determined both by the degree of plasticity and the time interval between internal selection events. At the point of an internal selection event, the merit of these different templates is evaluated on the basis of the relative performance of the set of practices and a new population of templates is specified. This new population of templates is determined by a process of differential selection among the existing set of templates, as well as the possibility of mutational change in the templates and the possible partial encoding of realized practices.

Insert Figure 1 about here

ANALYSIS

The focus of our analysis is on the interplay between processes of adaptation at different levels and via distinct mechanisms. In particular, there is the mechanism of local search, or hill-climbing, that is given greater scope with the degree of plasticity. In addition, the starting point for these local search efforts may change with the re-specification of the templates over time. While we are ultimately interested in the interplay among these mechanisms, it is important to understand how each of these processes operates in isolation as well. Furthermore, breaking down the overall organizational adaptive dynamics in this manner can help link our results to prior work in this general domain. As a result, we proceed by first analyzing the results of a baseline hill-climbing model and subsequently evaluating the incremental effects of introducing the “resetting” of behavior to be reinitialized at the template. Finally, we

then incorporate differential selection among templates on the basis of the relative performance of the realized practices.

Baseline model with no intra-organizational selection

The baseline setup of the analysis is defined as follows. A simple hill-climbing process for a fully plastic organization, ($p_1=1$), is contrasted with an organization that is completely non-plastic, ($p_1=0$). For this initial analysis, the remaining baseline parameters are specified as follows: p_c , the probability of evaluating a search alternative versus accepting it at random, is set equal to 0.5; the number of elements of each practice, N , equal to 20; the number of practices for each organization, W , is equal to 20; the degree of interdependence among elements of a given practice, K , equal to 9; the probability, f_r , that a fitness contribution associated with each element of each practice is respecified at each time step is set equal to 0.005.

Figure 2 reports the results of this initial analysis. The solid line illustrates the performance of a non-plastic organization. For a plastic organization, we indicate both the performance associated with the templates (dashed line) and the realized practices (dotted line).⁴

Insert Figure 2 about here

⁴ Each value reported in the analysis is obtained by averaging over a 1000 time steps in each simulation and across 250 independent simulations runs in which the seed of the random number generator is varied for each fitness landscape and for the specification of the initial templates.

In the absence of plasticity and with no selection and no resetting of behavior back to the value of the templates, average performance simply corresponds to the average value in the performance landscape, 0.5. Introducing plasticity, while maintaining this setting of no selection and no resetting of behavior back to the value of the templates, corresponds to a standard process of path-dependent learning as in Levinthal (1997). In this setting, the templates of the plastic organizations do not evolve, and hence the performance associated with the templates in this setting remains at its initial value of 0.5. The difference in the value of the templates (dashed line) and the set of practices for the plastic organizations (dotted line) indicates the returns to local search and corresponds to the results in Levinthal (1997). In the absence of selection, plasticity is an unabashed good. Greater plasticity increases the range of realized practices that can be achieved from a given starting point. Given that these “starting points” are randomly assigned templates, the capacity to modify practices from these arbitrary initial conditions (dashed line) is of value.

Resetting of the templates

Before analyzing the effects of differential selection on these baseline results, we proceed incrementally by simply adding the effect of “resetting” --- reinitializing behavior to take on the value of the templates and thereby restarting, and renewing the path-dependent search for superior practices. This exercise is indicated by the label “No Selection with Reset” in Figure 2. This setting offers a further control and contrast so as to introduce and isolate the effect of resetting from a pure model of

path-dependent learning and from the effect of selection among practices. Further, this idea of restarting is consistent with a view of internal organization evolution in which individual initiatives have a “beginning” and “end”, with the possibility of some carryover from one “generation” to the next.

In the absence of selection, resetting has no effect on organizations that lack plasticity (solid line). For plastic organizations, there are two effects of resetting. One is to increase the value of the template as some of the changes in the practice are retained (with probability p_r) and incorporated into the template itself. As a result, the dashed line increases with the presence of resetting. However, at the same time, there is a reduction in the value of the realized practices as this “resetting” interrupts and cuts short the path-dependent search process that is incrementally enhancing performance (dotted lines).

Two-level model with the presence of intra-organizational selection

In this step, a two-level model is examined in which the simple hill-climbing mechanism is supplemented with a process of differential selection among practices within the organization occurring at each period with probability p_s , where p_s is set equal to 0.2. Again, as noted earlier, this value of p_s is set to distinguish the process from one of simply path-dependent learning (Levinthal, 1997), which results as p_s approaches zero, and from a genetic algorithm, which would be characteristic of a very high value of p_s . This process of internal selection redefines an organization’s population of W practices. The evaluation of these practices is based on the

performance value that has been obtained as a result of the hill-climbing efforts subsequent to the prior selection event. At each instance of internal selection, the newly generated templates incorporate a proportion of p_r of the N bits of each practice evolved during the prior hill climbing efforts, with the remaining elements taking their value from the prior template. p_r is set at 0.5 as a baseline value. The probability of a random mutation of each bit with the respecification of the template, p_m , is set equal to 0.025. Therefore, under this setting, the template evolves as a joint effect of differential selection among alternative templates within the organization, mutation events at the time of the re-specification of the template subsequent to the selection event, and the retention of some subset of the realized practices at the time of the selection event. The value of the realized practices indicates the average fitness values obtained by the W practices as a result of their hill-climbing development from a given template.

Once intra-organizational selection is introduced, there is a qualitative change in the results. With selection among practices, the absence of plasticity results in a higher level of performance. The contrast between the solid line, the performance of non-plastic organizational forms, and the dashed line, the value of the template for plastic organizational forms, reveals the impact of plasticity on the differential selection among underlying templates. The contrast between the dotted and the dashed lines indicates the tension between the flexibility advantages of plasticity and the reduction in the reliability of the realized practices. With modest intensity of internal selection, (i.e., $SP = 1$ in Figure 2), plasticity allows the organization to

identify practices that exceed the performance of the underlying template.⁵ With a greater degree of differential selection among practices within the organization ($SP = 10$ and $SP = 20$), there is a marked increase in the performance associated with the underlying templates even for plastic organizations. From a starting point of these, on average, relatively high performing templates, an imperfect process of local search tends to lead to a reduction in performance rather than an improvement. Thus, with $SP = 1$, we see the net-benefit of greater flexibility in realized practices that may emerge for a given practice from the underlying template; whereas, with strong internal selection pressures generating relatively effective templates, the flexibility of greater plasticity underperforms the non-plastic organization by mitigating both the identification and reliable expression of high-quality templates.⁶

In sum, the potentially dysfunctional role of plasticity when differential selection is present stems from two distinct effects. One is that plasticity reduces the selectability of superior underlying templates (compare the solid line and the dashed line in Figure 2) as there is a looser coupling between the ultimate realized practice and the source template. Thus, we see a decline in the quality of the template with

⁵ However, this still results in an inferior performance relative to that achieved for a non-plastic organization.

⁶ In an unreported robustness analysis, rather than examining performance as measured by fitness value, we consider differential survival rates as a performance measure. The survival analysis yields similar qualitative results. Organizations with plasticity, in conjunction with strong internal selection, experience lower rates of survival relative to organizations that are less plastic and rely solely on processes of internal selection.

the presence of plasticity.⁷ The other effect is the unreliability of the realized practice from a given template. As argued by Nelson and Winter (1982), stable routines are critical to reliable organizational performance. This effect is reflected in the gap between realized practices and the underlying templates with the presence of plasticity (compare the dashed line with the dotted line in Figure 2).

Having established this basic tension between the benefits of plasticity in allowing for adaptation of individual practices and its costs in terms of reduced selectability of templates and decreased reliability in realized practices and identified conditions under which, on net, plasticity reduces organizational performance, we now explore the critical boundary conditions regarding this tradeoff.

Boundary Conditions

First, while the discussion to this point has highlighted the ability of non-plastic organizations to select superior templates at increasing levels of selection pressure, there is another important force in moderating the effectiveness of selection and that is the rate of mutation in the specification of templates subsequent to a selection event. In the absence of substantial variation, selection forces are attenuated (Aldrich, 1999; Campbell, 1965). Thus, as show in Figure 3 (right panel), in the absence of mutation, plasticity generates both superior templates and superior

⁷ Note that this effect is mitigated by the fact that the template itself changes subsequent to re-specification (parameter p_r) as the subsequent template incorporates both elements of the prior template and elements of the realized practice.

realized practices. In contrast, we see a sharp increase in the relative quality of templates for non-plastic organizations as the degree of mutation increases.

Insert Figure 3 about here

Further, there is the issue of how effective is the process of local hill-climbing search, as characterized by the value of p_c . Consider the left panel in Figure 3 illustrating the effect of varying p_c . With p_c equal to zero, the change in realized practice from a starting template is random. Even with realized practice being a random change from the underlying template, the process of internal selection is able, to some degree, to identify superior templates, though this effect is greatly diminished in the presence of plasticity. As p_c increases to 0.25, the gap between the value of the templates in the absence and the presence of plasticity narrows, though a substantial gap between the template under plasticity and the realized practice remains. With high levels of search capability ($p_c = 0.75$), we see that the value of the template with plasticity actually exceeds the quality of templates in the absence of plasticity. Realized practices that are loosely coupled to the underlying template can obscure the selection of superior templates. However, when p_c takes on a high value, the realized practices become a good proxy indicator for the quality of the templates. A template that led to a high performing policy will reliably, with a high value of p_c , lead to a high realized performance in a subsequent search effort, even if the realized practice is not identical to the first instance. Plasticity not only facilitates the identification of superior templates, but because some fraction (p_r) of the realized practice is

embedded in the template, there is a further link between effective plastic search and the quality of the template. The reliability penalty of plasticity is present, however, even with a search capability as high as $p_c = 0.75$. Indeed, even with a value of p_c of 0.75, the less than perfect examination of alternative practices from the starting templates leads to a net reduction in performance. Of course, with a p_c value of 1, a realized practice can only be greater than, or at minimum equal to, the value of the underlying template. As a result, in this setting, the performance gap for the realized practice favors the plastic organizations. In addition, the tight association between the quality of the template and the realized practice when $p_c = 1$ results in the quality of the average template for plastic organizations being superior to that of non-plastic organizations.

These findings suggest that plasticity is not necessarily beneficial for organizations. We show that plasticity, unless it is nearly perfectly reliable, obscures the evolution of fitter practices. Moreover, we find that this effect is greater when selection forces internal to organization are stronger. Thus, when organizations engage in stringent internal selection, the joint action of selection and plastic adaptation of individual practices may produce detrimental effects, relative to selection operating in the absence of plastic practices .

Sensitivity to other parameters

The “fodder” of selection is also clearly a function of how many distinct practices may simultaneously be present in a given organization. In the model, this is

characterized by W . While there is some slight increase in the relative effectiveness of non-plastic organizations when we contrast the setting of $W=10$ versus $W=20$, the impact of greater values of W beyond a moderate level is not significant. However, at the extreme with a very low value of W , there is a limited opportunity for selection to operate and plasticity leads to a superior performance level. Thus, organizations of a very small scale that are unable to sustain some substantial degree of parallelism in their practices will be better served by plasticity than by efforts at internal selection.

The contrast between the contribution of plasticity and the adaptation of practices from a given template and the importance of identifying superior templates is influenced by the complexity of the problem environment as reflected in the value of K .⁸ In a relatively simple setting of $K = 3$, it is possible to identify high performance practices through a process of local search. Thus, with $K = 3$, we see that with plasticity, on average, slightly superior templates are identified. However, even with on average somewhat superior templates, the reliability “penalty” of plasticity results in inferior realized performance. With more complex settings, the differential selection among non-plastic practices results in the identification of superior templates as well as superior realized practices.

In addition to the level of interdependence, K , N , the number of elements may play a role as well in influencing the possible value of plasticity. With a larger value

⁸ We refer here to the classic conceptualization of complexity as proposed by Simon (1969). More generally, the literature has pointed to other measures of complexity, including computational complexity (i.e., the number of steps to reach a solution (c.f., Garey and Johnson, 1979)) as well as measures denoting the size of minimal representations to generate the observed behavior or function, such as Page’s (1996) construct of coverage or Gell-Mann’s (1995) measure of algorithm information content.

of N , the challenge of identifying superior templates via internal selection becomes even more difficult. At the same time, as the dimensionality of the problem space increases, it becomes more valuable to supplement a given template with adaptive changes in practices and thus the performance penalty associated with the set of realized practices decreases with N .

More rapidly changing environments would naturally appear to favor the performance of plastic organizations. While increasing the rate of change in the environment enhances the relative performance of plastic organizations, even at very high rates of environmental change, non-plastic organizations generate superior templates and realized practice under the baseline settings. See Table 1 for a summary of the sensitivity analysis.

Insert Table 1 about here

DISCUSSION AND CONCLUSION

It is useful to highlight the distinctive contribution of our model and results with respect to the overall literature on organizational learning. This literature is quite considerable and we focus on a few central features and lines of arguments that link to the current analysis. First, learning is generally viewed as feedback driven --- actions associated with favorable outcomes are reinforced (Levitt & March, 1988). In models of choosing among alternative actions, this reinforcement takes the form of increasing the likelihood of choosing one alternative over another (Lave & March,

1975). In a similar vein, in models of hill-climbing, path-dependent search, alternatives that are identified to be superior to the current actions are adopted and become a new basis for action (Levinthal, 1997). In the context of a hill-climbing process, plasticity can be viewed a kind of minimal, 0th order, dynamic capability (Collis, 1994). Clearly, in the absence of such plasticity, there is no possibility of change in a given 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.

If we consider a process of internal selection in conjunction with some mechanism of learning and adaptation with regard to a given behavioral pattern, we are faced with the conceptual challenge as to what constitutes the stable and enduring elements of behavior in the context of such a selection process. Nelson and Winter (1982) provide what has 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 provides a close empirical examination of the enactment and re-enactment of routine-based behaviors 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 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. Thus, while organizations may possess enduring templates of behavior, the imprint of such a template does not deterministically characterize the set of enacted behaviors. Practices may be more or less codified (Zollo & Winter, 2002) and the coupling between these stable templates and the expression of the practice may be more or less tight (Jensen & Szulanski, 2007; Winter & Szulanski, 2001). The more codified bases of practices can be viewed as reflecting the quasi-genetic quality of routines that Nelson and Winter (1982) speak of, while the fact that realized practices may be more or loosely coupled to such templates (Birnholtz et al., 2007; Feldman, 2000; Jensen & Szulanski, 2007) is illustrative of the distinction between template and enacted practice that we make here. Feldman and Pentland’s (2003) contrast between the “ostensive” and the “performative” elements of a routine makes a similar point. While the ostensive may guide the realized routine, it does not define it. Further, in the spirit of our model, Feldman and Pentland (2003) argue that, over time, the ostensive characterization of the routine may be influenced by the performative.

This issue of the more or less intelligent selection among a set of practices 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). 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.

Our distinction between the expressed behaviors and the underlying template forming the stable root of those behaviors points to an additional threat to replication. If there is considerable play between the set of possible practices that may emerge from a given template, then one might observe quite a range in behaviors over time, even if the underlying basis of that behavior remains constant. There are ways in which the possibility of a broad range of possible practices may be quite functional. The particular behavior that emerges may simply 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 practice will not be successfully re-enacted, even if desired.

This concern with the reliability of enacted behavior and the risk of efforts at organizational change is central to work in population ecology. Inertia with respect to core organizational attributes is argued to be behaviorally descriptive of organizational populations (Stinchcombe, 1965; Hannan and Freeman, 1977, 1984). Further, inertia with respect to core elements is argued to be associated with heightened rates of organizational survival (Hannan and Freeman, 1984, 1989;

Barnett and Carroll, 1995). Change entails direct costs and may precipitate a cascade of other, potentially maladaptive changes (Hannan, Pólos, and Carroll, 2007).

Inertia plays a rather different role in the analysis developed here. In addition to a shared concern with the ecology arguments regarding the reliability of the reenactment of specific organizational practices and behaviors, a set of relatively inert, or non-plastic, behaviors are shown to enhance the intelligence of the selection of practices within this set. Thus, inertia, by improving the efficacy of selection processes within the organization, enhances the performance of the organization over time and thereby improves its likelihood of survival. Thus, there is a link between inertia and survival but through a very different mechanism.

Levinthal and Posen (2007) also point to the link between the relative stability of patterns of behavior and the enhanced selectability of those behaviors. Levinthal and Posen (2007) examined organizations characterized by a fixed “type”, where in their context an organization’s type is characterized by its search strategy. Search strategies that exhibited a high degree of correlation in performance across time tend to be positively selected for, for a given level of average performance. Thus, Levinthal and Posen (2007) consider the intelligence of selection at the population level among a population of organizations characterized by a single trait. In contrast, the analysis developed here considers the intra-organizational ecology of practices within an organization. Consistent with this contrast, Levinthal and Posen (2007) model a single, path-dependent, learning process at the organizational level, whereas our work examines continual cycle of enacted sets of behaviors, internal selection

over that set of behaviors, and the reenactment of a new population of behaviors within the organization.

Bruderer and Singh (1996) use the apparatus of genetic algorithms to consider the evolutionary value of the capacity to learn or adapt. As in our analysis, they consider a policy vector that consists of fixed behaviors and elements that are plastic or subject to change. However, in their set-up, there is no process of reinforcement learning at the level of change of individual policy elements. The set of plastic elements are specified at random and, if the resulting string matches an exogenously specified “target”, then the entire vector is rewarded. Davis et al. (2009) engage in a similar analysis. However their set-up has a more decision-theoretic approach as the organization is represented by a single policy string that may be more or less “plastic” and, as a result, no process of internal variation and selection is present.⁹ Within this structure, they examine the tradeoff between the optimal degrees of plasticity in different environmental conditions.

March (1991) considers both a process of internal variation, with the process of turnover serving as a mechanism of random mutation, and socialization, which acts as a selection-like mechanism reinforcing the beliefs associated with the dominant code. In addition to this process of individual socialization, the code itself is subject to an adaptive process as the code changes in a probabilistic manner to correspond to the beliefs of individuals whose beliefs are closer to the external reality. March finds

⁹ Further, it is important to note that in the Davis et al. (2009) analysis, the elements in the underlying template are assumed to match, on average, the values of the target vector. Thus, an important degree of correspondence, or match, between template and the target is postulated a priori.

that slow learning can be beneficial as a whole to organizational adaptation as slow learning helps preserve diversity in an organizational population of beliefs.

Our “limited plasticity” result reflects a very different mechanism. In our model, the degree of learning with regard to specific practices is tuned by the degree of plasticity, with no plasticity resulting in inert practices. The possible performance enhancing role of limited, rather than more extensive, plasticity is that this property enhances the selectability of the underlying templates. Indeed, in our model high plasticity, and thus high rates of learning at the level of individual practices, is associated with greater, not less, heterogeneity in templates. As plasticity increases, selection becomes noisier resulting in a more diverse set of templates. In contrast, with no or limited plasticity, the internal selection process will tend to weed out inferior templates and thereby reduce the degree of heterogeneity of templates. The two models are not inconsistent with one another, but rather highlight different tensions and mechanisms in nested systems of organizational adaptation.

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 implications of the adaptability of any particular facet of organizational behavior are, in general, ambiguous with respect to the adaptiveness of the organization as a whole. 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.

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 stable roots of these behavioral patterns in dynamic settings. As a result, plasticity tends to result in an inferior set of baseline templates, the enduring root of subsequent practices. Thus, superior performance entails a tension between plasticity's positive role in offering near-term flexibility in action and its long-term consequences for the quality of the underlying basis of organizational practices. In more stable environments, 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 relatively strong differential selection among them. In dynamic environments, the tradeoff between the flexibility benefits of plasticity and its negative implications for the quality of the underlying relative stable 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 that these individual changes are performance enhancing.

Internal selection pressure and variance in practices are complementary mechanisms of adaptive dynamics. In contrast, 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 plasticity, we have tended to neglect the role that relatively fixed diverse elements play 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 and parallel 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 underlying processes 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 particular organizational features or level of analysis 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.

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Figure 1. Model Structure

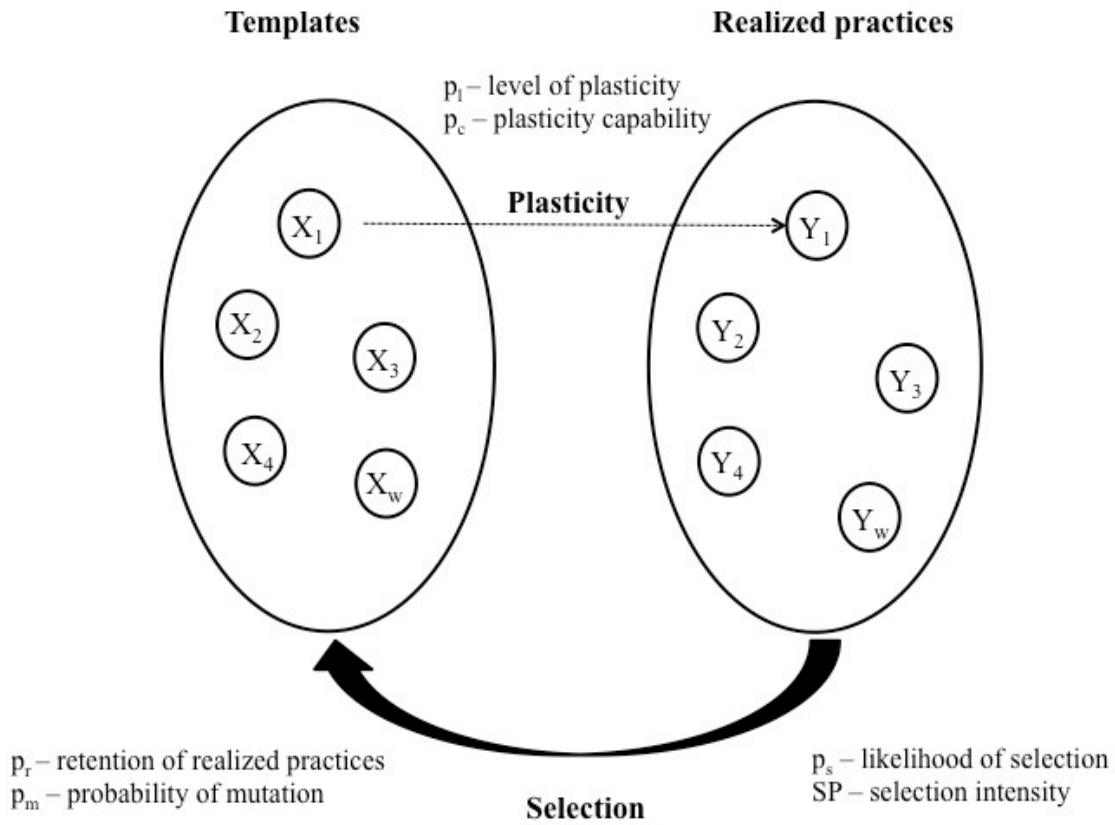
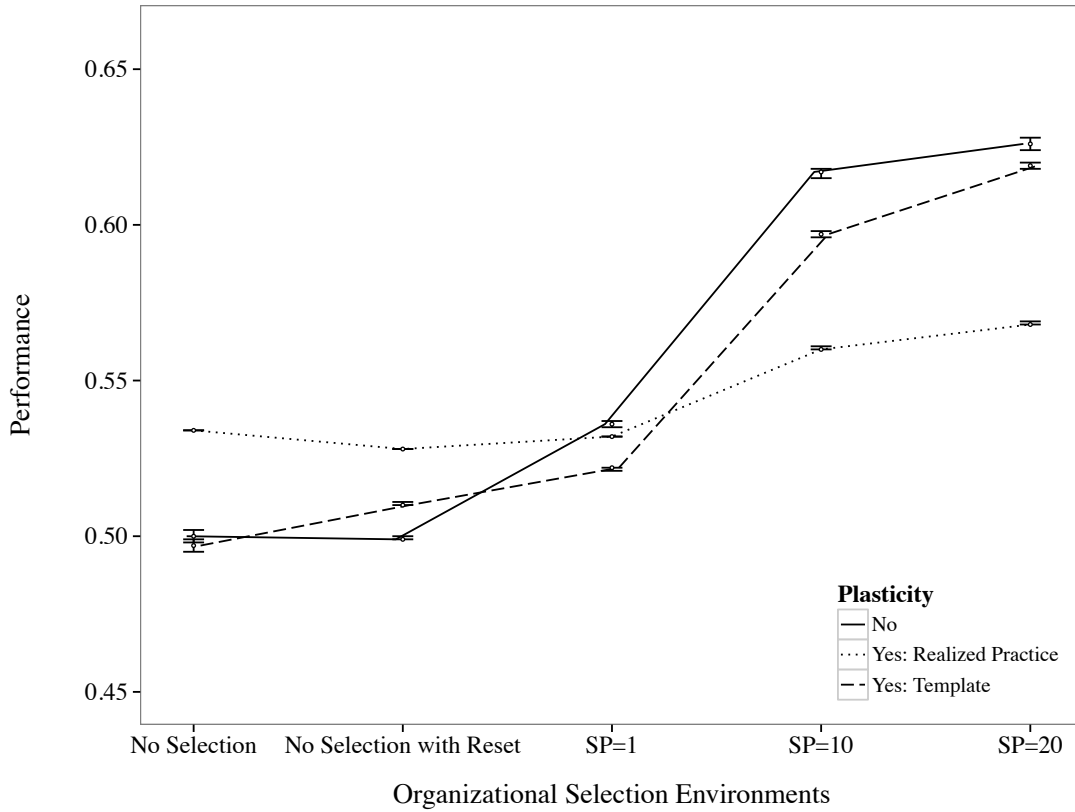
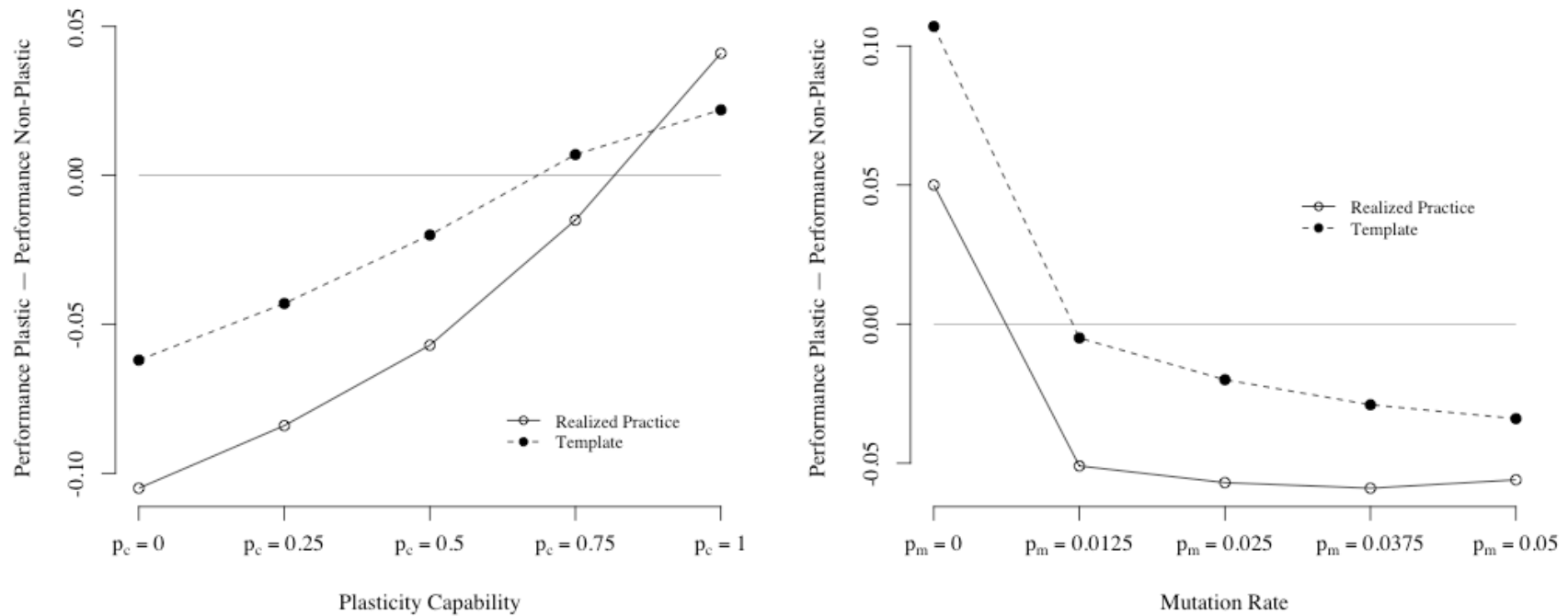


Figure 2. Organizational performance at different levels of plasticity and selection



NOTES: The graphs report average values over 1000 time steps in each simulation and 250 independent simulations runs. The vertical bars indicate the 95% confidence intervals. In the initial setting, “No Selection”, there are no selection events. In the second setting, “No Selection with Reset”, each period with probability $p_s = 0.2$, the practices are reset to the value of the underlying template, but at this point of “resetting” there is no selection over the templates. In the other settings, with probability $p_s = 0.2$, there is a selection event over the set of templates, with the selection intensity taking on the value $SP=1, 10, \text{ and } 20$. For each data series $W=20, N=20, K=9, f_r=0.005, p_r=0.5, p_c=0.5$.

Figure 3. Boundary conditions varying plasticity capability and mutation rate



NOTES: The graphs report the difference between the performance obtained by realized practices and templates of organizations with plasticity (p_i) equal to 1 and 0 at different levels of p_c and p_m averaged over 1000 time steps in each simulation and 250 independent simulations runs. For each data series, $W=20$, $N=20$, $SP=10$, $p_r=0.5$, $p_s=0.2$, $K=9$, $f_r=0.005$.

Table 1. Robustness Analysis

Plasticity (p_i)	Templates			Realized Practices			Templates			
	No (0)			Yes (1)			Yes (1)			
Parameters:	<i>C.I.</i>	<i>Mean</i>	<i>C.I.</i>	<i>C.I.</i>	<i>Mean</i>	<i>C.I.</i>	<i>C.I.</i>	<i>Mean</i>	<i>C.I.</i>	
<i>Baseline Setting</i>	0.618	0.619	0.621	0.56	0.56	0.561	0.596	0.597	0.598	
	<i>10 (K=4)</i>	0.649	0.652	0.655	0.589	0.59	0.592	0.653	0.655	0.657
N (Number of bits in each practice string)	<i>30 (K=14)</i>	0.592	0.594	0.595	0.549	0.549	0.55	0.564	0.565	0.566
	<i>10 (K=9)</i>	0.632	0.634	0.636	0.55	0.55	0.551	0.601	0.603	0.605
	<i>30 (K=9)</i>	0.603	0.604	0.606	0.569	0.57	0.571	0.584	0.585	0.586
W (Number of practices that compose an organization)	<i>1</i>	0.496	0.498	0.5	0.524	0.525	0.526	0.498	0.5	0.503
	<i>10</i>	0.604	0.606	0.608	0.555	0.555	0.556	0.583	0.584	0.585
	<i>30</i>	0.623	0.625	0.626	0.563	0.563	0.564	0.603	0.604	0.605
p_r (Probability of retention of realized practices)	<i>0</i>	0.618	0.619	0.621	0.55	0.551	0.552	0.571	0.573	0.575
	<i>1</i>	0.618	0.62	0.621	0.566	0.567	0.567	0.619	0.62	0.621
K (Degree of interdependence among the elements of a practice)	<i>3</i>	0.631	0.635	0.638	0.605	0.607	0.610	0.638	0.642	0.646
	<i>9</i>	0.616	0.619	0.622	0.558	0.560	0.563	0.594	0.597	0.601
	<i>15</i>	0.605	0.607	0.610	0.548	0.550	0.552	0.570	0.573	0.577
f_r (Probability that each fitness contribution associated with each practice element is respecified)	<i>0</i>	0.656	0.660	0.664	0.568	0.570	0.573	0.617	0.621	0.625
	<i>0.005</i>	0.616	0.619	0.622	0.558	0.560	0.563	0.594	0.597	0.601
	<i>0.01</i>	0.6	0.603	0.606	0.554	0.556	0.558	0.583	0.586	0.590

NOTES: The table reports the averages performance values averaged over 1000 time steps in each simulation and across 250 independent simulations. For the baseline configuration: $W=20$, $N=20$, $p_c = 0.5$, $SP = 10$, $p_r = 0.5$, $p_m=0.025$, $p_s=0.2$. The figure in bold indicates the average value while the values in the two surrounding columns in small font indicate the 95% confidence intervals.