Path dependence, nonlinear dynamic systems theory and some managerial implications

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Thomas Ehrmann

Westfälische Wilhelms-Universität Münster

Institute of Strategic Management

Leonardo-Campus 18

48149 Münster, Germany

Tel.: (0251) 83-38330

Fax. (0251) 83-38333
ehrmann@ism.uni-muenster.de

Michael Kopel

University of Graz

Institute of Organization and Economics of Institutions

8010 Graz, Austria

michael.kopel@uni-graz.at

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As path dependence research is expanding and maturing, we see a wider range of topics explored and more complex theories applied. The work by Sydow, Schreyögg and Koch (2009) represents a worthwhile effort in this direction. Drawing on complexity theory, evolutionary economics, economic history, and on research on technological paths, the authors explore the underlying logic of how organizations become path-dependent. They suggest a dynamic framework that differentiates three distinct developmental phases of path dependence and explore whether and how organizational path dependence can be overcome. By enabling a better understanding of the notion of path dependence, the authors' work stimulates the discussion of ideas on the actual meaning and logic of path dependence.

Central to the authors' proposed theory is that it "conceptualizes an organizational path as a tapering social process. [...] This pattern is likely to become persistently reproduced and to crowd out alternative solutions to an extent that it gets locked in (Phase III) and is accompanied by immediate or future inefficiency." (Sydow, Schreyögg, & Koch, 2009: 8) Concerning the authors' argument on the interplay of inefficiency, lock-in and the avoidability of paths, as well as the mathematical foundations of their work, several critical issues need to be addressed (see also Vergne and Durand 2010):

1. The need for stringent definitions in path dependence research,
2. the adequacy of the authors' model setup (see Adner 2009) for path dependence research, and
3. complementary implications of the authors' proposed framework.

In this dialogue, we will offer comments on the article and suggestions for further research in the spirit of Sydow et al. along these three themes. Specifically, we will argue that an alternative model setup can lead to additional insights about path dependence in organizations.

THE NEED FOR STRINGENT DEFINITIONS

The authors acknowledge that “calling a lock-in ‘inefficient’ always implies a base of reference” (Sydow et al., 2009: 7). Yet, the question remains whether they compare the outcome of the “tapering social process” with a reachable better solution or with a “nirvana” (Demsetz, 1969) equilibrium. The “nirvana” equilibrium can be reached only in a perfect world where actors are endowed with supernatural (i.e. super rational) powers. Unfortunately, Sydow et al. do not define their base of reference explicitly.

This implies that they generate the notion of “real inefficiency” by comparing an equilibrium *with* and another one (chosen by default) *without* path characteristics, where the latter serves as a simple “base of reference”. The world without a path follows the counterfactual “neoclassical” assumptions of complete information, costless choices, and complete reversibility of managerial decisions.

In the path world, as the path develops, the management performs constrained optimization using the available information, processes, resources and so forth, until they arrive at the path’s end. Due to limited information (there is no “second order observation”, see Sydow et al., 2009: 14), the management can make “wrong” decisions. The authors explain that when given the correct information ex post, there is inefficiency because the firm has kept to the path. Yet, this interpretation is incorrect, as by using the information and activities that were available to the management when decisions were made, they decided correctly, as constrained optimization procedures would have it. Just in retrospective, an observer (including the management) can realize that decisions were suboptimal in view of additional information (or new activities). Arriving in this situation can be regarded as “avoidable” only if “they should have known (and done) better” or if there is someone else who knew better (and also could have *really* done better). Thus, the idea that the firm is locked-in in an inferior state (path dependence) must rest on the implicit comparison of a world with paths with a world without paths, where by definition, the former will always be inefficient compared with the latter.

It follows that the lock-in “equilibrium” must be avoidable to constitute a “real” inefficiency (Demsetz, 1969; Liebowitz & Margolis, 1995). Avoidability rests on two assumptions: the process has to be (at least partly) predictable and the management must have a set of activities at hand to realize a better solution. If the outcome is unavoidable, meaning there was no feasible alternative, the only activity left to the management would be to regret the outcome. The authors are not clear about this issue, which leads to subsequent problems. Providing stringent definitions by explicating underlying assumptions and offering explicit measurement categories of theoretical dimensions to clarify the interplay of inefficiency and avoidability would benefit this research.

MODEL SETUP

Concerning predictability, the authors refer to the model setup by Arthur (cited 18 times). For the random walk analyzed, Arthur explains that “in the increasing returns case *[which is the only interesting one, according to Arthur]* predictability is lost” (1989: 121). In Arthur’s world, actors maximize under the regime of lost predictability, and there is no authority or actor that could, *at least theoretically*, know better at the time of the decision that starts the path. So, by definition, there can never be “real” inefficiency, because actors who decide on the basis of the insufficient information available decide correctly (see above).

The authors are more optimistic than Arthur about predictability in the later stages of the process (Sydow et al., 2009: 5). Thus, they stand at the crossroads: either, they follow

Arthur’s path dependence that implies unpredictability and does not allow activities to prevent the “tapering process”. Or, they assume avoidability, including (at least some) predictability and activities that prevent the worst outcome. The latter alternative implies to opt for the real world, where actors perform constrained optimization and end up somewhere where there is room for improvement. The authors’ idea of “breaking paths” forces them to focus on the real world, where management can act – even if there is a set of activities that is only second best compared to the nirvana model idea. Whether we call it “strategic understanding” or “second order observation”, to change anything, we need some predictability to know where we head for and we need a set of activities that gets us there (see Figure 1; Sydow et al., 2009: 4). Therefore, the authors must leave Arthur’s random walk and base their theory on a different mathematical idea that does not suffer from the restrictions of Arthur’s approach (see Page, 2006 on the usability of Arthur´s modelling approach for path dependence).

Adner et al. (2009) have elaborated on the benefits of adequate formal theory for the management literature. We believe that an adequate model for the analysis of path dependence has to combine the topic of complementarity between organizational design variables (e.g. Roberts 2004, etc) with new concepts in nonlinear dynamical systems theory. To make matters concrete, consider a firm which has to determine its resource configuration a_{t+1} for the next period given its resource configuration in the current period, a_t. For simplicity and tractability we assume that the variable representing resource configurations is one-dimensional, although potentially it could be given by a vector consisting of multiple design variables. For example, in his simulation model Zott (2003) considers the rate of product innovation, the level of process innovation and the output quantity as design variables. Each of the oligopolistic firms in Zott’s model solves a constrained optimization problem, that is it selects its next period’s resource configuration such that expected profit is maximized (subject to imitation, experimentation and status quo bias) given the firm's prediction of the behavior of its competitors. In other words, given a firms' current resources, it tries to make a prediction of the state of the world in the next period and adjust its resources as a best reponse to this prediction. Such a rule-based search behavior is boundedly rational, in the sense that decision makers possess only local information about the state of the world, but try to make the best choices given this (imperfect) information. For our simple model, we focus on the decision rule of a firm which captures the decision-making mechanism of these boundedly rational agents and links the current resource configuration a_t with the future configuration a_{t+1}. If we denote the decision rule by F, this linkage between periods gives rise to a dynamical system $a_{t+1}=F(a_t)$. In Figure 1 (bottom panel) we depict one possible shape of the decision rule and illustrate that repeated application of this rule might lead to two different outcomes, X and Z, in the long run. The dynamic paths which are depicted in the figure start from two different initial resource configurations, and are close to X or Z just after a few time steps. To generate these dynamic paths we start from the initial resource configuration a_0 and apply decision rule F to generate the next period's resource configuration a_1. As we move one period ahead a_1 becomes the current configuration, so in the graph we have to move a_1 from the vertical axis (future state) to the horizontal axis (current state). In the graph this transition is achieved by using the diagonal where $a_{t+1}= a_t$, so that the "future resource configuration" a_1 is now moved to the axis capturing the "current resource configuration" a_1. We can now use the (graph of the) decision rule F to determine the new resource configuration a_2, which is then again moved to the horizontal axis using the diagonal. Iterating this procedure leads to the dynamic paths of resource configurations displayed in the figure. Note that in this case the intersection point Y of the graph of F with the diagonal is the demarcation point between the two "basins" of the long run outcomes X and Z. If the initial resource configuration is to the left of Y, the long run outcome X is reached; if the intial resource configuration is the the right, then outcome Z emerges.

Insert Figure 1 about here

Hence, we can conclude that given a firm's initial configuration and its decision making mechanisms described by F, the firm's resource combinations will be close to X or Z and, in this sense, the firm is "locked-in" in one of these final states. Note that if a_t is a multi-dimensional vector, then the long run outcomes (X or Z) represent the steady state configurations where the individual resource variables exhibit a strategic fit in the sense that no further adjustments are made in the design variables. In such a situation of multiple stable long run outcomes and lock-in, the immediate question is which of these outcomes yields the better performance for the firm. In Figure 1 (top panel) we show a possible performance plot, which illustrates that in such a scenario long run outcome X would yield better performance than long run outcome Z (see also Roberts 2004). Hence, a firm might get locked-in into Z realizing that X would yield improved performance, but change is difficult to achieve. In order to switch from Z to X, the decision makers have two options. First, they can change its resource configuration drastically such that it is located to the left of Y. Of course, this is complicated by the fact that Y itself is unknown, but can be potentially achieved by imitating a better-performing competitor. Note that such a change is almost always accompanied by temporary reductions in performance during the change process. Second, the decision makers might be tempted to change the decision rule F. This, however, is an endeavor full of complexities, since changing the decision rule changes the location of long run outcomes X, Y, and Z, and most likely the graph of the performance measure.

Even in a situation where a firm's decisions eventually lead to long run outcome X, changes in its environment eventually leads to suboptimality in the firm's resource configuration. Over time, as technology, competition, supplier and customer relationships, and regulation change, so does the curve linking choice and performance. This is illustrated in Figure 2, where the performance graph now depends on a parameter α, where $\alpha = \alpha_1$ denotes the initial situation depicted in Figure 1. That is, at first a firm with resource configuration (close to) X has higher performance than firms in Z. As the environment changes, the parameter α changes from $\alpha = \alpha_1$ to $\alpha = \alpha_2$, and then to $\alpha = \alpha_3$. As a consequence, the performance relation changes and the long run outcome on the other side of the local minimum Y becomes the organizational design with the higher performance. Again, firms are suffering from a lock-in and switching from the previously optimal, but now suboptimal configuration to the new and better organizational design is a difficult process.

Insert Figure 2 about here

Our model can be used to illustrate two further interesting points dealing with subtleties of organizational design processes, namely complementarities between resource variables and firm heterogeneity (symmetry-breaking).

1. Complementarity and complicated basins: Let us look at the complementarity issue first. Considering Figure 1 we realize that the long run outcome Z is reached if the level in the resource configuration is sufficiently high in the current period t ($a_t > Y$). In this case this high current level gives rise to an even higher level in the next period ($a_{t+1} > a_t$), and so on. This positive feedback between the resource levels in period t and t+1 eventually leads to the long run outcome Z. On the other hand, a negative feedback

is at work if the initial resource level is rather low ($a_t < Y$) eventually leading to the long run outcome X. The question arises if the dynamic process leading to the long run outcomes is always so simple. The answer is no. Figure 3 depicts the graph of a decision rule F, again leading to three intersection points. However, the unstable point Y now no longer demarcates the two basins of the long run outcomes. Initial resource configurations to the right of Y and closer to the long run outcome Z eventually are adjusted by repeated applications of the decision rule F and lead to convergence to X. In the Figure we show the regions of initial resource configurations which are to the left of Y, but eventually lead to long run outcome X by bold lines and notice that the “basin” of the long run outcome X is now quite complicated; it is a non-connected set.

Insert Figure 3 about here

From nonlinear dynamical systems theory we know that in higher-dimensional systems the basins can be very complicated sets even if these systems are deterministic without any random influence. It is very important to notice that the bifurcation process leading to such complicated basins (so-called global bifurcations) are independent from the well-known (e.g. period-doubling) bifurcation process leading to instability and complicated behavior. In other words, we may find situations where multiple stable long run outcomes occur (so-called multi-stability) with each of these long run outcomes having its own basins of attraction. The point is that these basins might be quite complicated and “intermingled” sets, which demonstrates that it might be hard to predict the trajectory of resource configurations, in particular in the presence of low-variance noise. These two types of complexity are further described and explained in Kopel (2009). So far only the loss of local stability and its impact on organization theory have been described in the literature; see e.g. xx. In our view, a situation of multi-stability is more interesting from a practical perspective and so more relevant to organization theory although it has been completely neglected in current research.

2. Firm heterogeneity and symmetry-breaking: In the model presented above, we did not address the issue of firm heterogeneity. In fact, to keep things simple, we have abstracted from any interfirm interaction and just have focused on the dynamic evolution of resource configurations of a single firm. Considering a situation where multiple firms interact in imperfect markets and each firm individually selects its resource configurations (e.g. Zott 2003), the questions arises if our model can explain the emergence of firm heterogeneity even if firms have access to the same resources. The answer is yes, and the reason is strikingly simple. Imagine a situation where two firms – call them firm A and firm B – compete in a duopoly market. In each period t, firms A and B have to select their resource configuration for the next period (denoted by a_{t+1} and b_{t+1}), given their current resource configurations a_t and b_t of period t. The variables (or vectors) a_t and b_t can represent quantity choices or investments in (product or process) innovation. Clearly, in a duopoly market the market price depends in the quantity supplied by both firms. Hence, each firms' profits depend on the resource configurations of both firms. Furthermore, in such a situation there is strategic uncertainty. That is, firms are aware that the future (or expected) profit not only depends on the choice of their own resource selection, but also on the selection of the other firm. However, since the future choice of the rival firm is unknown, the firms must try to predict the other firms' choice. Denote firm A's prediction of firm B's choice in the next period b^e_{t+1} and firm B's prediction of firm A's choice a^e_{t+1}. Given the current level of resources and the predicted actions of the other firm, the firm then

selects its next period's resource configuration as a best response. Similarly to the simple model described above, we obtain a dynamical system of the form $a_{t+1}=F_A(a_t, b^e_{t+1})$, $b_{t+1}=F_B(b_t, a^e_{t+1})$, where F_A and F_B represent the respective firms' decision rules. With the tools provided by nonlinear dynamical systems theory, simulations and numerical studies, it is possible to investigate the dynamics of time paths generated by such higher-dimensional systems. Furthermore, it is possible to analyze the resulting attractors and their changes they undergo if parameters representing the environment change, and visualize the basins of these attractors and the changes which occur due to global bifurcations (e.g. Bischi et al. 2010, Matsuyama 2002). For a two-dimensional Cournot model with expectations along the lines described above it can be shown that long run outcomes may exist where firms make heterogenous choices (Bischi and Kopel 2001). In other words, even if firms are identical a priori, this symmetry may be broken and the dynamics governed by their boundedly rational decision rules lead them to asymmetric choices of their resource configurations over time. The source of this symmetry-breaking mechanism is the complex interplay between the (strategic) complementarity and (strategic) substitutability between the firms' activities, which means that the marginal benefits or costs of an activity increases or decreases with the level of activity of the other firm (Matsuyama 2002). In such a situation, small differences grow bigger over time and eventually lead to very different resource combinations. Again, the firms' initial resource configurations matter for the long run evolution, but since the basins of the multiple long run outcomes may be complicated and intermingled sets, it might be difficult – in particular in the early stages of the organizational paths – to predict which long run outcome might be chosen. This latter statement is particularly true if low-variance noise plays a role.

COMPLEMENTARY IMPLICATIONS

The central question as regards the “unpleasant” outcomes (i.e. lock-in) is, how can firms get out? Sydow et al state that “the new alternative has to be a superior one” (2009: p. 14) but claim, “it is necessary to construe and integrate an exogenous perspective—that is, an activity that is not under the regime of path dependence. Such integration of an external lens or—if you like—a ‘second-order observation’ (von Foerster, 1991) enables knowledgeable agents to reflect practices in terms of path dependence and potentially opens a window for path-breaking activities” (Sydow et al., 2009: 14). Where (and how) can such an exogenous perspective be realized? Potential prerequisites for the second order observation needed to break a path can be “additional rationality” or increased incentives to behave rational.

Turning to the first possibility: it does not seem plausible that it takes a crisis to develop *(additional) rational management qualities* (as stated by Sydow et al., 2009), because sending down additional rationality to the management seems like a “deus ex machina” solution (why now and why so late?). Turning to the second: when there is an efficiency loss in path dependence, the management will have an interest in avoiding the loss. In a severe crisis, the expected loss from sticking to the old path is so immense that every attempt to break the path seems worth a try. Thus, the rationality already available in the firm gets more influential during a crisis. As can be seen in figure 1, the unavoidable (short-term) losses of path-breaking explain that it needs a crisis to develop the determination necessary for both a new strategic understanding of the situation (“second order observation”) and for starting new activities to leave the path. Based on this argument, Sydow et al.’s story can be told coherently.

In a nutshell: using nonlinear dynamic systems theory allows conveying the story of path dependence with precise assumptions (Adner et al. 2009) about inefficiency, avoidability of processes and provision of additional management rationality. The difficult work on paths starts here: by defining “real” inefficiency (by comparing “better” and “worse” paths), clarifying the avoidability of specific processes and where additional insights for path-breaking behavior can come from, based on an appropriate mathematical model setup. Sydow et al. rightly claim that “the second major element of an advanced path analysis is the identification, exploration, and reconstruction of the *self-reinforcing feedback mechanisms* possibly underlying the organizational rigidity in question” (2009, p. 704). We strongly believe that the mathematical framework presented here is both appropriate to reach this research objective and to add to this analysis by bringing in the new perspective of interactions between firms in markets.

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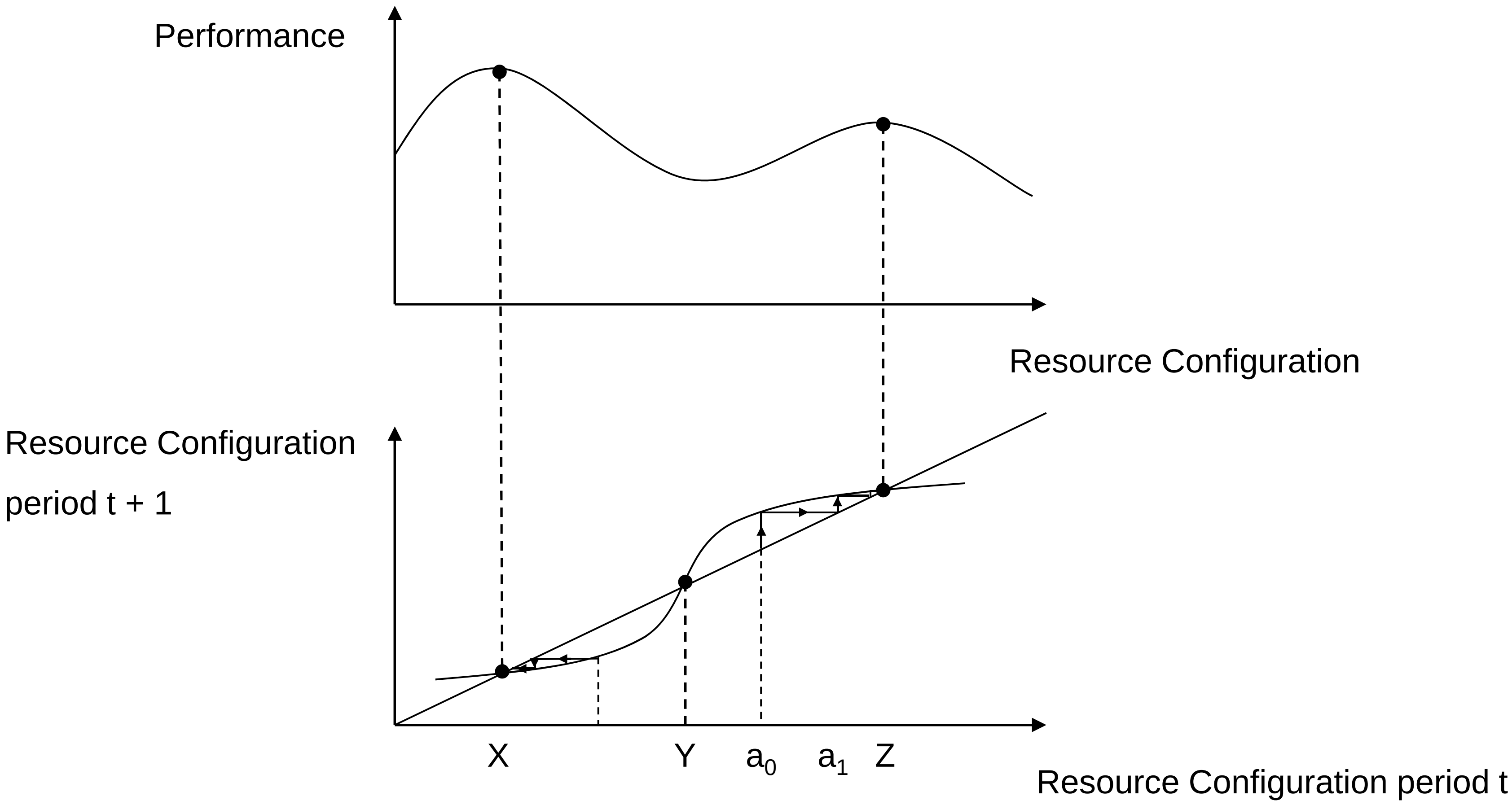
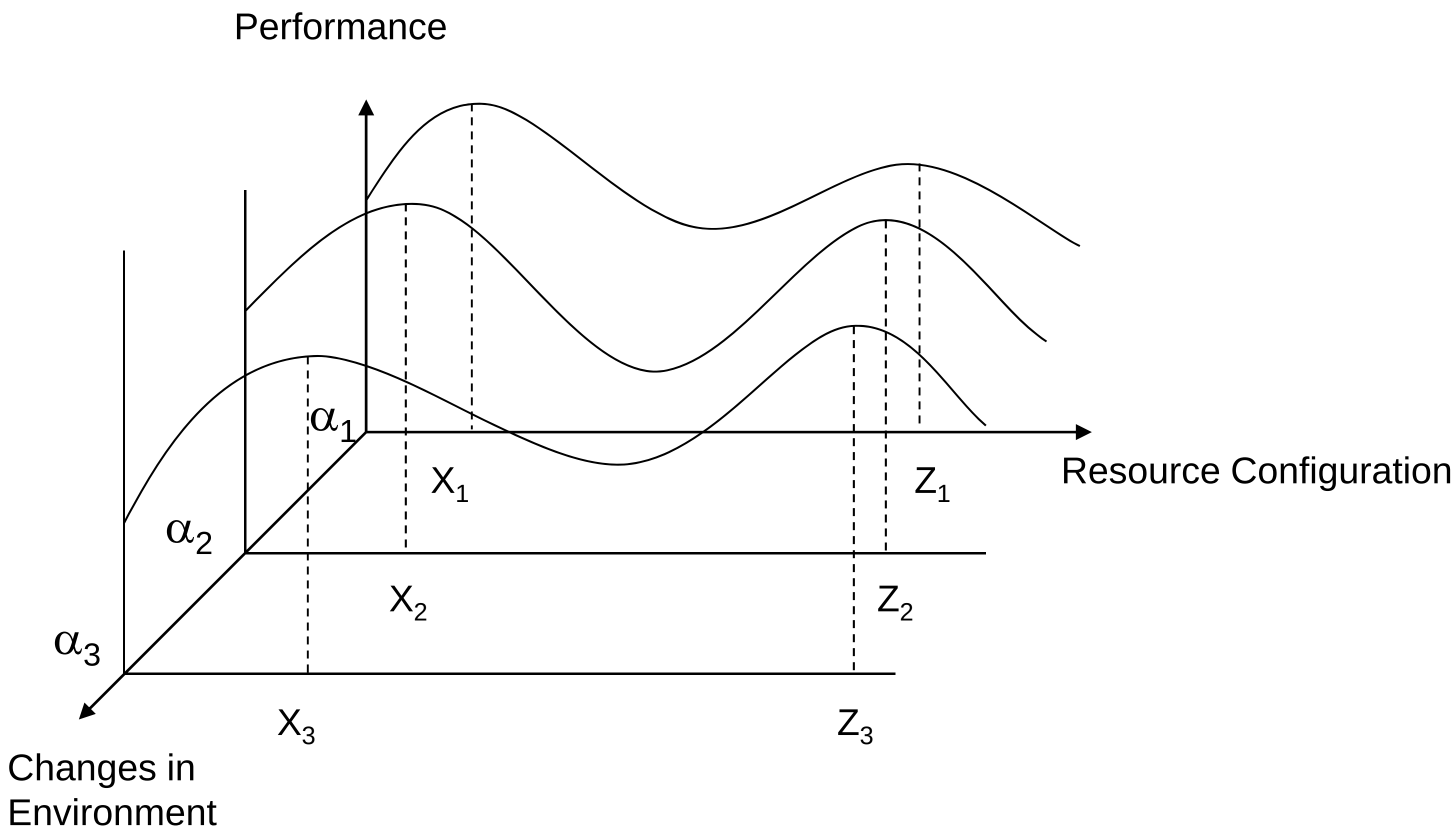

Performance
Resource Configuration
Resource Configuration
period t + 1
X
Y
a_0
a_1
Z
Resource Configuration period t

Figure 1


Performance
Resource Configuration
Changes in
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α_1
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Z_2
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Figure 2

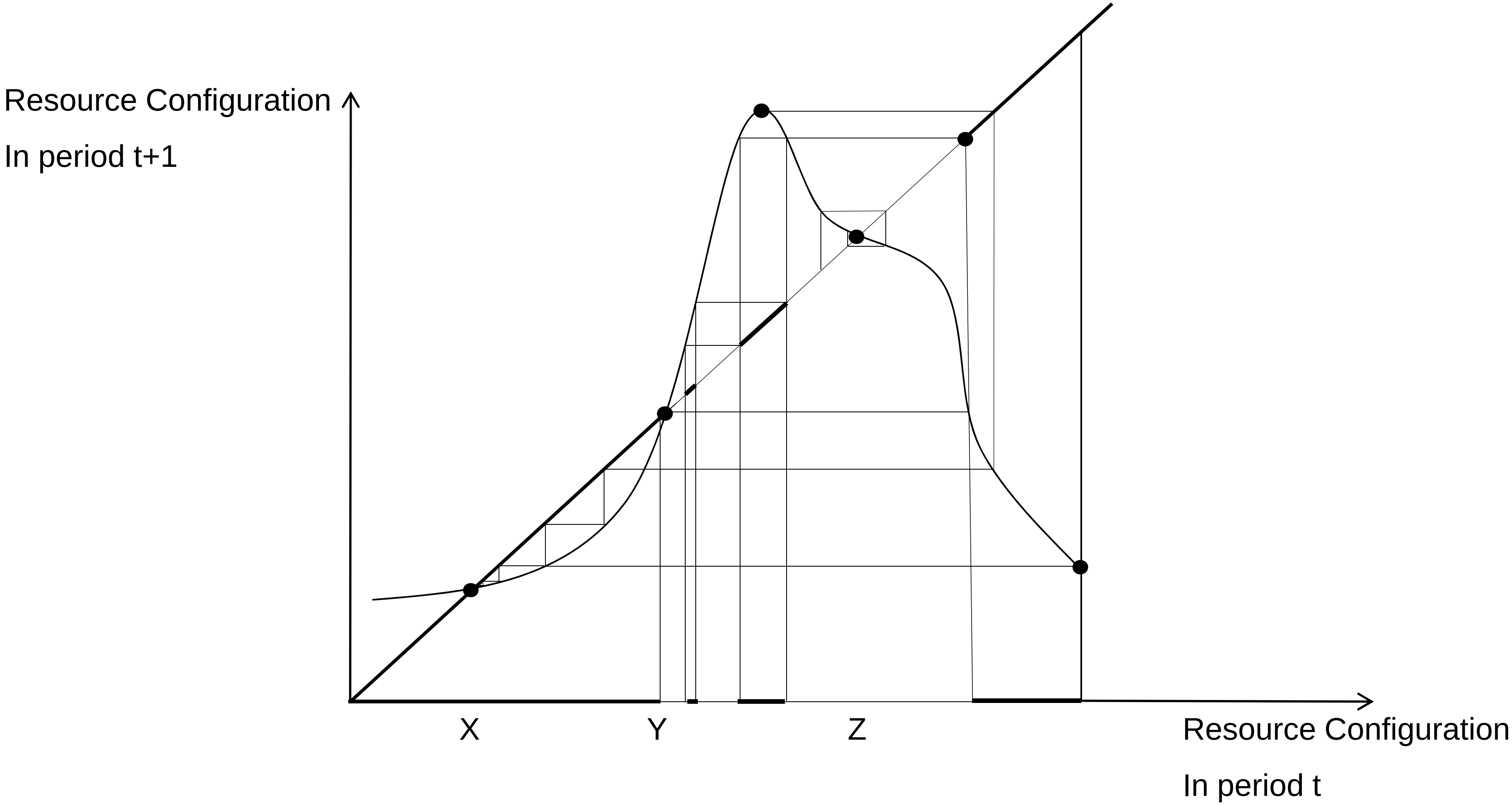
Resource Configuration
In period t+1
X
Y
Z
Resource Configuration
In period t

Figure 3