Organizational Path Dependence: The Prevalence of Positive Feedback Economics in Hierarchical Organizations

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ABSTRACT

We focus on the application of path dependence logic in organizations, particularly on the role of self reinforcing mechanisms in the evolution of institutions in business firms. Path dependence theory suggests that self reinforcing mechanisms may lead to very high persistence of inefficient institutional solutions. The so called lock-in can create a growing threat to an organization's viability. While path dependence theory is developed as a market based approach and widely accepted in economics, some critics doubt its application to organizations science. They argue that asymmetric power structures in organizations contradict with the basic assumptions of perfect markets and thereby models of path dependence cannot properly be applied to organizations. Attempts to incorporate asymmetric power structures to formal models of path dependence are difficult because they create process-oriented, complex models of interaction on different levels that become mathematically intractable. With the use of computer simulation, institutional change in organizations can be modeled as an interdependent multilevel-process and analyzed numerically. The results allow predictions of institutional long-term states of the system and the conditions, which result in a lock-in situation. By varying the magnitude of the complementary effects and organizational structure as the two independent variables, the institutional evolution in social systems prone to positive feedback can be examined. The results of this work in progress will add to both path dependence theory and the discussion about optimal organizational design.

Keywords: path dependence; institutional change; complementarity, simulation

INTRODUCTION

The role of institutional arrangements in organizations cannot be overestimated: *"Institutional change determines the development of social systems over time and thus is the key in the understanding of historic change. (...) The differences in economic performance over time depend heavily on how the institutions evolve." (North, 1990)* Complementary effects are at the heart of positive feedback-loops that drive the process of institutional development. Path dependence theory suggests that under these conditions inefficient institutions may become

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locked-in, meaning that it is not possible to abandon them by actions undertaken from within the system (Sydow, Schreyögg, & Koch, 2009).

First we present an overview of path dependence literature and the main arguments. We focus on the process of adopting new institutional solutions. A simple simulation model of institutional evolution in a social system with self reinforcing mechanisms is presented. Applying the building block method suggested by Davis, Eisenhardt, and Bingham (2007) we developed an advanced model that includes organizational structure as independent variable. The advanced model will enable us to test the predictions of path dependence theory for different types of organizational hierarchy and different degrees of hierarchical power. Although the work on the advanced model is still in progress, we provide some insights from the first test runs.

PATH DEPENDENCE THEORY

As a dynamic theory path dependence theory basically assumes that initial decisions may increasingly restrain present and future choices. Paul David initiated the discussion on path dependence from an economic perspective (David, 1985). Within his historical studies he explored the development of the QWERTY keyboard technology and describes how this inferior standard was diffused and maintained although superior technological innovations were available at some point. Similar studies were carried out by others on the technologically surprising dominance of inferior technologies (Cusumano, Mylonadis, & Rosenbloom, 1992; Katz & Shapiro, 1986). As already noted, path dependence theory is based on the fact that history matters (Teece, Pisano, & Shuen, 1997; Nooteboom, 1997). Brian Arthur (1989; 1994) has formalized and to a minor extent also simulated path-dependent processes by highlighting the additional importance of self-reinforcing mechanisms.

From that perspective, path dependent processes are generally described as self reinforcing processes characterized by non-predictability, non-ergodicity, inflexibility, and potential inefficiency (Arthur, 1989, 1990; David, 2001; Pierson, 2000). In other words, the path's final outcome among possible different alternatives is not predictable and might become a dysfunctional trap, inhibiting the organization to deviate from it. Thus, path dependence is conceptualized as the outcome of a dynamic process that is ruled by one or more self-reinforcing mechanisms which lead to a narrowing of the variation and range of (managerial) discretion (Sydow, Schreyögg, & Koch, 2009). Path dependence describes a tapering process. Thus, a path constitutes a restriction of choice for a social or psychic decision-making system. While choice is not restricted to start with, it becomes restricted in the process of following that path. Figure 1 illustrates all three stages. The degree of path dependence increases with the duration of Phase II and is full-blown in Phase III (lock-in).

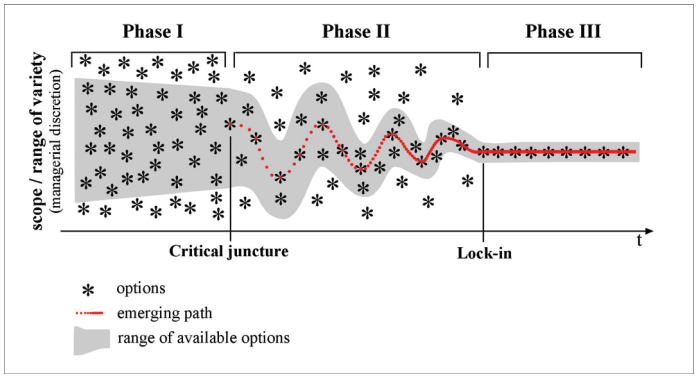

FIGURE 1:
The three stage model of path dependence
(Sydow, Schreyögg & Koch, 2009)

Phase I is characterized by contingency, although certain choices and events may already have a slight narrowing impact, illustrating that history already matters in

that early phase (Teece et al., 1997; David, 1994). In Phase II, self-reinforcing mechanisms increasingly limit the scope of choice and thereby facilitate the evolvement of an organizational path (Sydow et al., 2009; Stieglitz & Heine, 2007; North, 1990). With the transition to Phase III, the diminishing window of opportunity finally closes, leaving the organization strategically trapped in an unalterable state.

The idea of self-reinforcing mechanisms implies a positive feedback. A self-reinforcing mechanism is a necessary precondition for what is defined as a path. That presumes that agents act (consciously or unconsciously) upon these mechanisms and by doing so they reinforce the path-building effects. The diminishing variety and the rising limitations of choices are collateral effects of this process. Hence, the hallmark of path dependence theory is its focus on self-reinforcing effects (Arthur, 1994; David, 1993; Bassanini & Dosi, 2000). These effects are understood as the central triggering elements that drive path dependence (Sydow et al., 2009). Up to now, path dependence research has hallmarked the crucial elements that drive path emerging processes and finally lead to a lock-in in phase II (see Figure 2) of the model. At least six different forms of self-reinforcing mechanisms (Sydow, Schreyögg, & Koch, 2005) can be distinguished from a technological and from an institutional perspective: (1) economies of scale and scope, (2) direct and indirect network externalities, (3) learning effects, (4) adaptive expectations, (5) coordination effects and (6) complementary effects.

The first three mechanisms particularly apply to diffusion processes of technological standards. Economies of scale and scope refer to the market's supply-side and cost advantages due to production expansion as well as synergy effects of adjunctive product variety. Direct and indirect network externalities refer to the demand-side and cover the single agent's additional utility stemming from the technologies diffusion rate. Learning effects build on a rather individual level of the demand-side with illuminating experiences agents gain with their adoption of a specific technology. Learning effects also play an important role from an institutional perspective. Here the implementation and the repeated appliance of institutions lead to learning effects and the internalization of these institutions, resulting in a declining attractiveness of deviation. Adaptive expectations relate to the agents' interaction and their co-building of preferences. The more an agent expects others to prefer a particular product or standard, the more attractive it becomes.

From the institutional perspective of this paper the final two mechanisms are of most relevance. The coordination effect was introduced by North (1990) and refers to the general benefit of coordinated behavior. The more agents adopt a specific institution the more efficient the interaction among these agents becomes. In other words, shared rules contribute to the anticipation of other agents' behavior; reactions can be foreseen and uncertainty as well as coordination costs will be reduced. From a single adopter's point of view it the attractiveness of adopting an institution rises with its spread.
The well-known traffic-rule example illustrates this (Arthur, 1994: 14): Imagine an island having roads but neither cars nor any traffic rule. Once cars are introduced, drivers have to decide for left-hand or right-hand driving in order to prevent unwanted collisions. Oncoming indifferent drivers coordinate their behavior, others accordingly adapt and at some point one alternative dominates the other, with the obvious benefit of coordinated interaction.

Complementarity effects on the other hand result from plurality and

connectivity between different institutions (Stieglitz & Heine, 2007). Essentially, complementarities mean synergy resulting from the interaction of two or more separate and different institutions, where the institutions' advantages do not just add up but create a surplus based on complementarity: $F_{(x+y)} > F_{(x)} + F_{(y)}$ (Sydow et al., 2009). In other words: an institution is reinforced by another one and vice versa. Referring to the traffic-rule example, introducing the institution of giving way at crossroads to drivers coming from the right reinforces right-hand driving.

At this point it should be stated that these effects can only be differentiated on an analytically level, empirically they are rather jointly at work than acting separately.

Conceptual argument of complementarity feedback

In our study we focus on one of the mechanisms: complementarity. Complementary effects form positive feedback loops that may pave the way for path dependence and lock-in. We adopt the understanding of David (1994) arguing that two (or more) institutions are complementary to one another when the existence (or more precise: a higher diffusion rate) of the focal institution makes the adoption of the other institution(s) more attractive for the relevant decision makers in the system and vice versa. David argues that in dynamic and complex environments new problems emerge all the time, creating the necessity of adopting new institutional solutions. In the process of finding new institutional arrangements capable of solving the problem at hand decision makers favor those institutions that are more compatible with already existing institutions over those which are less compatible. The main argument here is the desire of decision makers to avoid so called misfit-costs. Those include time and resources needed to solve conflicts resulting from the installation of less-compatible institutions. The tendency to avoid misfit-costs favors the emergence of a set of institutions that are highly compatible with each other (in the sense of having very low misfit-costs when existing together with the other institutions in the set). Such a set is called an institutional cluster (North, 1990). Whenever a new institutional arrangement is highly compatible with the existing institutional cluster, the cluster becomes denser. This means that future misfit costs will significantly rise for institutions that are not compatible with the already established institutions in that cluster. Thereby chances increase for forthcoming institutional arrangements to be again in line with the institutional cluster – forming an even denser cluster. This conceptual argument of institutional complementarity is illustrated in figure 2.

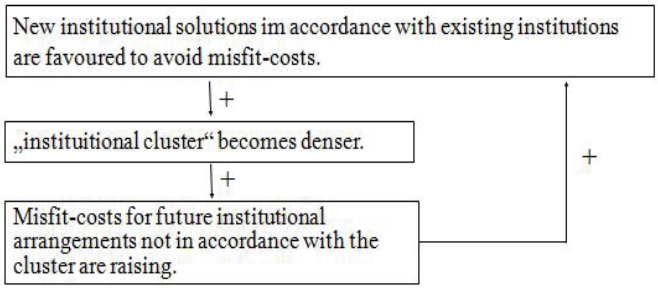

FIGURE 2:
The conceptual argument of positive feedback created through complementary effects

SIMULATING COMPLEMENTARY EFFECTS

Because of the interdependency of the macro variables (density of the institutional cluster, diffusion rate of institutions) with the variable on the micro-level process (decision of members of the social system who adopt one institutional rule or the other), an analytical approach applying solely mathematical deduction is not promising, as the differential equations that describe the systems behavior become intractable even with very restrictive assumptions and number of variables (see the work of

Arthur, 1989). Davis, Eisenhardt, and Bingham (2007) suggest a numerical solution when nonlinear, multilevel and longitudinal processes need to be modeled, and call for the application of computer simulations.

Computer simulations as scientific method

Besides logical deduction and empirical research computer simulations have become a third way of doing research in social sciences. When interdependencies between variables in complex and dynamic systems make the problem mathematically intractable, computer simulation offers a numerical solution to many problems. "Simulation is particularly useful when the theoretical focus is longitudinal, nonlinear, or processual, or when empirical data are challenging to obtain." (Davis et al., 2007) In simulation research a formal model is implemented into computer codes and often run numerous times to uncover the system's behavior. When examining the development of institutions in organizations and disclosing path dependencies we face most of the difficulties mentioned by Davis et al. Thereby computer simulation seems a very promising method.

A Simple Model

In a simple model we examine the process of institutional evolution in a multi-level, interdependent system. Our goal is to concentrate on the implications of complementary effects that trigger positive feedback loops. Here we put aside the influence of organizational hierarchy which will be included later on in the advanced model.

We adopt the idea of the netlogo implementation of the opinion formation model and look at a very simple social system consisting of a number of agents (i.e. 1000 agents) who decide whether to comply with one of two possible institutional solutions. In accordance with that simple traffic-rule example given above, the two institutional solutions are exclusive, meaning that they offer incongruous solutions to the same problem. In the simulation model colors are assigned to each solution, so for simplification it is possible to speak of a red and a blue institutional solution. The system contains a set of agents while each agent has exactly one attribute which is the behavior regarding the two contradicting institutional solutions red and blue. We applied a discrete timeline where time is counted in so called "ticks". For every tick, each agent decides whether he complies with the blue or red institutional solution. The decision function that defines the agent's decision is at the heart of the model. Deriving from path dependence theory, random small events (Arthur, 1990) are present and potentially influencing the process with earlier occurring events being potentially more influential than later ones. Due to complementary feedback, decision makers favor an institutional solution that is compatible to a denser cluster (David, 1994). In the modeled system two institutional clusters exist, one containing the blue and one containing the red institution. (Note: Arthur (1989) showed analytically that in cases where the diffusion of only one technology (respectively institution A) enjoys positive feedback while the other one (B) does not, the domination of A is inevitable.) The independent variable is the magnitude of complementary feedback. The initial density of the two institutional clusters can be varied in different simulation runs. The results stated in this paper are obtained with equal initial density for each cluster at the beginning of each simulation run.

Implementation of simulation model

The formal model was implemented using netlogo 4.0 implementation environment. At every tick, all agents adopt red or blue behaviors according to the actual diffusion of institutional rules and the density of

each cluster, taking into account the misfit costs arising from a choice that is incompatible to the denser cluster. The corresponding variables implemented in the simulation model are called 'pop-state' and 'complementarity'. 'pop-state' varies from -1 to 1 and shows whether agents actually favor the red institutional solution over the blue (pop-state < 0) or the blue institutional solution over the red (pop-state > 0). When 'pop-state' reaches the value of 1 (-1), the corresponding system behavior shows a diffusion rate of 100% of the blue (red) institution, meaning that all individuals have fallen in line with the institutional solution compatible to the denser cluster. 'Complementarity' is the strength of the complementary feedback. It is the independent variable of the model. It regulates the impact of a higher diffusion rate of the focal institution on the institutional cluster's density. 'Complementarity' ranges from 0 to +1. A value of 0 means that an additional highly compatible institutional solution does not change the clusters density at all while a value of +1 means that an additional highly compatible institutional increases the clusters density dramatically. Also at every tick a random number is drawn for every agent, incorporating personal preferences and random small events into the decision process. In the netlogo implementation the corresponding variable is called 'random-number' which is a random number between 0 and +1. A value of close to 0 is associated with a very strong random tendency to choose red behavior. A value close to 1 is associated with the very strong tendency to choose blue.

Adopting the logic of the motivational theory formed by Vroom (at first 1964) for this context, agents experience a *force to act* in accordance with A (FTA_A) or B (FTA_B) depending on random events describing their personal preferences at time t (α,β), the density of the institutional cluster (x), and the strength of complementay effects (c) inherent in the system. With every tick, one agent after another chooses to adopt the red or the blue institutional solution corresponding to the following decision rule: Behave in accordance with A if and only if FTA_A (x) > FTA_B (x) and B if and only if FTA_B (x) > FTA_A (x) and if FTA_A (x) = FTA_B (x) do not alter the previous behavior. FTA_A (x) and FTA_B (x) are specified as follows: $FTA_A(x) = \alpha * f_{A,c}(x)$ and $FTA_B(x) = \beta * f_{B,c}(x)$ with $f_{M,c}(x) := e^{m*c*x*1.5}$ and fixed $c \in [0,1]$; α,β randomly $\in [0,1]$; $M \in \{A, B\}$ and m=1 for $f_{A,c}(x)$ and m=-1 for $f_{B,c}(x)$ (for a detailed introduction of the formal model logic see Petermann 2010:140).

Figure 3 shows the netlogo interface and a sample run of the simulation model.

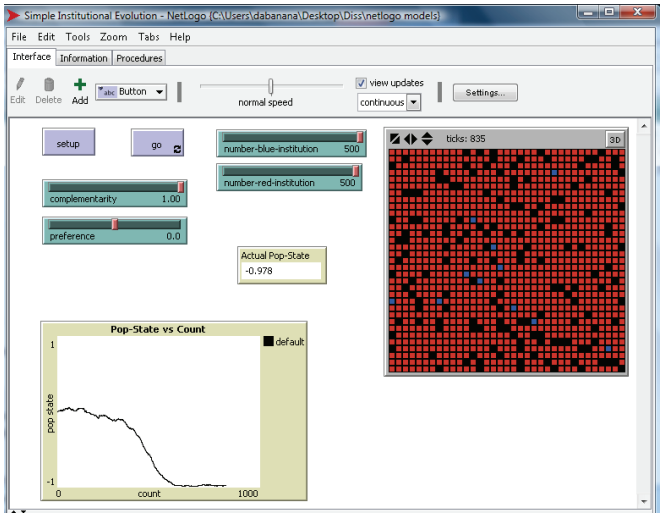

FIGURE 3:
A Sample run of the simulation model

Results

Applying the Monte-Carlo method, the system behavior can be examined over time for different degrees of complementary feedback strength. Figure 4 shows the results for complementarity c = 0 and c = +1. When there are no complementary effects at work (complementary c = 0), random small events govern the process. Because of 1.000 agents making simultaneous decisions every tick, the law of large numbers applies: In the long run both institutions persist with significant

diffusion rates. Decision makers are not bound to a dominant behaviors rule but can choose dependent on their personal preferences and actual circumstances (small events).

In contrast if strong complementary feedback applies, the probability of finding a system with significant diffusion rates for both institutional solutions decreases with time, approaching zero in the long run. Dependent on the random small events governing the process in the early stage, one of the two institutional solutions becomes dominant and locked-in, being the only alternative for decision makers at some point.

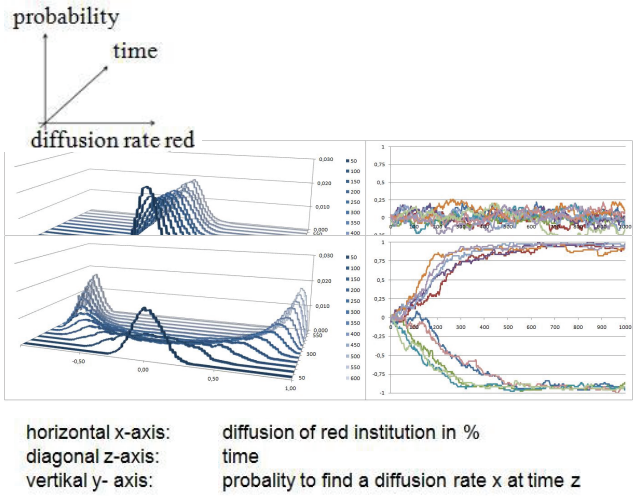

FIGURE 4
Results of the simple model: high complementarity necessarily leads to a lock-in situation

The results shown in figure 4 are consistent with the results of Arthur's deductive analysis of positive feedback processes. With the application of computer simulation it was possible to model the process much more realistically and with less restrictive assumptions compared to Arthurs polya urn model (Arthur, 1989).

Towards an advanced model: implementing organizational hierarchy

Path dependence theory is a market based approach (David, 1985, Arthur, 1989). The application to social systems like a firm is often criticized because a firm lacks some basic constituents of a perfect market, especially the absence of power. While scholars of market-based approaches at least theoretically argue that total competition and the absence of power do exist, management scholars cannot negate one of the fundamentals of a firm, namely the organizational structure that explicitly creates power inequalities among the members of the organization. Thereby it seems necessary to include hierarchy into the model to address the fact that power structures and maybe the specific organizational design might impact the evolutional diffusion processes of institutions (and technologies) within organizations.

In an attempt to embrace this argument, the notion of organizational hierarchy has been added to the simple model. A formal organizational structure is introduced by assigning a superior to every agent in the system. In the simple model, agents decide exclusively on the basis of small events and mis-fit costs arising from dense institutional clusters. Now a third variable influencing the individual decision making process is introduced, which is called 'leadership impact' (li). This variable includes explicit orders from superiors as well as more implicit elements, as individuals in organizations try to meet the expectations of their superiors. The individual's decisions are now dependent on random small events, complementary feedback *and* hierarchical influence of their superiors.

At every tick, one agent after another chooses to adopt rather the red or the blue institutional solution corresponding to the following decision rule: Behave in accordance with A if and only if FTA_A (x,y) > FTA_B (x,y) and B if and only if FTA_B (x,y) > FTA_A (x,y) and if FTA_A (x,y) = FTA_B (x,y) do not alter the previous behavior. FTA_A (x,y) and FTA_B (x,y) are specified as follows: FTA_A (x,y) = $\alpha * [f_{A,c}(x) + i (y) * li]$and FTA_B (x,y) = $\beta * [f_{B,c}(x) + i (y) * li]$ with $f_{M,c}(x) :=$

$e^{m*c*x*1.5}$ and fixed c ϵ [0,1]; α,β randomly ϵ [0,1]; M ϵ {A, B}; m=1 for $f_{A,c}(x)$; m=-1 for $f_{B,c}(x)$; li fixed ϵ R^+ and i(y) ϵ {-1,1} depending on the adoption behavior of the superior which determines the order to adopt A or B that the agents receives from his superior (for a more detailed introduction of the formal model logic see Petermann 2010:186).

Advancing the simple model with the assigning of superiors who influence the decisions of their subordinates is our research agenda. A typical hierarchical organizational design has been implemented. The netlogo implementation is shown in figure 5.

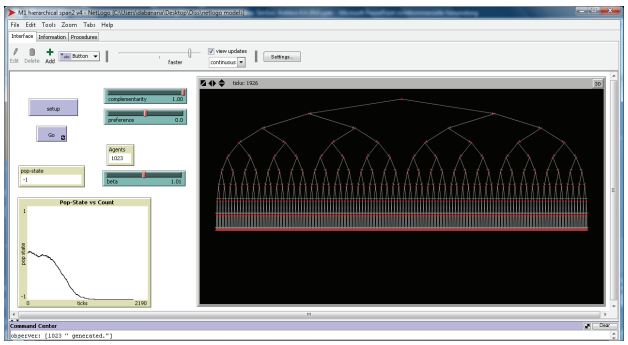

FIGURE 5:
The Advanced model with hierarchical organizational design

Future prospects

The advanced model is modified for different types of organizational designs and run with different values for complementary feedback and hierarchy influence. The analysis of this data is not yet presented in this paper. Detailed insights from the results will be presented during the conference indicating that the path dependence logic holds also for systems with hierarchic structure. It can be shown that hierarchy in organizations seems to influence the process of complementary feedback in degree, but not in kind. When complementary feedback is strong path dependent logic leads to a lock-in, a close to 100% diffusion rate for on institutional solution. Which of the competing institutional solutions will prevail and dominate the systems in the long run seems to depend on random events and leadership influence in the beginning of the process, while the influence of those at the hierarchical top fades away as time goes by and institutional clusters become more and more dense.

CONCLUSIONS AND DIRECTIONS

We formally modeled the impact of complementarity effects in the process of institutional development. By means of computer simulation we technically validated the predictions made by scholars of path dependence theory about the importance of positive feedback in institutional evolution. Our simple model is much more sophisticated (i.e. agents can revoke their decision as time goes by) than the polya urn model introduced by Arthur (1989). The consistency of our results with Arthur's mathematical deduced solution to the polya urn model is a good means of validation for our work. The latest results of the advanced model will be presented during the presentation for different organizational designs. This approach enables us to clarify if and to what extend the predictions of path dependence theory hold when asymmetric power structures are incorporated in the social system observed. The results provide insight to the questions, which organizational designs are more or less prone to the dangers of path dependence and lock-in. The results will thereby add to path dependence research and to the ongoing discussion about optimal organizational design.

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