THE LIFE CYCLE OF OPEN SOURCE SOFTWARE DEVELOPMENT COMMUNITIES

André L. S. Guimarães
BNDES – Brazilian Development Bank
Rio de Janeiro, Brazil
aguimaraes@bndes.gov.br

Helaine J. Korn
Zicklin School of Business, Baruch College
City University of New York
New York, NY, USA
helaine.korn@baruch.cuny.edu

Namchul Shin*
Seidenberg School of Computer Science and Information Systems
Pace University
New York, NY, USA
nshin@pace.edu

Alan B. Eisner
Lubin School of Business
Pace University
White Plains, NY, USA
aeisner@pace.edu

ABSTRACT

Drawing from the concept of entropy in open systems theory, this article contributes to organizational theory by illuminating organizational life cycle theory and exploring open source software development communities (OSSDC) with quantitative longitudinal data. In particular, this study uses functional data analysis to uncover the development patterns of open source software projects in terms of effectiveness and activity levels. Our findings show that the life cycles of OSSDC display an inverted-U shape in terms of effectiveness level and an inverted-S shape in terms of activity level. Although our results provide some evidence of distinct states, they do not imply that such states are predetermined or irreversible. On the contrary, these numerous states are viewed here as intrinsically dynamic. These findings not only give empirical support to the organizational life cycle metaphor in the context of OSSDC, but also aid practitioners and policy-makers in assessing online communities. Taking an open systems view of organizations, this study aids in reconciling some issues in life cycle theory, such as the irreversibility and pre-determinacy of life cycle models, and adds to a young but fast growing stream of literature on open source projects. Lastly, our findings remark the importance of fostering active communities for superior effectiveness and long-term survival of the community.

Keywords: Online communities; open source software development; life cycle.

1. Introduction

The notion of the organizational life cycle has been in the literature for more than forty years [Greiner 1972; Lippit & Schmidt 1967]. In spite of the long history, relatively few empirical studies have been conducted [Levie and Lichtenstein 2008]. Furthermore, those few studies have often brought in significant assumptions (e.g., pre-determined number of stages) and have been conducted in settings that might be perceived as less dynamic [D'Aveni 1994] than those faced by most organizations today.

* Corresponding author

Research on the development of online communities also lacks empirical grounding [for a recent review, see Iriberri & Leroy 2009]. Some notable exceptions are: the study of the relationship between turnover and collaboration in Wikipedia [Ransbotham & Kane 2011]; the study of the relationship between critical mass and online survival that also remarks the relationship between activity levels and community survival [Raban et al. 2010]; and the changes in individual roles in Twitter tag-based communities [Sonnenbichler & Bazant 2012].

This research seeks to fill this gap, expanding our horizons in relation to life cycle and growth models and exploring the new field of online communities with quantitative data. Instead of assuming the existence of life cycle stages, this research aims to determine whether the theorized pattern of organizational development can be verified empirically.

As the Internet changes our culture [Rettie 2002], online communities are quickly becoming commonplace, and corporations are increasingly turning to online communities to create valuable information [Ransbotham & Kane 2011], enabling virtual self-managing teams and embracing openness as a new strategy to improve innovation and competitiveness [Chesbrough 2003]. In such scenario, it seems important to understand whether life cycle models are applicable to online communities or whether there are other new patterns that can be uncovered that might help us better understand how these organizations develop over time. This study attempts to do this through the application of functional data analysis to the study of open source software development communities (OSSDC), such as the ones that have created the Apache web server, the Linux and Android operating systems, and quite numerous other applications.

An important distinction of this study is the attention to activity, in addition to the classic view of effectiveness patterns over time. Looking at effectiveness and activity levels, instead of effectiveness alone, gives the analyst a richer picture of development over time, and makes it easier to establish the firm's position relative to a certain point of reference along the expected theoretical organizational life cycle.

The findings of this study lend empirical support to the relationship between community activity and community effectiveness, and call upon users of online communities in general, and OSSDC in particular, to pay greater attention to processes underlying community activity and participation dynamics as these might directly and strongly impact community effectiveness and survival [Faraj & Johnson 2010, Raban et al. 2010]. Studies such as this are relevant because they contribute to our understanding of organizational development patterns through models of organizational development over time that allow scientific examinations of the complexities involved in the change process, and therefore make high-impact contributions to organizational science [Chan 1998, Dass & Shropshire 2012].

The rest of the article is organized as follows: We first briefly review the organizational life cycle literature, discuss some of its issues and limitations, and attend to the relevance of testing the organizational life cycle pattern empirically. We then provide the methodological details of the study, with a brief introduction to functional data analysis, a set of statistical tools developed to study information on curves or functions, such as the patterns exhibited by theoretical models of change in organizational phenomena [Dass & Shropshire 2012]. Finally, we present the results and discuss the findings of the study, while introducing a basic four-state organizational life cycle model empirically-supported.

2. Theory and Hypotheses

2.1. An Overview of the Organizational Life Cycle Literature

There have been some comprehensive reviews of organizational life cycle literature [Cameron & Whetten 1983, Hanks et al. 1993; Levie & Hay 1998, Quinn & Cameron 1983]. In these reviews, four major perspectives emerge: the pure biological analogy (n.b.: organisms), structural/contextual variables as determinants of life cycle stages, the problems-based approach, and the evolution/revolution dilemma.

The four perspectives seek to elucidate how to conceptualize the space in time into growth patterns such as inception, maturation, revival, or decline, experienced by organizations [Churchill & Lewis 1983]. Collectively these studies share a common challenge: to identify and model, amidst all the variance, the regularities and patterns in organizational development.

2.2. Biological perspective

The biological perspective posits an organismic development analogy (i.e., organizational life stages resemble those of organic life) and with it three core propositions about the nature of organizational development. The first is that organizations, just as organisms, experience distinct stages of development. The second proposition is that the order in which they undergo these recognizable stages is predetermined and predictable. The final proposition states that just as all organisms of the same species undergo the same sequence of developmental stages, so will organizations of a given population [Levie et al. 1998].

Levie and Hay [1998] argued powerfully that organismic models of development are fundamentally flawed and lack empirical support when tested on large samples of organizations. They conclude that although organizations pass through or experience qualitatively different and clearly identifiable stages or configurations at different times, there is modest empirical support when stages are defined by sets of problems rather than by sequence. Support for propositions that stages occur in a set sequence followed by all organizations is nearly non-existent.

The idea that organizations can be defined in terms of a life cycle finds some support from Bessant's [2003] remark that only one firm in the Fortune 100 index actually made it from the beginning to the end of the 20th century. It is widely accepted, though, that organizations do experience expansion and contraction over time, thus the linear, unidirectional implications of biological models are obviously inadequate. Rutherford and colleagues, based on a sample of 2,903 small and medium-sized firms, found that human-resource problems vary over the life cycle according to a four-stage model [Rutherford et al. 2003]. Confirming the argument [Bailey & Grochau 1993] that stages are uncorrelated with age, age did not emerge as a significant indicator of stage of development [Rutherford et al. 2003].

2.3. Structural/Contextual determinants

In their quest to adapt to dynamic environments, firms change their structures, processes and resources. Often, these new arrangements require different managerial practices in order to be effective [Penrose 1959]. As firms move from one stage to the next, more sophisticated capabilities are required [Miller and Friesen 1983] and, as firms increase in size and complexity, they face new problems. Indeed, the view of patterns of organizational change through time is as powerful as it is appealing, as it resonates well with the familiar and tangible experience of organism growth [Levie & Hay 1998]. This view also takes into account the claim of the evolutionary perspective that organizations in environments where the rate of change exceeds their own capacity to change will face extinction [Hannan & Freeman 1984].

Critics of life cycle theory [LCT] challenge its underpinning assumptions, and highlight the limited empirical evidence to support these assertions. They also attack the narrow conceptualization of the phenomenon under study, often describing movement across stages in terms of organizational and structural variables, hence, defining transitions according to organizational variables such as change in numbers of employees or turnover, and ignoring the contextual contingencies that might define stages otherwise [Stubbart et al. 1999]. Another concern is the lack of agreement [Hanks et al. 1993] about the numbers of stages or what constitutes a stage. Through a comparison of stage models ranging from three to ten stages, Hanks et al. [1993] discover a reasonably consistent pattern of organization evolution over startup, expansion, maturity and subsequent diversification or decline. The authors also point out that much of this work has been either theoretical or conceptual, or grounded in empirical models of questionable validity, and conclude that there is much work to be done in order to be able to determine whether or not there are contingencies that affect the number of stages and whether all organizations progress through the same series of stages.

However, there is also some supporting evidence in favor of LCT. Miller and Friesen [1984] examined the predictions of stage models that (1) each stage is described by a set of variables (i.e., environment, strategy, structure, decision making processes); (2) that is qualitatively different from each other stage, and; (3) organizations progress sequentially through five stages they recognize as implicit in the conceptual literature. Their longitudinal analysis showed long-term evolutionary patterns giving some support to LCT, but also showed various exceptions. Thus, they argued that there are multiple transitional paths available to organizations. Importantly, however, they also provide some evidence of regression, movements against the predicted unidirectional path, which invalidates the organismic metaphor.

2.4. Problems-based approach

A specific variation of the structural/contextual theme stands out in the literature. These models conceptualize stages in terms of the nature of the problems faced by organizations and the necessary structures to cope with such problems [Hanks et al. 1994]. Indeed, part of the purported power of the stages models is in their ability to anticipate potential problems and needs of organizations throughout their lives. Some studies define the transition across phases in terms of the dominant problems that management needs to address [Kazanjian 1988, Kazanjian et al. 1990, Smith et al. 1985] or critical junctures [Vohora et al. 2004], which is a refinement of the notion of revolution and crises implicit in earlier models [Churchill et al. 1983, Greiner 1972]. As organizations progress from one stage to the next they undergo transformations in their strategies and structures [Hanks et al. 1994] enabling them to face new challenges characteristic of the new stage [Kazanjian et al. 1990].

2.5. Evolution or revolution dilemma

Life cycle models can also be thought of as being either evolutionary or revolutionary. Evolutionary models show a relatively smooth progression through the stages, as a function of size, growth rate, or age, while revolutionary models offer a more stochastic stance in which progression from one state to the next is contingent on a given critical event. Greiner's [1972] model is an example of this, in which progress involves a revolution or crisis that demarcates the transition into the next stage. Also, each stage is characterized by a specific managerial problem and its accompanying generic solution.

The proposition that growth does not follow a linear, smooth evolutionary pattern, but rather goes through alternate periods of evolution and revolution punctuated by crises was tested by Tushman, Newman, and Romanelli [1986], who found that firms seemed to follow a sequence of punctuated stages and that there were no patterns in the sequence of frame breaking stages. Such perspective resembles Lewin's [1958] model of social change, in which transitions occur between phases of stability and instability. When forces favoring change are greater than those resisting it, firms move from one state to another. During transitions, either managers adapt current practices to the new environment, creating conditions for future growth, or fail to adapt, and the firm stagnates or dies [Abetti 2001].

2.6. Is the Life Cycle Metaphor Useful? From Stages to Dynamic States

Despite all the criticism, organizational life cycle models are quite appealing because they can serve as useful metaphors for researchers seeking to understand organizational development. More importantly, a valid organizational life cycle model would have tremendous implications for policy and practice. Managers could use it as a roadmap, identifying critical organizational transitions and avoiding pitfalls while their organizations grow and become more complex. However, in order to deliver on such promises, the organizational life cycle construct requires some "tightening" [Hanks et al. 1993], through stronger empirical support. This study is a step in this direction. It tests, through longitudinal quantitative research, the life cycle metaphor in the context of open source software development communities.

This study also takes the "dynamic states" perspective of organizational life cycle, compared to the viewpoint considering stages as pre-determined and irreversible. Levie and Lichtenstein [2008] argue that by replacing stages with "dynamic states", most of the issues with the organizational life cycle literature are resolved. For them, dynamic states seek to reflect an optimal relationship between the firm and its environment, and since both sides of the equation can change, there can be any number of dynamic states in an organization's existence. If the theory is right, at least for populations of firms, a pattern must hold. However, for any given firm, change can occur in any given sequence.

Having reviewed the organizational life cycle literature, the following section offers a brief description of open source software development communities and how issues faced by these communities evolve over time.

2.7. The Life Cycle of Open Source Software Communities

Open source software development communities are formed by geographically-dispersed individuals that collaborate to develop software to be distributed under a certain license that warrants open access to the source code of the software. Well-known examples are the Linux operating system kernel and the web browser Mozilla Firefox. There is widespread recognition that OSSDC constitute examples of online communities [Dahlander & Magnusson 2005, Lerner & Tirole 2002, O'Mahony 2002, Rosenkopf & Tushman 1998, von Hippel 2002, von Krogh et al. 2003, West & O'Mahony 2005].

OSSDC also fit the view of an organization as a coalition [Cyert & March 1963] and of communities of practice [Aldrich 1999, Wenger et al. 2002], viewed as the "patterned social interaction between members that sustains organizational knowledge and facilitates the reproduction of routines and competencies" [Aldrich 1999]. Through frequent interaction, members acquire organizational knowledge, learning their roles, and how to apply what they know and come to learn. In the process, members develop shared understandings about the group and its environment. These socially-constructed forces drive community success and shape its development [Yap 2002].

The organizational life cycle perspective has also been effectively applied to communities [Wenger et al. 2002, Iriberri & Leroy 2009]. Iriberri & Leroy [2009] reviewed research on online communities and, similarly to Wenger and colleagues, argued that online communities evolve following distinctive lifecycle stages, proposing a five-stage life-cycle model of online communities, comprising: inception, creation, growth, maturity and death. The authors also discuss the main success factors associated with each stage.

Because OSSDC align well with the type of communities described by Wenger and his colleagues, it is instructive to understand the major challenges faced by these communities as they develop. According to Wenger and his colleagues, early stages are often associated with establishing a clear definition of the scope and boundaries of their domain in a way that will attract and engage potential members, rather than determine the community's final shape. Successful communities are able to focus on problems that are important to their members, who often either are or become passionate about the topic and the community itself. The scope is defined broadly enough to bring in new people and new ideas, and narrowly enough to sustain the interest of the membership. Also, the community should encourage knowledge sharing from the start, as it often and rapidly becomes a powerful motivator. In order to clarify the importance of the domain for users and to engage membership, project leaders should build a case for action [Wenger et al. 2002]. A good case for action will consolidate the group identity, binding individuals together and strengthening their relationships.

As the community begins to grow, communication and coordination often require greater attention [Wenger et al. 2002]. While this leadership role may emerge without intervention, it is crucial to define a coordinator in the early stages of community development, as this person will be responsible for early recruiting, interviewing potential members and connecting contributors. But coordinators should also be responsible for identifying important issues in their domain, planning and facilitating events and communication; linking members and other communities; managing community boundaries; fostering membership development; stimulating the setup and maintenance of a knowledge base; documenting best practices, lessons learned, tools, and methods; and assessing the health of the community.

In summary, the community coordinator role can be quite time consuming as it requires strong communication skills and considerable technical expertise in order to transmit the messages well. The coordinator needs not to know all the answers, but should know all the questions, and who in the community is best prepared to address each question. The coordinator must be, above all, a great listener and politically-savvy in order to balance the need to maintain focus against the need to stimulate new contributions.

As it matures, the community must clarify its focus, role, and boundaries [Wenger et al. 2002]. The community will eventually face a tension between focus and expansion. This tension can only be resolved as the community "learns to preserve relationships, excitement and trust as it expands membership, and when it can maintain helping interactions while systematizing its practices" [Wenger et al. 2002]. If the community successfully resolves this tension it reaches to a deeper sense of identity and improves the confidence in the value of its domain, otherwise confusion arises and participation declines. Successful mature communities will often have to face a second tension: that between their own history and openness, or between their past and their future [Wenger et al. 2002]. As the community evolves, it develops tools, methods and approaches, a common body of knowledge summarizing its expertise and relationships. In order to remain relevant, the community must not become enchanted by its past achievements. On the contrary, it must embrace openness in order to encourage a new stream of ideas, approaches and relationships, and to allow the emergence of new leaders.

2.8. Hypothesis Development

Having reviewed the literature on stage models, a number of issues stand out as in need for further clarification. First, this study seeks to test organizational life cycle theory in the context of OSSDC. Second, as O´Rand and Krecker [1990] point out, most studies of organizational development assume that a sequence of stages or phases exists. This is, in fact, one of the major gaps in the literature that this study seeks to fill. No hard a priori assumption is made about the existence of life cycle stages. Instead, this study aims to determine whether the theorized pattern of organizational development can be verified empirically. Further, this study seeks to identify whether significant variations exist in the pattern, which might be construed as states of organizational development. Finally, by adopting an open systems view and applying the uncovered effectiveness and activity curves, we propose taxonomy of states of organizational development. Table 1 shows the theoretical perspectives in the organizational life cycle [OLC] literature, the gaps in the literature, and the perspectives this study takes in order to address the gaps.

Table 1. Organizational Life Cycle Literature, Gaps, and Theoretical Lens of the Study

Literature Reviewed	Literature Gaps	Theoretical Lens
Biological Perspective Structural/Contextual Determinants Problems-based Approach Change Process: Evolution vs. Revolution	OLC Stages vs. Dynamic States [Predetermined and Irreversible Stages] Single Variable [Effectiveness Pattern over Time]	Open Systems View Dynamic States of OLC OLC metaphor for OSSDC [Effectiveness and Activity Patterns over Time]

Cameron [1986] reviewed the organizational effectiveness literature and identified eight commonly used models of organizational effectiveness: (1) the goal model [Etzioni 1960, Perrow 1961, Price 1972, Thompson & McEwen 1958], where an organization is effective when it accomplishes its stated goals; (2) the system resource model [Etzioni 1960, Georgopoulos & Tannenbaum 1957, Katz & Kahn 1966, Lawrence & Lorsch 1967, Yuchtman & Seashore 1967], where effectiveness means acquiring necessary resources; (3) internal processes model [Cameron

1979, Cyert et al. 1963, Mahoney & Weitzel 1969, Seashore 1979], where effective organizations function smoothly without internal strain; (4) the strategic constituencies model [Gaertner & Ramnarayan 1983, Pfeffer & Salancik 1978, Zammuto 1984], where all strategic constituencies are at least minimally satisfied; (5) the competing values model [Quinn & Rohrbaugh 1983], with emphasis on how constituency preferences are met; (6) the legitimacy model [Hirsch 1975, Singh et al. 1986], where effectiveness equals gaining legitimacy; (7) the fault-driven model [Cameron 1984], where effectiveness means lack of faults or traits of ineffectiveness and (8) the high-performing systems model, where effective organizations are judged relatively to other similar organizations [DiMaggio & Powell 1983].

Although the eight models listed above can be adequate in certain circumstances, selecting the appropriate model to each situation can be challenging [Cameron 1986, Cunningham 1977]. In this study, the goal model is adopted as it can better handle clear, time-bound, measurable results [Cameron 1986].

Reviewing LCT models, Quinn and Cameron [1983] noticed that organizational life cycle models typically propose “a predictable pattern that can be characterized by developmental stages”. Although the number of stages proposed in various studies varies considerably, almost 80% of the models (i.e., 23 out of 29) reviewed by Levie and Hay [1998] report between 3 and 5 stages, and describe an inverted-U pattern that can be encapsulated as startup, growth, maturity, decline, and death.

Following LCT, it is expected that the pattern of effectiveness levels over time will resemble an inverted-U shaped curve, which indicates that effectiveness will be low during inception, high during growth and mature periods, and low again during decline. Therefore, we propose the following hypothesis:

Hypothesis 1: OSSDCs’ effectiveness levels over time will resemble an inverted-U.

James March, one of the most prominent scholars in organization studies, argued that: “it is process that gives meaning to life, and meaning is the core of life” [March 1991]. For March, “outcomes are generally less significant … than process” [March 1991]. Although not all researchers would agree with that strong affirmative, many would agree that processes are, at least, more interesting than outcomes. Practitioners would probably take the opposite side and be more concerned with outcomes than processes. Regardless of what side one takes, there is a nearly perfect symmetry between process and outcome [Donabedian 1980], and the validity of assessments of process and outcome depends on an assumed causal linkage between the two.

To examine the relationship between processes and goals in the context of OSSDC, one can look, for example, at the relationship between effectiveness levels and activity levels. Common logic teaches us that results depend on action (or lack thereof). Surprisingly, though, there has been little attention devoted to investigating the relationship between activity levels and effectiveness. That does not mean the relationship is non-existent or irrelevant. For most organizations, this lack of research is understandable, as capturing all relevant actions in a traditional organization is impractical. For OSSDC, though, collecting data on every shared or public action becomes feasible. We do not suggest, though, that every action taken affects, or leads to, results. However, considering the strong incentives that participants have to establish and maintain a solid reputation, the number of irrelevant actions is expected to be limited.

In the context of this study, the open systems approach is useful as it explicitly portrays activity and effectiveness levels as inextricably linked. The view of organizations as open systems [Katz et al. 1966, Thompson 1967] illuminates our discussion of the life cycle metaphor [Lippit et al. 1967, Schumpeter 1942, Van de Ven & Poole 1995, Vernon 1966]. In fact, it seems plausible that some of the conflicts and criticisms commonly found in the life cycle literature are results of conflicting views of organizations as closed or open systems. Let us consider, for example, the concept of entropy.

In closed systems, all irreversible processes lead to increased entropy, increasing decay and decreasing overall order. In open systems, the system can import negative entropy from the external environment, transform the available energy and export some product into the environment. This pattern of energy exchange has a cyclic character. When the amount of imported negative entropy is greater than the increase of entropy of the system, the system develops toward greater order, otherwise the system decays.

What does that mean, in the context of the life cycle metaphor? Splitting the life cycle curve across its apex, we have two sections: the first going up, and the second going down. Organizations will experience growth and remain in the first section when they are able to import more negative entropy than the entropy they generate; and will follow the decline path, described on the second section, when they fail to do so. Borrowing from the open systems principle of entropy, we argue that activities capable of importing negative entropy tend to drive effectiveness up, while those unable to do so tend to drive effectiveness down. In other words, activity levels are expected to exhibit an inverted-S shape, such as the one portrayed in the classic product innovation curve in the Abernathy-Utterback model [1978], with higher levels during inception and growth, decreasing during maturity, and reaching its lower levels at the end of the life course. Therefore, we propose the following hypothesis:

Hypothesis 2: OSSDCs' activity levels over time will resemble an inverted-S.

3. Methodology

3.1. Sample and Setting

SourceForge.net (SF) is the world's largest open source software development web site, with the largest repository of open source code and applications available on the Internet. Owned and operated by OSTG Inc., SF provides free services to open source software developers. Consistently with the open source spirit, OSTG has shared certain SF data with researchers studying the Free/Open Source Software phenomenon.

The SF web site is database driven and the supporting database includes historic and status statistics on over 100,000 projects and over 1 million registered users' activities at the project management web site. However, as Howison and Crowston [2004] warned, SF data is great but troublesome. Prior to any analysis, it is necessary to remove confounding data, for example data for projects that had never produced any code.

From the SF database, information was extracted for projects that had downloads, bugs, forum messages and source code activity information (all greater than zero), have had at some point in time at least three members, and have had at least twelve observations (in months, sequential) that satisfied all the conditions above.

Projects with fewer than three participants were discarded, as they make a less interesting subject in terms of organization and coordination. Also, the reduced number of participants suggests that membership might not be as open as expected. In order to make the analysis more relevant and to allow for greater validity, the dataset was inspected in order to make sure the projects sampled would include sufficient data (i.e., targeting at least 30 projects) for different quantities of monthly observations collected. Projects with fewer than twelve monthly observations were excluded because they offered too little data per project, possibly failing to contain an entire cycle and certainly adding a lot of noise to the observed curve. Projects with more than forty-one monthly observations were discarded because there were too few of them, and this reduced number of cases would cause the variance within this range (i.e., $t > 41$) to be severely inflated[1].

This resulted in a dataset with 1030 projects and about 24400 monthly observations. Although the remaining sample represents only a small fraction of the OSSDC population (estimated to be circa 0.6%, considering projects outside SourceForge), it is still a large sample, and represents well the group under study (i.e., OSSDC with three or more members and that were able to produce artifacts[2]).

3.2. Measures

In this study, effectiveness levels are operationalized as the number of downloads in a month[3], while activity levels are operationalized as the monthly count of actions (i.e.: bugs opened, bugs closed, messages posted, pieces of code contributed, patches opened, patches closed, artifacts opened, artifacts closed, tasks opened, tasks closed, support tickets opened, support tickets closed, and file releases) importing negative entropy into the system.

To facilitate the analysis, variables were transformed in order to make values commensurate, adjusting for project size. The value for each monthly observation was divided by the maximum value of that project, so that values would fall into an interval between zero and one. Of course, the transformation applied does not change the distribution.

3.3. Functional Data Analysis

According to hypotheses H1 and H2, effectiveness levels over time would resemble an inverted-U shaped curve, while activity levels over time would resemble an inverted-S shaped curve. In order to assess these hypotheses, the functional data analysis (FDA) toolset is used.

Functional data analysis is a new development in statistics involving the study of curve data [Ramsay & Silverman 2002, 2005]. Ramsay & Silverman [2002, 2005] give a detailed explanation of the method, and Dass & Shropshire [2012] introduce the method to organizational researchers. The set of techniques has been evolving rapidly with the technological and computational advances of the past two decades and opens new possibilities to data collection and analysis. Functional data are characterized by observations that are functions of some continuous measurement. In FDA, the data consists of functions not vectors. Observations taken at time points t1, t2, …, tn are converted into functions: x[tj], where t=1, 2, ... n.

[1] Repeating the analysis with $t<44$, the overall shapes of the curves are maintained.
[2] That does not mean it represents well the entire population of open source software projects.
[3] The number of downloads is a frequently used measure of success for open source software projects (Beaver et al. 2009, Crowston et al. 2004a, 2004b, 2006, Fellet et al. 2004, Subramaniam et al. 2009).

FDA analyses are appropriate when each individual is measured repeatedly through time or through a specific signal factor, for example, frequencies, rotating speeds, and compression loads. There are numerous examples of functional data ranging from height and weight measurements taken at different ages for the same subject, to sound patterns, to weather conditions, to tumor size and brain activity measurements, all of which can be plotted as curves as they are recorded over time. The method is particularly useful in situations where the variables under investigation exhibit complex patterns varying over time [Ramsay & Silverman 2005].

Because FDA determines the functional structure of each individual subject, the method is able to deal with highly heterogeneous data [Reddy & Dass 2006]. FDA has been applied successfully in multiple fields, such as biology, psychology, and the social sciences. For example, Jank and Shmueli [2006] explored and analyzed data originating from electronic commerce, pointing out several statistical challenges accompanied by some solutions using FDA. Stewart et al. [2006] explored the application of FDA as a means to study the dynamics of software evolution in the open source context, finding it a useful tool for uncovering and categorizing patterns of evolution in OSS projects. Dass [2011] applied FDA to investigate the willingness to spend dynamics in simultaneous online auctions.

For scholars dealing with dynamic and complex longitudinal organizational data, FDA facilitates the visualization and identification of complex patterns, such as life cycle stages of firms, with a few simple measures [Dass & Shropshire 2012]. Functional techniques allow for measures of varying intervals and rates of change in a nonlinear fashion; therefore they can help us better understand how intra- and inter-organizational characteristics coevolve [Dass & Shropshire 2012].

Because we are interested in the significant shapes of the curves, we followed the steps for functional principal components analysis [fPCA] described by Dass and Shropshire [2012], which are summarized below:

1. Recover underlying function
    a. Data collection;
    b. Generate a continuous smooth curve from discrete observations using the Smoothing Spline approach;
2. Identify the significant shapes [Functional PCA]
    a. Decompose curves into functional principal scores; and
    b. Investigate subjects based on the scores.

After data was organized and ready for analysis, the first major step in any functional data analysis consists of recovering, from the observed data, the underlying functional object. An important difference between FDA and other techniques such as trend analysis and time series, is that FDA does not require that the time periods analyzed for all cases are the same. By treating each case as a function (process), different time lapses can be analyzed in conjunction. It is fair to say that such approach treats time as relative (i.e., from beginning=0 to end=1), not absolute. This is quite convenient to help detect the underlying overall pattern, but imposes limits on inferences about the duration of each stage (n.b., that is out of the scope of this paper).

To discover the underlying functions of the observed data, in line with previous research [Dass & Shropshire 2012, Reddy & Dass 2006], we apply a smoothing polynomial spline that is flexible and adequate for most types of organizational data and does not impose constraints on the underlying function [Ramsay & Silverman 2005]. To improve the recovery of the underlying trend and avoid overfitting, we imposed a roughness penalty function [Reddy & Dass 2006] that is high when the data points are highly non-linear and the polynomial function fits the data well and that is low when the data points are linear. Finally, the b-spline module developed by Ramsay [2003] was applied in order to find a function that minimizes the penalized residual sum of squares (PENSS). Following Ramsay and Silverman [2005], we chose the lambda smoothing parameter (i.e., $\lambda = 0.0001$) that minimized the average generalized cross-validation (GCV) criterion.

In order to explore the first two hypotheses, the functional objects are recovered and the curves displayed along with their respective confidence intervals. The procedures are based on the ideas developed in Ramsay and Silverman [2005] and were implemented using the open source statistics software R version 2.11.1 [R Development Core Team 2010] and the fda package version 2.2.6 [Ramsay et al. 2010].

4. Results

The recovered curves and their respective confidence intervals are presented in Figure 1. As hypothesized, the effectiveness curve satisfies the pattern of an inverted-U. The activity curve also resembles the predicted inverted-S shape.

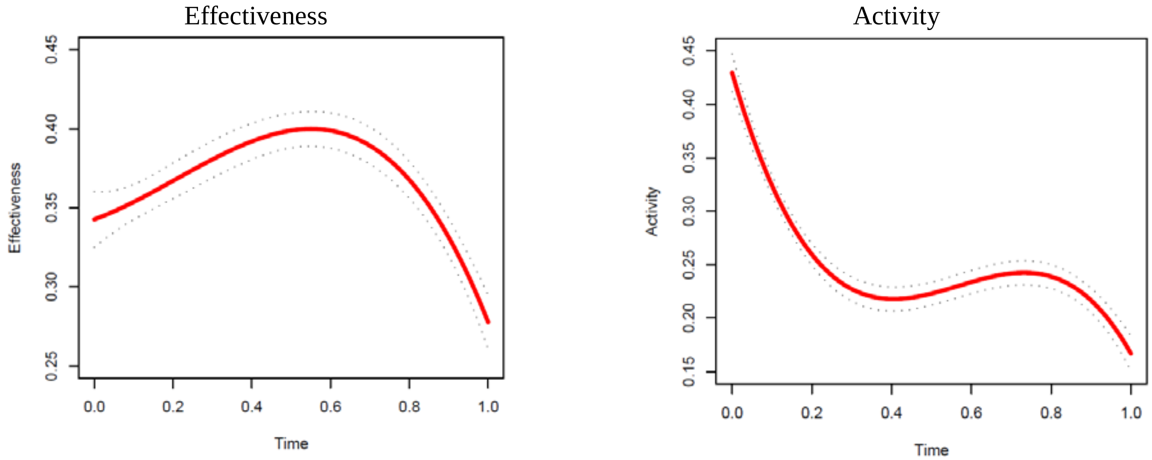

Figure 1. Recovered Curves with Point-wise Confidence Intervals

Both results lend support to hypotheses H1 and H2, although H1 might be more strongly supported than H2. For hypothesis H1, a simple visual inspection of Figure 2 shows that the entire range of the effectiveness curve (i.e., left chart), within the confidence interval, conforms to the shape of an inverted-U. Also, mathematically, the second derivate of the function is negative, implying concavity for all values of X. For H2, the evidence is less strong. It was expected that the first section of the activity curve would have been more accentuated. The curve misses especially the beginning of the inverted-S, probably due to the number of periods (and actions) not included in our sample as they would have happened before the first download (i.e., an artifact of the data collection procedure adopted in the study). Although the recovered pattern does not fully conform to the expected inverted-S, and therefore the results are not conclusive, the hypothesized inverted-S pattern cannot be ruled out.

After recovering the curves, we performed functional principal component analysis (fPCA), in order to identify the main components that account for the variation in the data. The scree plots (Figure 2) for both functional objects (i.e., effectiveness and activity models) indicate that four principal components explain the variation. After applying varimax rotation to the principal components, we analyze the fPCA results for the effectiveness and activity FDA models.

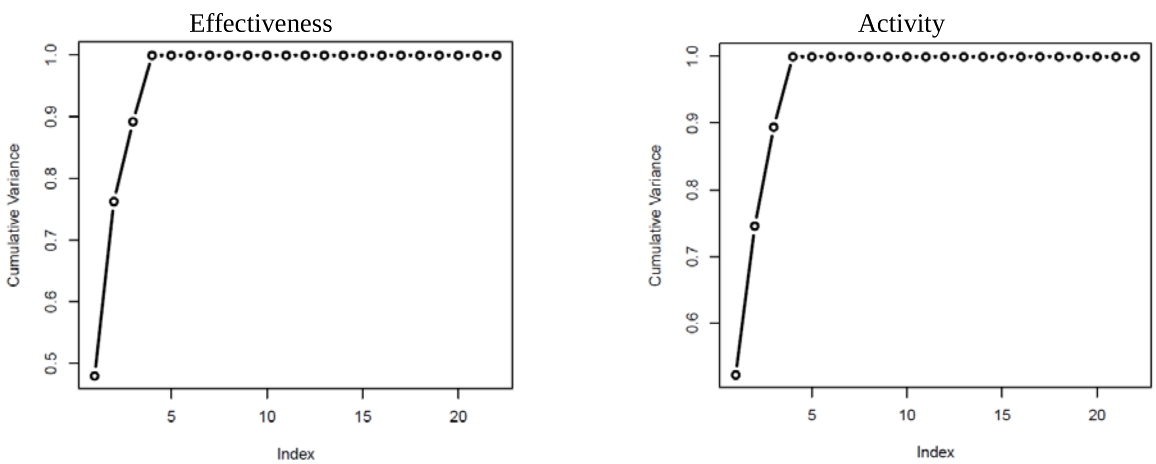

Figure 2. Scree Plots

The fPCA results of the effectiveness functional model show that four principal components explain 100% of the variation (Figure 3). Each rotated principal component accounts for departure from the mean for some period of time (horizontal axis). This gives support to the existence of four distinct states of organizational development.

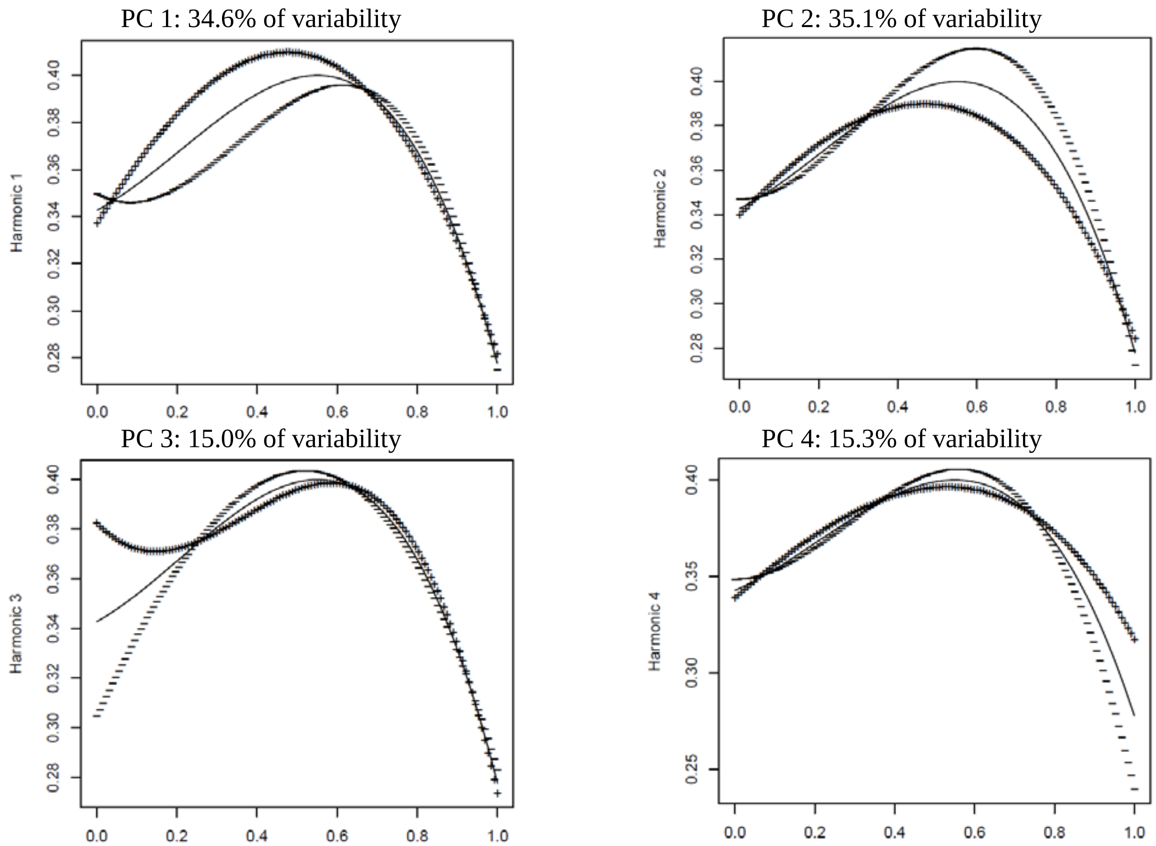

Figure 3. fPCA - Effectiveness

The fPCA results of the activity functional model also show that four principal components explain 100% of the variation (Figure 4). Similarly to the fPCA results of the effectiveness functional model, each rotated principal component accounts for departure from the mean for some period of time (horizontal axis). The findings also lend support to the existence of four periods of significantly different activity levels. We must also highlight that the percentages explained by each principal component across the two models are almost the same, therefore reinforcing the notion of four states.

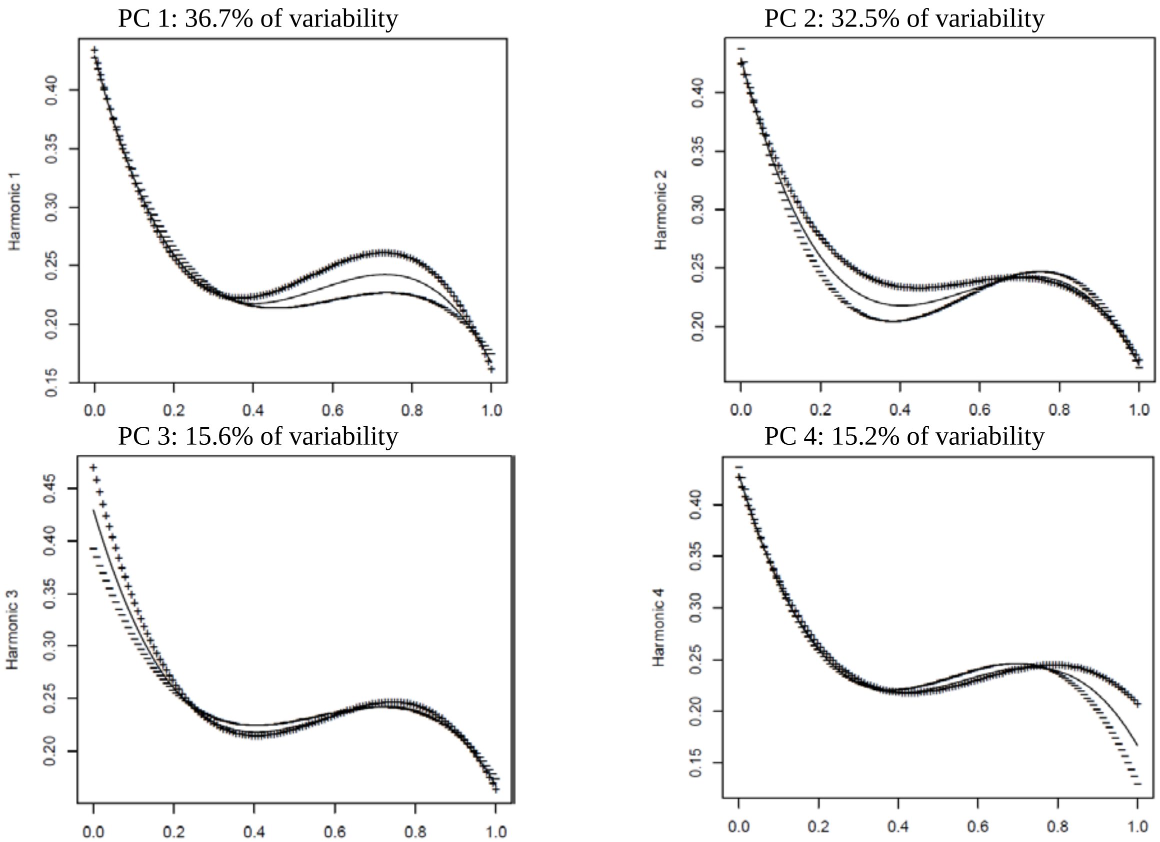

Figure 4. fPCA - Activity

5. Discussion

5.1. Summary of Findings

The primary findings of this study lend support to the concept of the life cycle in the context of open source software development communities. Through the analysis of effectiveness and activity in tandem, this study escapes the inevitability trap that often undermines life cycle theories. Instead of showing firms blindly following along a pre-determined life cycle curve, this study assesses development over time in terms of effectiveness and activity levels.

Hypotheses H1 and H2 address the expected shapes of the effectiveness and activity curves over time (i.e., respectively, an inverted-U and an inverted-S). Both are supported, although H1 more strongly than H2. Support of H2 would, likely, have been stronger if the data collection approach had been able to take into account some unobserved activity prior to the release of the first product. In other words, the limited support is an artifact of the design of the study and the available data. As one can imagine, there is some considerable amount of activity involved in putting together the initial release of software. If this study had been able to capture this early activity, the shape of the curve would probably resemble more closely an inverted-S, that is: closer to the lower limit of the confidence interval.

Having uncovered the patterns of the two curves, an empirical typology of ‘dynamic states’ of development is derived. Most classification scholars refer to conceptually derived schemes as typologies and empirically derived schemes as taxonomies [McKelvey 1982, Sneath & Sokal 1973]. Following Hambrick [1983], the term “typology” is used here to mean any classification scheme.

Typologies have multiple advantages, such as allowing the construction of gestalts [Miller & Friesen 1977], with each type representing a comprehensive testable set of attributes that can serve as a useful basis for further research [Hambrick 1983]. An interesting and important implication is that this view of the life cycle stage as a particular type of configuration does not imply irreversibility or pre-determined path, two of the main criticisms of the classic organismic view of the life cycle.

Back to the theoretical drawing board, if we superimpose the effectiveness and activity curves and assuming, arguendo, that there are two levels (high and low) of effectiveness and activity, we obtain four states of organizational development depicted in Table 2. State here is a conceptual construct that can represent both the state of the organizational development and a given region of the life course. And this region can be inferred by looking at the interplay between effectiveness and activity.

Table 2. Simplified Life Cycle Model of Online Communities

Effectiveness / Activity	Low / Down	High / Up
Low / Down	4 – Decline	3 –Maturity
High / Up	1 – Emergence	2 –Growth

Table 2 allows for states to be derived from absolute (i.e., Low or High) or relative levels (i.e., Up or Down). Absolute levels might not be easy to determine, requiring specific knowledge about the market or industry. Relative levels, however, can be easily obtained, by looking at change in levels from one period to the next. These states tend to be more volatile if the size of the period being analyzed is too small (n.b., size of period should take in consideration the dynamics of the market or industry; for OSSDCs, our preliminary analysis shows that change over a period of three months reduces state volatility significantly while yielding meaningful results). Although the 2x2 matrix might be appealing and simple, it fails to capture the dynamics and nuance of the two overlaid curves. Also, a 2x2 matrix can only depict four states, while looking at the interplay between effectiveness and activity curves allows for virtually any number of states. Although the data analyzed provided some evidence of the existence of four distinct states, we argue that knowing the actual number of states is not as important as being able to detect different patterns and account for them both theoretically and from a practical point of view. For organizations, as well as for organisms, it is more useful and meaningful to picture the life cycle as a continuum from birth to death[4], or emergence to decline. Such continuum is not a function of time, but of behavior. Clearly, age does not define behavior. On the contrary, behavior seems to define our perceptions about age or, more precisely, life expectancy.

Resuming our four-state analytical exercise, an OSSDC in its early life would experience high levels of activity and low levels of effectiveness. As it develops, effectiveness grows sharply, while activity slowly declines. If the project, as it matures, is unable to sustain the interest of its membership base, activity levels decline more sharply, while effectiveness slowly starts to decline. If unable to reverse this situation by attracting new members or renewing the interest of their existing membership, activity levels decline even further and effectiveness levels rapidly follow – the project reaches the end of its cycle.

Notice, that in contrast to the organismic life cycle view, this kind of analysis does not imply irreversibility. In fact, this view is intrinsically dynamic, allowing movement from one stance to the other, back and forth, as they are able to become relevant once again and attract the interest of contributors and users. This dynamism does not imply chaos. For example, because it is process-based, provided data is gathered in adequate resolution, it is expected that the position on the curve would move from one position to an adjacent one (i.e., forward or backwards).

6. Conclusion

This article adds to our vista of studying organizational theory by illuminating life cycle theory and exploring online communities with quantitative longitudinal data. In particular, this study contributes to our understanding of organizational development by uncovering patterns of organizational development in the context of OSSDC and by highlighting the importance of fostering active communities for superior effectiveness and long-term survival of the community. Research of this nature allows more rigorous examinations of the organizational change process, and therefore constitutes relevant contributions to organizational science [Chan 1998, Dass & Shropshire 2012]. For practitioners, the proposed empirically grounded taxonomy of dynamic states of organizational development can be a useful tool for assessing organizational development.

The findings of this study aid practitioners seeking to deploy open source software projects within their organizations, enhancing their ability to select projects that will remain relevant over time and improving their returns on investment. A simple direct implication of the findings would be to, ceteris paribus, prefer projects with more intense recent activities. For online communities in general, and OSSDCs in particular, this study highlights the importance of stimulating new contributions as a means of improving community effectiveness. Furthermore, taking into account the fact that online communities are quickly becoming commonplace, and corporations

[4] For organizations, "death" is not certain but possible. This fact does not invalidate the metaphor of the life cycle as a continuum of "possibilities".

increasingly enable virtual self-managing teams and embracing openness as a new strategy to improve innovation and competitiveness [Chesbrough 2003], the findings of this study might appeal to a wider audience.

Similarly, the findings of this study are relevant to policy makers, as governments around the world begin to expressly tilt the playing field toward open source software, subsidizing its production and use [Hahn 2002]. The findings of this study give policy makers an insight into the development patterns over time and the relationship between effectiveness and activity levels at different stages of the life cycle.

Finally, the study adds knowledge to the literature of organizational theory by testing empirically the life cycle metaphor in the context of OSSDC and offering a complementary perspective based on both activity and effectiveness levels. To some extent, this study is also a step towards addressing the call for the investigation of open systems properties [Ashmos & Huber 1987]. By exploring the relationship between activity and effectiveness levels, this study gives support to the notion of systems as energy-transforming cycles, filling an important gap in organization theory. Although identifying the number of states was not one of the goals of this study, the results of the functional principal component analyses of the effectiveness and activity curves offer some support to the existence of four distinct states of online community development. At the same time, this study sheds light into a long-standing debate involving irreversibility in LCT by providing empirical support to the existence of 'dynamic states' and adds to a young but fast growing stream of literature on OSSDC.

REFERENCES

Abernathy, W. J. and J. M. Utterback, "Patterns of Innovation in Industry," Technology Review, Vol. 80, No. 7: 40-47, 1978.

Abetti, P. A., "Accelerated growth: helping companies get and stay on the fast track," International Journal of Manufacturing Technology and Management, Vol. 3, No. 1-2: 15-30, 2001.

Aldenderfer, M. S. and R. K. Blashfield, Cluster analysis, CA, Newbury Park: Sage, 1984.

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

Ashmos, D. P. and G. P. Huber, "The Systems Paradigm in Organization Theory: Correcting the Record and Suggesting the Future," The Academy of Management Review, Vol. 12, No. 4: 607-621, 1987.

Bailey, D. and K. E. Grochau, "Aligning Leadership Needs to the Organizational Stage of Development: Applying Management Theory to Nonprofit Organizations," Administration in Social Work, Vol. 17, No. 1: 23-45, 1993.

Beaver, J. M., X. Cui, J. L. St Charles, T. E. Potok, "Modeling success in FLOSS project groups," Proceedings of the 5th International Conference on Predictor Models in Software Engineering. NY, New York: ACM, 2009.

Bessant, J. Challenges in Innovation Management. In L. V. Shavinina (Ed.), International handbook on innovation: 761-774. UK, Oxford: Elsevier Science Ltd., 2003.

Cameron, K. S., "Evaluating Organizational Effectiveness in Organized Anarchies", Paper presented at the Academy of Management, 1979.

Cameron, K. S. and D. A. Whetten, "Models of the Organizational Life Cycle: Applications to Higher Education", Review of Higher Education, Vol. 67: 269-299, 1983.

Cameron, K. S., "Assessing Institutional Ineffectiveness: A Strategy for Improvement," New Directions for Institutional Research, Vol. 11, No. 1: 67-83, 1984.

Cameron, K. S., "Effectiveness as Paradox: Consensus and Conflict in Conceptions of Organizational Effectiveness", Management Science, Vol. 32, No. 5: 539-553, 1986.

Chan, D., "The conceptualization and analysis of change over time: An integrative approach incorporating longitudinal means and covariance structures analysis (LMACS) and multiple indicator latent growth modeling (MLGM)," Organizational Research Methods, Vol. 1, No. 4: 421-483, 1998.

Chesbrough, H. W., Open Innovation: The New Imperative for Creating and Profiting from Technology, MA, Cambridge: Harvard Business School Press, 2003.

Churchill, N. C. and V. L. Lewis, "The five stages of small business growth," Harvard Business Review, Vol. 61, No. 3: 30, 1983.

Crowston, K., H. Annabi, J. Howison and C. Masango, "Towards A Portfolio of FLOSS Project Success Measures," Proceedings of the 4th Workshop on Open Source Software Engineering, Scotland, Edinburgh: 2004a.

Crowston, K., H. Annabi, J. Howison and C. Masango, "Effective work practices for software engineering: free/libre open source software development," WISER '04 Proceedings of the 2004 ACM workshop on Interdisciplinary software engineering research, NY, New York, 2004b.

Crowston, K., J. Howison, and H. Annabi, "Information systems success in free and open source software development: theory and measures. Software Process: Improvement and Practice", Special Issue on Free or Open Source Software Development (F/OSSD) Projects, Vol. 11, No. 2: 123–148, 2006.

Cunningham, J. B., "Approaches to the Evaluation of Organizational Effectiveness," Academy of Management

Review, Vol. 2, No. 3: 463-474, 1977.
Cyert, R. M. and J. G. March, A behavioral theory of the firm. NJ, Englewood Cliffs: Prentice-Hall, 1963.
D'Aveni, R., Hypercompetition: Managing he Dynamics of Strategic Maneuvering. NY, New York: Free Press, 1994.
Dahlander, L. and M. G. Magnusson, “Relationships between open source software companies and communities: Observations from Nordic firms”, Research Policy, Vol. 34: 481-493, 2005.
Dass, M., “An Investigation of Willingness to Spend Dynamics in Simultaneous Online Auctions,” Journal of Electronic Commerce Research, Vol. 12, No. 1:44-60, 2011.
Dass, M. and C. Shropshire, “Introducing Functional Data Analysis to Managerial Science,” Organizational Research Methods, Vol. 15, No. 4: 693-72, 2012.
DiMaggio, P. J. and W. W. Powell, “The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields,” American Sociological Review, Vol. 48, No. 2: 147-160, 1983.
Dodge, H. R. and J. E. Robbins, “An Empirical Investigation of the Organizational Life Cycle,” Journal of Small Business Management, Vol. 30, No. 1: 27, 1992.
Dodge, H. R., S. Fullerton, and J. E. Robbins, “Stage of the Organizational Life Cycle and Competition as Mediators of Problem Perception for Small Businesses,” Strategic Management Journal, Vol. 15, No. 2: 121-134, 1994.
Donabedian, A., Explorations in Quality Assessment and Monitoring: The Definition of Quality and Approaches to Its Assessment. MI, Ann Arbor: Health Administration Press, 1980.
Eggers, J. H., K. T. Leahy, and N. C. Churchill, “Stages of Small Business Growth Revisited,” Frontiers of Entrepreneurship Research: 131-144, 1994.
Etzioni, A., “Two Approaches to Organizational Analysis: A Critique and a Suggestion,” Administrative Science Quarterly, Vol. 5: 257-278, 1960.
Faraj, S., and S. L. Johnson, “Network Exchange Patterns in Online Communities,” Organization Science, Vol. 22, No. 6: 1464-1480, 2010.
Feller, J., B. Fitzgerald, S. Hissam, and K. Lakhani, “Collaboration, Conflict and Control,” Proceedings of the 4th Workshop on Open Source Software Engineering, Scotland, Edinburgh, 2004.
Gaertner, G. H. and S. Ramnarayan, “Organizational Effectiveness: An Alternative Perspective,” Academy of Management Review, Vol. 8, No. 1: 97-107, 1983.
Georgopoulos, B. S. and A. S. Tannenbaum, “A Study of Organizational Effectiveness,” American Sociological Review, Vol. 22, No. 5: 534-540, 1957.
Greiner, L. E., “Evolution and Revolution as Organizations Grow,” Harvard Business Review, Vol. 50, No. 4: 37-46, 1972.
Greiner, L. E., “Evolution and Revolution as Organizations Grow,” Harvard Business Review, Vol. 76, No. 3: 55-68, 1998.
Gupta, Y. P. and D. C. W. Chin, “Strategy making and environment: An organizational life cycle perspective,” Technovation, Vol. 13, No. 1: 27, 1993.
Hahn, R. W., Government Policy toward Open Source Software: Brookings Institution Press, 2002.
Hair, J. F. and W. C. Black, Cluster Analysis. In L. G. Grimm and P. R. Yarnold (Eds.), Reading and understanding more multivariate statistics. Washington, DC: American Psychological Association, 2002.
Hanks, S. H., C. J. Watson, E. Jansen, E., and G. N. Chandler, “Tightening the Life-Cycle Construct: A Taxonomic Study of Growth Stage Configurations in High-Technology Organizations,” Entrepreneurship: Theory and Practice, Vol. 18, No. 2: 5-30, 1993.
Hanks, S. H. and G. Chandler, “Patterns of Functional Specialization in Emerging High Tech Firms,” Journal of Small Business Management, Vol. 32, No. 2: 23-36, 1994.
Hannan, M. T. and J. Freeman, “Structural Inertia and Organizational Change,” American Sociological Review, Vol. 49, No. 2: 149-164, 1984.
Hirsch, P. M., “Organizational Effectiveness and the Institutional Environment,” Administrative Science Quarterly, Vol. 20, No. 3: 327-344, 1975.
Howison, J. and K. Crowston, “The perils and pitfalls of mining sourceforge,” Paper presented at the Workshop on Mining Software Repositories at the International Conference on Software Engineering - ICSE, 2004.
Iriberri, A.; and G. Leroy, “A life-cycle perspective on online community success,” ACM Computing Surveys, Vol. 41, No. 2, 2009.
Jank, W. and G. Shmueli, “Opportunities and Challenges Applying Functional Data Analysis to the Study of Open Source Software Evolution,” Statistical Science, Vol. 21, No. 2: 155-166, 2006.
Katz, D. and R. L. Kahn, The social psychology of organizations. NY, New York: Wiley, 1966.
Kazanjian, R. K., “Relation of Dominant Problems to Stages of Growth in Technology-Based New Ventures,” Academy of Management Journal, Vol. 31, No. 2: 257-279, 1988.

Kazanjian, R. K. and R. Drazin, “An Empirical Test of a Stage of Growth Progression Model,” Management Science, Vol. 35, No. 12: 1489-1503, 1989.

Kazanjian, R. K. and R. Drazin, “A Stage-Contingent Model of Design and Growth for Technology Based New Ventures,” Journal of Business Venturing, Vol. 5, No. 3: 137, 1990.

Kimberly, J. R., “Issues in the Creation of Organizations: Initiation, Innovation, and Institutionalization,” Academy of Management Journal, Vol. 22, No. 3: 437-457, 1979.

Lawrence, P. R. and J. W. Lorsch, “Differentiation and Integration in Complex Organizations,” Administrative Science Quarterly, Vol. 12, No. 1: 1-47, 1967.

Lerner, J. and J. Tirole, “Some simple economics of open source,” Journal of Industrial Economics, Vol. 52: 197-234, 2002.

Levie, J. and M. Hay, “Progress or just proliferation? A historical review of stages models of early corporate growth”, London Business School working paper, UK, London: 1998.

Levie, J. and B. Lichtenstein, “From Stages of Business Growth to a Dynamic States Model of Entrepreneurial Growth and Change,” Hunter Centre for Entrepreneurship working paper, University of Strathclyde. UK, Glasgow: 2008.

Lewin, K., Group decisions and social change. In E. E. Maccoby, T. M. Newcomb and E. L. Hartley (Eds.), Readings in social psychology, 3rd ed.: 197-221. NY, New York: Holt, Rinehart and Winston, 1958.

Lippit, G. L. and W. H. Schmidt, “Crises in a developing organization,” Harvard Business Review, Harvard Business School, No. 45: 102-112, 1967.

Mahoney, T. A. and W. Weitzel, “Managerial Models of Organizational Effectiveness,” Administrative Science Quarterly, Vol. 14, No. 3: 357-365, 1969.

March, J., “How Decisions Happen in Organizations,” Human-Computer Interaction, Vol. 6, No. 2: 95-117, 1991.

Marriott, F. H. C., “Practical Problems in a Method of Cluster Analysis,” Biometrics, Vol. 27, No. 3: 501-514, 1971.

Miller, D. and P. H. Friesen, “Successful and Unsuccessful Phases of the Corporate Life Cycle,” Organization Studies, Vol. 4, No. 4: 339-356, 1983.

Miller, D. and P. H. Friesen, “A Longitudinal Study of the Corporate Life Cycle,” Management Science, Vol. 30, No. 10: 1161-1183, 1984.

O’Mahony, S. C., The emergence of a new commercial actor: community managed software projects. Unpublished PhD. Dissertation, CA, Stanford: Stanford U., 2002.

O’Rand, A. M. and M. L. Krecker, “Concepts of the Life Cycle: Their History, Meanings, and Uses in the Social Sciences,” Annual Review of Sociology, Vol. 16: 241-262, 1990.

Penrose, E., The Theory of the Growth of the Firm. UK, Oxford: Oxford University Press, 1959.

Perrow, C., “Goals in Complex Organizations,” American Sociological Review, Vol. 26: 859-866, 1961.

Pfeffer, J. and G. R. Salancik, The external control of organizations: a resource dependence perspective. NY, New York: Harper and Row, 1978.

Price, J. L., “The Study of Organizational Effectiveness,” Sociological Quarterly, Vol. 13: 3-15, 1972.

Reddy, S. K., and M. Dass, “Modeling on-line art auction dynamics using functional data analysis,” Statistical Science, Vol. 21, No. 2: 179-193, 2006.

Quinn, R. E. and K. Cameron, “Organizational Life Cycles and Shifting Criteria of Effectiveness: Some Preliminary Evidence,” Management Science, Vol. 29, No. 1: 33-51, 1983.

Quinn, R. E. and J. Rohrbaugh, “A Spatial Model of Effectiveness Criteria: Towards a Competing Values Approach to Organizational Analysis,” Management Science, Vol. 29, No. 3: 363-377, 1983.

R Development Core Team, R: A Language and Environment for Statistical Computing. Austria, Vienna: R Foundation for Statistical Computing. ISBN 3-900051-07-0, 2010.

Raban, D. R., M. Moldovan, Q. Jones, “An empirical study of critical mass and online community survival,” Proceedings of the 2010 ACM conference on Computer supported cooperative work. 71-80, 2010.

Ramsay, J. O. and B. W. Silverman, Applied Functional Data Analysis: Methods and Case Studies, (1st ed.). NY, New York: Springer, 2002.

Ramsay, J. O. and B. W. Silverman, Functional Data Analysis, (2nd ed.). New York, NY: Springer, 2005.

Ramsay, J. O.; H. Wickham, S. Graves, and G. Hooker, fda: Functional Data Analysis. R Software Package. Available at http://cran.r-project.org/web/packages/fda/index.html, 2010.

Ransbotham, S.; G. C. Kane, “Membership Turnover and Collaboration Success in Online Communities: Explaining Rises,” MIS Quarterly. Vol. 35, No. 3: 613-627, 2011.

Rettie, R., “Net Generation Culture,” Journal of Electronic Commerce Research, Vol. 3, No. 4: 254-264, 2002.

Rosenkopf, L. and M. L. Tushman, M. L., “The Coevolution of Community Networks and Technology: Lessons from the Flight Simulation Industry,” Industrial and Corporate Change, Vol. 7, No. 2: 311-346, 1998.

Rutherford, M. W., P. F. Buller, and P. R. McMullen, “Human Resource Management Problems Over the Life Cycle of Small to Medium-sized Firms,” Human Resource Management, Vol. 42, No. 4: 321-335, 2003.

Schumpeter, J. A., Capitalism, Socialism and Democracy. NY, New York: Harper and Brothers, 1942.

Scott, M. and R. Bruce, “Five Stages of Growth in Small Business,” Long Range Planning, Vol. 20, No. 3: 45-52, 1987.

Seashore, S. E., “Assessing Organizational Effectiveness with Reference to Member Needs,” Paper presented at the Academy of Management, 1979.

Singh, J. V., D. J. Tucker, and R. J. House, “Organizational Legitimacy and the Liability of Newness,” Administrative Science Quarterly, Vol. 31, No. 2: 171-193, 1986.

Smith, K. G., T. R. Mitchell, and C. E. Summer, “Top Level Management Priorities in Different Stages of the Organizational Life Cycle,” Academy of Management Journal, Vol. 28, No. 4: 799-820, 1985.

Sonnenbichler, A. C., and C. Bazant, “Application of a Community Membership Life Cycle Model on Tag-Based Communities in Twitter,” Challenges at the Interface of Data Analysis, Computer Science, and Optimization, 301-309, 2012.

Stewart, K. J., D. P. Darcy, and S. L. Daniel, “Opportunities and Challenges Applying Functional Data Analysis to the Study of Open Source Software Evolution,” Statistical Science, Vol. 21, No. 2: 167–178, 2006.

Stubbart, C. I. and R. D. Smalley, “The Deceptive Allure of Stage Models of Strategic Processes,” Journal of Management Inquiry, Vol. 8, No. 3: 273, 1999.

Subramaniam, C.; R. Sen, M. L. Nelson, “Determinants of open source software project success: A longitudinal study,” Decision Support Systems, Vol. 46, No. 2: 576–585, 2009.

Thompson, J. D. and W. J. McEwen, “Organizational Goals and Environment,” America Sociological Review, Vol. 23: 21-33, 1958.

Thompson, J. D., Organizations in action; social science bases of administrative theory. NY, New York: McGraw-Hill, 1967.

Tushman, M. L., W. H. Newman, and E. Romanelli, “Convergence and Upheaval: Managing the Unsteady Pace of Organizational Evolution,” California Management Review, Vol. 29, No. 1: 29, 1986.

Van de Ven, A. H. and M. S. Poole, “Explaining Development and Change in Organizations,” Academy of Management Review, Vol. 20, No. 3: 510-540, 1995.

Vernon, R., “International Investment and International Trade in the Product Cycle,” The Quarterly Journal of Economics, Vol. 2: 190-207, 1966.

Vohora, A., M. Wright, and A. Lockett, “Critical junctures in the development of university high-tech spinout companies,” Research Policy, Vol. 33, No. 1: 147, 2004.

von Hippel, E., Open source projects as horizontal innovation networks - by and for users. Cambridge, MA: MIT Sloan Working Paper, 2002.

von Krogh, G., S. Spaeth, and K. Lakhani, “Community, joining, and specialization in open source software innovation: a case study,” Research Policy, Vol. 32, No. 7, 2003.

Wenger, E., R. McDermott, and W. M. Snyder, Cultivating Communities of Practice: A Guide to Managing Knowledge. MA, Boston: Harvard Business School Press, 2002.

West, J. and S. C. O’Mahony, “Contrasting Community Building in Sponsored and Community Founded Open Source Projects,” Paper presented at the Hawaii International Conference on System Sciences, HI, Waikoloa, 2005.

Yap, A. Y., “Enabling E-commerce Growth Through the Social Construction of a Virtual Community's Culture,” Journal of Electronic Commerce Research, Vol. 3, No. 4: 279-294, 2002.

Yuchtman, E. and S. E. Seashore, “A Systems Resource Approach to Organizational Effectiveness,” American Sociological Review, Vol. 32: 891-903, 1967.

Zammuto, R. F., “A Comparison of Multiple Constituency Models of Organizational Effectiveness,” Academy of Management Review, Vol. 9, No. 4: 606-616, 1984.