# Toward a Theory of the Evolution of Business Ecosystems:
## Enterprise Architectures, Competitive Dynamics, Firm Performance and Industrial Co-Evolution

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**ABSTRACT**

This research lies at the intersection of the intellectual domains of strategic management, organizational science and complex systems theory. It aims to contribute to fundamental debates in these fields regarding the source of long-term firm performance – namely does it reside within the firm or in the firm's environment, and what are the roles of managerial adaptation and environmental selection in its creation? Crucially, how does this shape our understanding of strategic leadership? At its most fundamental level therefore, this research addresses a question that has been posed by evolutionary theorists in the economics and sociology literatures for decades: "Why do firms in the same industry vary *systematically* in performance *over time*?" Seeking a *systematic* explanation of a *longitudinal* phenomenon inevitably requires characterizing the evolution of the ecosystem, as both the organization and its environment are co-evolving. This question is therefore explored through the lens of Engineering Systems: 1) within the *domain* of Extended Enterprises, where architectural competition is examined in three classic engineering systems: aerospace, automotive and airlines; and 2) using the *approaches* of Design and Dynamics, by analyzing enterprise architectures and their change management processes and by modeling the competitive dynamics of these complex ecosystems.

The research builds grounded theory on empirical findings which suggest that sources of firm performance appear to lie neither exclusively within the firm, nor in its environment, but in *how* the firm interacts with its environment – i.e. in the network *architecture* of the firm's extended enterprise which enables and constrains managerial agency through spatially and temporally bounded rationality. A theoretical framework is proposed which endogenously traces the co-evolution of firms and their environments using their highest-level system properties of *form, function* and *fitness* (reflected in the system sciences of *morphology, physiology* and *ecology*). The framework captures the path-dependent evolution of heterogeneous populations of extended enterprises engaged in *symbiotic inter-species competition* and posits the evolution of "dominant designs" in enterprise architectures that oscillate deterministically and chaotically between *modular* and *integral* states throughout an industry's life-cycle. Architectural innovation – at the extended enterprise level – is demonstrated to contribute to the failure of established firms, with causal mechanisms developed to explain tipping points.

The research is based primarily on a seven-year, multi-level, multi-method, longitudinal empirical case study of two firms in a global *mixed* duopoly as well as the key stakeholders in their extended enterprises. The theory is further tested and generalized across a theoretical sample of firms in manufacturing and service sectors, with both historical comparative analysis and nonlinear dynamic simulation models developed to capture the evolution of business ecosystems. The resulting framework is grounded empirically, analytically as well as theoretically by synthesizing a broad range of literatures from economics to sociology, from physics to biology.

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## INTRODUCTION

### Research Question

At its most fundamental level, this paper addresses the following question that has been posed directly and indirectly by evolutionary theorists in both the economics (Nelson, 1991) and sociology (e.g. Hannan & Freeman, 1977; Carroll, 1993) literatures:

> "Why do firms in the same industry vary *systematically* in performance *over time*?"

Although it is typical that the unit of analysis is the firm and the dependent variable is long-term performance, addressing this question more subtly requires a *systematic* explanation of *longitudinal* phenomena, which inevitably requires characterizing the evolution of the business ecosystem, as both firm and industry are co-evolving.[1]

Early in our research, intriguing empirical data began to be revealed: as firms and industries co-evolved, the dominant form of the firm's objective function and its resulting interaction with its environment appeared to change. This manifested itself in the counter-intuitive observation that firms which were not focused on exclusively maximizing shareholder value, were in fact delivering significantly more of it than firms who focused exclusively on maximizing it. This result appeared in a variety of industries ranging from manufacturing to services. The exploration of why, when and how this phenomenon happens became a driving impetus of the research. Thus a second question emerged which appears to lie at the heart of the first question which was originally posed fifty years ago by Edith Penrose (1959):

> "How do firms that have a *stakeholder* approach differ in competitiveness from firms that maximize *stockholder* wealth?"

### Proposed Theoretical Framework

Most research implicitly assumes that competing firms are of the same species, and thus focus on second-order *efficiency*-based explanations. We propose an alternative first-order *effectiveness*-based explanation, namely that where significant sustained long-term variance in performance between firms exists (e.g. *Toyota Motors* vs. *General Motors*, or *Southwest Airlines* vs. *United Airlines*) it is more productive to classify such competition as *inter-species*. We therefore characterize a late-entrant "challenger" species of organization (driven to maximize *stakeholder surplus*) which has evolved to systematically out-compete over the long term, the traditional "incumbent" species (driven to maximize *shareholder value*).[2]

We will argue that firms adopting different objective functions, will have different enterprise architectural forms (Hannan and Freeman, 1977), and will present a typology of isomorphic (DiMaggio and Powell, 1983) organizational sets ranging from integral to modular enterprise architectures, and having different levels of fit with their environment (Lawrence and Lorsch, 1967). In addition, the greater the variance in architectural forms, the greater the potential variance in long-term firm performance, contingent upon the demands and opportunities provided by the competitive environment of the enterprise's ecosystem.

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[1] Wiggins & Ruefli (2002) empirically explore the sustainability of competitive advantage using a rare longitudinal sample comprising 6,772 firms in 40 industries over 25 years, demonstrating just how rare the phenomenon is.

[2] Note: in order to assist the reader to easily and rapidly identify the various "species" throughout this paper, we highlight in **blue**, the early-entrant incumbent species and in **red**, the late-entrant challenger species.

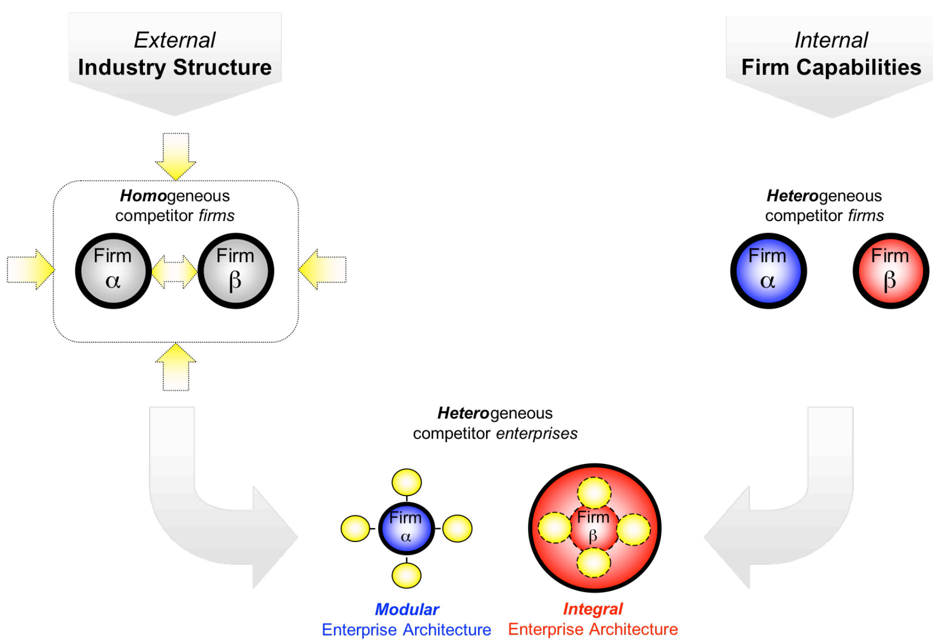
## LITERATURE REVIEW

### Situating within the Literatures

While significant research has been undertaken to understand how firms compete and (separately) how environments evolve, little theoretical work has been undertaken to understand how organizations and environments interact and co-evolve, and even less empirical work exists to begin to ground such theoretical studies. In the following, we briefly summarize three broad literatures, situating our potential contribution within them.

**Strategic Management.** Research on competition between firms is mature, and captures a rich debate which spans exogenous industry-level explanations for firm performance (Mason, 1939; Bain, 1956; Porter, 1980 and 1985), as well as endogenous firm-level explanations (Penrose, 1959, Wernerfelt, 1984) known as the resource-based view. Relatively little work has been done to begin to endogenize the environment in order to provide a higher-level of analysis – that of competition between organizational sets (i.e. extended enterprises), and the resulting evolution of organizational fields (i.e. ecosystems) as shown in Figure 1 below. Importantly, this analysis of "how" the firm engages the environment begins to re-ingtegrate strategy *process* and strategy *content* schools (Petttigrew, 1992).

Figure 1: Contributing to the Debate in Strategic Management

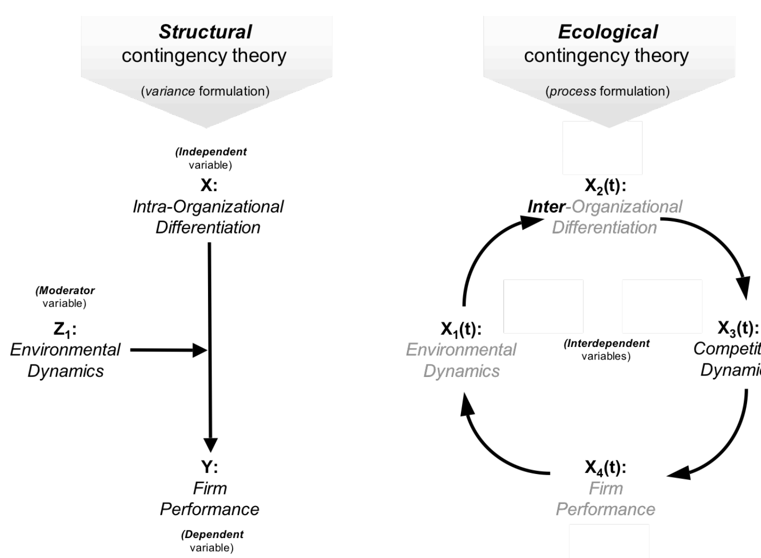



The industrial organization literature characterizes the firm's environment as a locus of competition or "extended rivalry" (Porter, 1980), with the objective function of the firm being profit-maximization, usually for maximizing the objective function of one specific stakeholder: the shareholders, resulting in a zero-sum competition within the organizational set. Conversely, relatively little work has been done to characterize other forms of organizational set, where the objective function is a more plural maximization of stakeholder surplus (Freeman, 1984) and the interaction between the two in *mixed duopoly* (e.g. Lambertini and Rossini, 1998). The *strategic complementarities* literatures in economics and political science (e.g. Milgrom and Roberts, 1990 and 1995; Hall and Soskice, 2001) have produced the basis from which to build empirically.

**Organization Science.** Within the broad field of open systems organization science, the past 30 years has seen the emergence and maturing of four major "schools" under the rubric of "organizations and environments" (Scott, 2003): organizational ecology (Hannan and Freeman, 1977 and 1984), neo-institutionalism (Meyer and Rowan, 1977; DiMaggio and Powell, 1983; Uzzi, 1997), resource dependence (Pfeffer and Salancik, 1978) and transaction cost economics (Williamson, 1975 and 1985). While these schools tend to address the limitations inherent in the strategic management literature – namely exogenous treatment of the environment – each has its limitations in endogenizing the environment. Organizational ecology and neo-institutionalism tend to focus on populations of isomorphic organizations; resource dependence tends to focus on static distributions of power within an organizational set; transaction cost economics tends to focus on efficiency as the primary driving mechanism defining firm boundaries. This paper attempts to address these limitations, namely: heterogeneous populations, competing dynamically, with effectiveness (not efficiency) being the governing performance mechanism (Brittain and Freeman, 1980; Brittain, 1994).

Finally, the theory that contributed significantly to the development of the aforementioned four schools over 40 years ago, *structural* contingency theory (Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Thompson, 1967) proposed a similar framework to the *ecological* contingency theory presented herein with two noteworthy differences. First, their *intra*-organizational characterization of the processes of differentiation and integration has similarities to architectural modularity and integrality presented herein, but now with *inter*-organizational focus. Second, their contingency theoretic framework was essentially expressed as *variance* theory, with the environmental variable expressed as a moderator variable, and no explicit mediator variable. This paper attempts to build from Lawrence and Lorsch's (1967) classic by 1) moving from firm to organizational set as the unit of analysis, and in doing so, 2) endogenize the environment in a process theory. The micro-mechanisms of managerial agency are captured across the macro-level of the organizational set and included as mediator variables covering strategic and operations choices. The differences between the variance-based *structural* contingency theory and the proposed process-based *ecological* contingency theory are summarized in Figure 2 below.

Figure 2: Comparing *Structural* Contingency Theory with *Ecological* Contingency Theory



**Complex Systems Theory.** While the two literatures mentioned above, each focus on organizational systems, the complex systems literature concentrates on the abstract principles governing general systems ranging from physical, to biological, to organizational. While general systems theory is a broad and mature literature (Von Bertalanffy, 1950 and 1962), we aim to focus this discussion on three primary threads of system science: system architecture, system dynamics, and ecosystem dynamics which theorize about complexity.

System architecture has its roots in managing *functional* complexity (Simon, 1962; Alexander 1964; Rechtin, 2000). It has impacted various socio-technical domains, including: product design (Ulrich, 1995) and more recently in *intra*-organization design (Anderson and Tushman, 1990; Henderson and Clark, 1990) and *inter*-organization design (Langlois, 1988; Sanchez and Mahoney, 1996; Fine, 1998; Schilling, 2000; Sako, 2003; Aoki and Jackson, 2008). While much of this work focuses on supply chain design, little of it focuses explicitly and more broadly on the architecture of entire organizational sets. This literature would therefore be an example of *progressive* intertextual coherence (Locke and Golden-Biddle, 1997).

System dynamics has its roots in defining and managing *dynamic* complexity in social systems (Forrester, 1961; Sterman, 2000), that is, where cause and effect are distant in space and time. Although it has been applied to various complex organizational settings (Forrester, 1958; Hall, 1976; Morecroft, 1985; Sastry, 1997; Repenning, 2002), it has only occasionally been used to explain how the competitive dynamics among firms interacts with the industry's evolution. Where such studies have been made (Paich and Sterman, 1993), inter-firm competition occurs between homogeneous enterprise architectures. System dynamics has yet to be combined with system architecture to develop a theory of how functional and dynamic complexity evolve in organizational settings. Again, this literature would be another example of *progressive* intertextual coherence.

Ecosystem dynamics has its roots in defining *competitive* complexity. While population growth models have a long history (Verhulst, 1938), and simple intra-species competition models have been proposed (Lotka, 1925; Volterra, 1931; Hannan and Freeman, 1977), only more recently have inter-species typologies been proposed in biology (MacArthur and Wilson, 1967) and subsequently in sociology (Brittain and Freeman, 1980). The science of ecosystem dynamics has yet to develop significant theoretical and empirical research on inter-species competition. Again, this literature would be another example of *progressive* intertextual coherence.

**Problematizing the Literatures**
Having situated this paper within the extant literatures, we would like to now note where this paper departs and where possible contributions may lie.

**Incomplete.** From the above discussion of a variety of literatures interested in explaining the dependent variable of organizational performance, it is clear that the literatures, while mature, are *incomplete*. A gap exists regarding how competition occurs at the organizational set level and how these co-evolve with the organizational fields within which they are embedded.

**Inadequate.** The extant literatures have not adequately addressed the question, by underemphasizing the role that complexity (functional, dynamic, behavioral, and competitive) plays in understanding the evolution of business ecosystems. System architecture and ecosystem dynamics serve as a set of organizing principles which characterize the evolution of a spectrum of system forms, functions and environmental fit.

**Incommensurate.** Finally, because these extant literatures have gaps that have not been filled, or have been filled with inadequate literatures, there are rare but noteworthy cases where the extant theories can result in misleading characterizations of competition and industry evolution. Examples of such counterintuitive insights, which go against the received conventional wisdom - discussed later in this paper - are briefly summarized.

In the strategic management literature's industry structure school (Porter, 1980), the treatment of members of one's organizational set as "extended rivals", may not under certain conditions result in maximization of profits to the focal firm. Likewise, the objective function that seeks to maximize shareholder value, may not under certain conditions achieve its aim. Conversely, the objective function that seeks to maximize stakeholder surplus, may under certain circumstances achieve more shareholder value than firms who are expressly trying to maximize this metric.

In the organizational ecology literature (Hannan and Freeman, 1977), which assumes homogenous *intra*-species competition, late entrants exhibit higher mortality rates than early entrants. However, when competition involves heterogeneous *inter*-species competition, late entrants not only survive, they can end up dominating the industry.[3]

**Contribution to the Literatures**

Although the fields of strategic management and organization science, with their half-century old roots in economics and sociology are considered by many to be mature, there is clearly an opportunity to integrate prior streams of research from distant disciplines to produce a new framework in order to resolve its original unsolved debates of *internal* vs. *external* sources of firm performance and *adaptation* vs. *selection* processes of organizational change. A contribution might be made in bringing for the first time, a typology or configuration from the intellectual domains of system architecting and system dynamics (i.e. complexity science) formally and systematically to the study of organizations in order to explain their evolution, structure, function and performance.

**Methodological Fit with the State of Literature**

From this discussion of the extant literatures, it is clear that the strategic management field exists in a general state of maturity, particularly with respect to the establishment of *variance* theories that explain sources of competitive advantage and firm performance. Strong methodological fit exists, therefore with more quantitative methods to test and validate these existing theories (Edmondson and McManus, 2007).

However, as little empirical and theoretical research exists to describe *how* business ecosystems evolve, the state of the field with respect to *process* theory can be considered nascent. In this research environment, strong methodological fit exists for a more qualitative approach to the research design.[4] In the following section, therefore we will describe the research methods that are designed to meet the challenges of this nascent literature.

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[3] Under the environmental conditions of industry maturity.

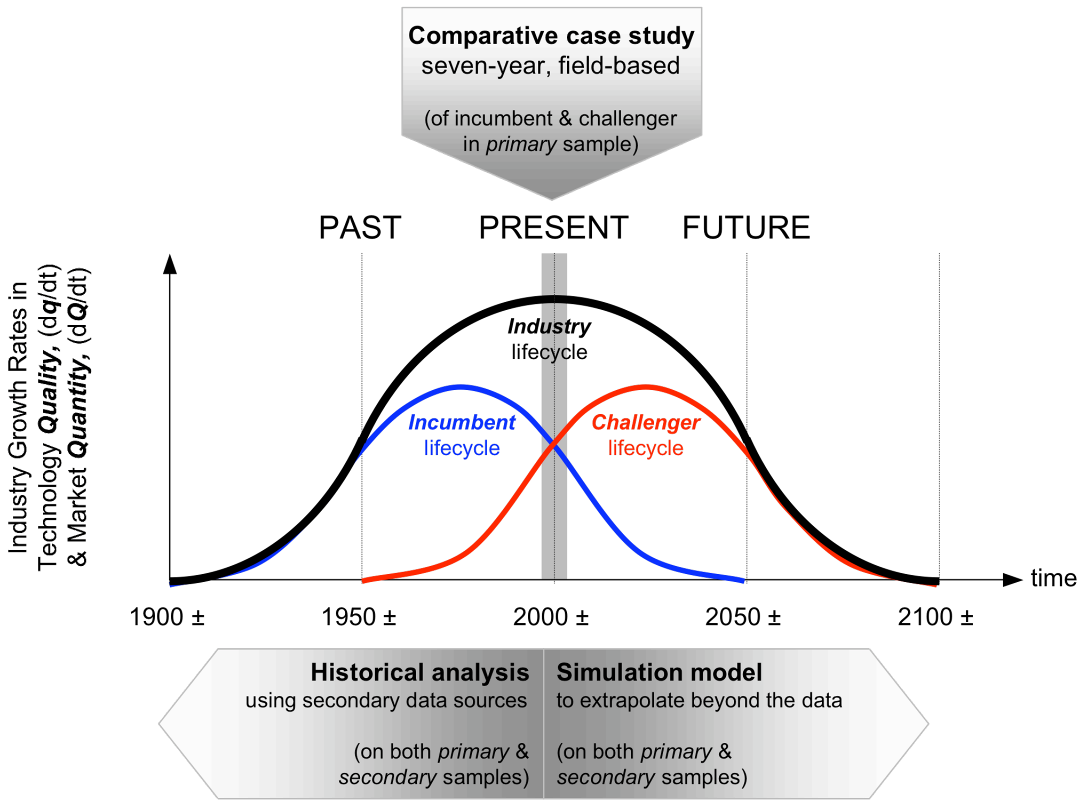
[4] Edmondson and McManus (2007) note that the use of qualitative methods in a mature field represents an "off-diagonal" methods strategy, which may generate new opportunities for insights provided that a study's focus is reframed from the broad to the narrow. In this case, we are focusing from variance to process theory.

## RESEARCH METHODS

### Research Design

In order to build grounded theory, data from the *past* and *present* were iteratively analyzed to develop a causal model of the *future* using three methods respectively: *historical analysis, comparative case studies* and *numerical simulation* as shown in Figure 3 below.[5] While the methods were used concurrently, the data evolved generally from more qualitative to more quantitative.

Figure 3: Summary of Research Design




**Comparative Case Studies.** Data analysis followed inductive grounded theory building techniques (Glaser & Strauss, 1967; Eisenhardt, 1989; Eisenhardt & Graebner, 2007), in which coding of observational, interview and archival data, generated robust sets of constructs.

**Historical Analysis.** In order to verify and extend the analysis of the above field-based case studies back in time, analysis of past data followed methods of business history (Chandler, 1962) using secondary data sources in both the primary and secondary samples.

**Numerical Simulation.** In order to verify and extend the above analyses, a simulation model was created to integrate the explicit causal structures and to explore the dynamic behavior generated by the model.[6]

[5] This combination of case-based grounded theory and numerical simulation has been recently used in the management literature (Rudolph and Repenning, 2002) to induce theory both from data and other theories.
[6] The purpose of this numerical simulation is not for quantitative calibration and prediction, but instead to gain qualitative understanding and insight into the posited governing "physics" of the underlying causal structures.

## Empirical Sample

This research inductively builds grounded theory from a comparative study of six organizations – in three pairs – with each pair competing in the same industrial environment.[7] Each pair consisted of focal firms having significant variance in both the dependent variable (firm performance) and independent variable (enterprise architecture). The sample is summarized in Table 1 below.

Table 1: Summary of Research Sample

| **Sample Type** | **Research Methods** | **Sector** | **Industry** | **Focal Firm** | **National Origin** | **Date of Birth** | **Current Enterprise Architecture** | **Firm Long-term Performance** |
|---|---|---|---|---|---|---|---|---|
| Primary | Field-based case study | Manu-facturing & Services | Large Commer. Airplanes | *Boeing* | US | 1916 | Modular | Decreasing |
| | | | | *Airbus* | EU | 1970 | Integral | Increasing |
| Second-ary | Available data analysis | Manu-facturing | Auto-motive | *GM* | US | 1908 | Modular | Decreasing |
| | | | | *Toyota* | Japan | 1937 | Integral | Increasing |
| | | Services | US Airlines | *United* | US | 1926 | Modular | Decreasing |
| | | | | *Southwest* | US | 1970 | Integral | Increasing |

The theoretical sample was selected for two reasons: one theoretical and the other methodological. First, the non-random theoretical sample was chosen to represent variance in organizational set[8] and environmental variables in order to assert a degree of generalizability in this exploratory stage of grounded theory building. The cases demonstrate that the theoretical framework has the possibility of applying to industries ranging from manufacturing to services, and in socio-economic environments including the US, Japan and Europe.

Second, in order to gain and sustain access to executive-level informants of the competing firms in the primary sample, we needed to mitigate conflict of interest issues and provide informants with other industry examples illustrating the theory. As a result, the secondary sample includes acknowledged world-class firms in both manufacturing e.g. *Toyota Motors* (Womack, Jones and Roos, 1990) and services e.g. *Southwest Airlines* (Hoffer Gittell, 2003). This served as the basis of discussion around which the senior decision-makers of the primary sample revealed their cognitive frames regarding themselves and those of their competitor.[9]

**Potential Limitations.** This non-random, small-N, theoretical sample used for theory *building* necessarily draws critiques of theory *validation* using random, large-N, statistical sample. As we aim to build *process* (not *variance*) theory which links "dependent" and "independent" variables in endogenous closed-loop feedback, capturing longitudinal switching of high and low performers, we begin to mitigate the concerns of sampling on the dependent variable[10] and survivorship bias.[11]

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[7] This comparison of pairs of high- and low-performers in the same industries is similar to other theory building research in strategy *content* (e.g. Lawrence and Lorsch (1967) and strategy *process* (e.g. Pettigrew and Whipp, 1990).

[8] Each firm is posited to be representative of a population of isomorphic organizational sets, giving the theoretical sample potential for increased external validity.

[9] In order to protect the anonymity of the informants, evidence is reported based on generic enterprise architecture type, and not individual firm.

[10] Where the criterion for selecting the sample of firms is based on the "dependent variable", firm performance.

[11] Where the survivors are fallaciously compared with the historic average, despite having unusual properties.

**Data Collection**
The data collection strategy utilized multiple methods and multiple sources as is briefly described in the following sections.

**Primary Data Sources.** For the primary case study, we constructed a macro-level model of the structure, function and evolution of the organizational set from the micro-level cognitive frames of senior decision makers within each stakeholder of the organizational set. These data came from over 100 senior level informants (e.g. CEOs, presidents, vice-presidents and directors) distributed both vertically within the organizations and horizontally across both organizational sets.

The field-based data for the primary sample are largely taken from over 3,500 hours of ethnography (Van Maanen, 1988) and clinical methods participant observation (Schein, 1987) spread longitudinally over seven years from January 2002 to January 2009. Three-month field visits occurred every summer for seven years, with additional two-week trips every winter and spring. This included over 150 in-depth, semi-structured interviews and interview-based surveys, totaling over 300 hours. My relationship to the informants in both organizational sets was as a doctoral student paid to teach strategy in executive education and workshop format to senior decision-makers.

This longitudinal design allowed for intensive triangulation of the data sources across endogenous and exogenous changes. For example, during the five years of the study informants occupied multiple positions and positions (such as CEO), were occupied by multiple informants. In addition, the longitudinal design allowed for observation of how the competing organizational sets responded to changing environmental conditions including the exogenous shock of the September 11, 2001 terrorist attacks, the normal rise and fall of the business cycle, as well as the change in market leadership, which for the first time shifted from the incumbent to the challenger during the time of this study.

**Secondary Data Sources.** In addition, in order to ascertain the structure, function and evolution of the organizational sets beyond the temporal scope of direct observation, access was acquired to historical available data sources, including public documents and official records (e.g. annual company reports and SEC filings), private documents (e.g. internal company memos) and mass media (e.g. historical interviews of leaders in the business press and trade journals). By way of example, in order to paint a historical record of the evolutionary trajectory of the firms in the primary sample, all of the annual company reports covering nearly 100 years of history, totaling over 3,500 pages were collected for analysis.

**Data Smoothing for Trends.** Finally, as this research aims to explain long-term trends (i.e. a "first-mode" *signal*), the transfer of data to theory requires a smoothing of short-term *noise,* manifested as local events.[12] Such smoothing requires "empirical patience", which operationally implies a long data gestation time constant, before the stock of potential data, is drained by an outflow into the stock of theory-building data.

[12] By analogy, in a theory of annual seasonal weather change (i.e. "due to the earth's tilt and its solar orbit, winter is colder than summer in the northern hemisphere") the fact that "noisy" daily temperature measurements might reveal local "inconsistencies" with the trend does not necessarily invalidate the theory.

## THEORETICAL FRAMEWORK & EMPIRICAL EVIDENCE

### Overview of Theoretical Framework

**Definitions.** Before specifying the unit of analysis and levels of analysis, we provide four definitions along the dimensions of competition-cooperation and substitutes-complements as continuous (not binary) variables. These definitions, given in both economics and sociology terminology, are summarized in Figure 4 below.

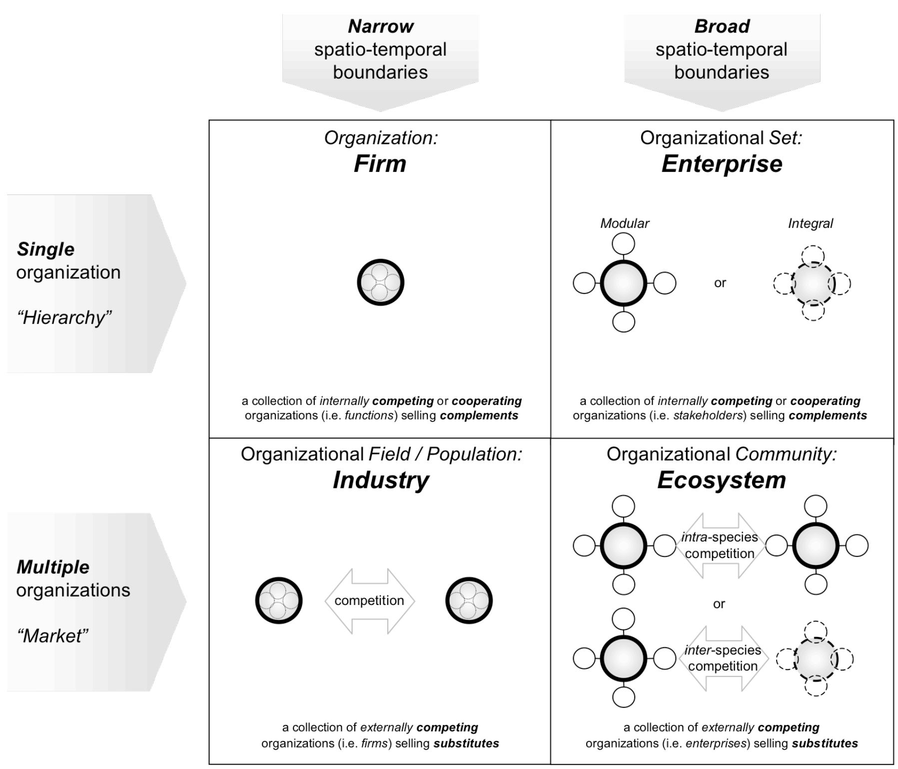
The type of *organization* under consideration is the *firm*, which is comprised of a collection of interacting internal functional organizations (e.g. marketing, R&D, manufacturing). These internal interactions tend toward the *cooperative* trading of *complementary* services.

The organizational *field* (DiMaggio and Powell, 1983) or *population* (Hannan and Freeman, 1977) or *industry* (Porter, 1980) is defined as an aggregate collection of externally interacting organizations or competing firms. These external interactions tend toward the *competitive* selling of *substitute* products and services.

The organizational *set* (Blau and Scott, 1962) or "extended *enterprise*" is defined as a focal firm and its key exchange actors (e.g. customers, suppliers, investors and employees). The set is therefore a collection of interacting internal functional organizations (or stakeholders). These internal interactions tend toward the *cooperative* selling of *complementary* products and services.

Finally, the organizational *community* (Aldrich, 1999) or *ecosystem* is defined as an aggregate collection of externally interacting heterogeneous organizations or competing enterprises. These external interactions tend toward the *competitive* selling of *substitute* products and services.

Figure 4: Summary of Primary Definitions



***Units* of Analysis.** The theoretical framework utilizes multiple units of analysis operating at different levels. The formal unit of analysis that defines the dependent variable is that of the business *firm* and specifically the performance of the single product "strategic business unit" within the more general diversified corporation (Porter, 1980).

In order to understand and explain the sources of firm performance, this framework posits the construct of an *extended enterprise*[13] that serves as the primary explanatory or independent variable of the framework.

Finally, in order to understand and explain the evolutionary forces that generate the primary explanatory variable, this framework posits the construct of an *ecosystem* of competing extended enterprises having different ecological forms or belonging to different ecological species (Hannan and Freeman, 1977).[14]

***Levels* of Analysis.** The levels of analysis occur both above and below the level of the firm. At a micro-level, the cognitive frames (Goffman, 1974) of the most senior leaders are mapped across the macro-level extended enterprise in order to determine and triangulate on the enterprise's architectural form and its function. In this dual micro- and macro-level of analysis, the enterprise architecture is analyzed as an enacted system that enables and constrains but does not determine managerial action (Giddens, 1979).

**Variables.** This paper however breaks with traditional strategic management research which strives to build and test *variance* theory - relating dependent and independent variables under strict necessary and sufficient conditions. Instead, this paper favors the building and testing of *process* theory, which seeks only necessary conditions plus a recipe for how they interact (Mohr, 1982; Van de Ven and Poole, 1995). In this way, the "dependent" and "independent" variables are linked via "moderating" and "mediating" variables to become a system of temporally and causally-linked "interdependent" variables. The entire system of causal relations therefore forms a closed feedback model whereby the evolution of business ecosystems is actually an endogenous theory, and the variables become antecedents (Richardson, 1991).

Despite this focus on process theory, we believe it useful to also characterize the four primary variables in familiar *variance* theoretic terms for illustrative purposes. In its simplest form, the dependent variable is long-term firm performance, and the independent variable is the enterprise architecture. We identify two types of intervening variables that relate the "dependent" and "independent" variables: *environmental maturity*, which describes the conditions that create and sustain different enterprise architectures, and *enterprise stability*, which describes how the enterprise functions or competes in strategic and operational terms.

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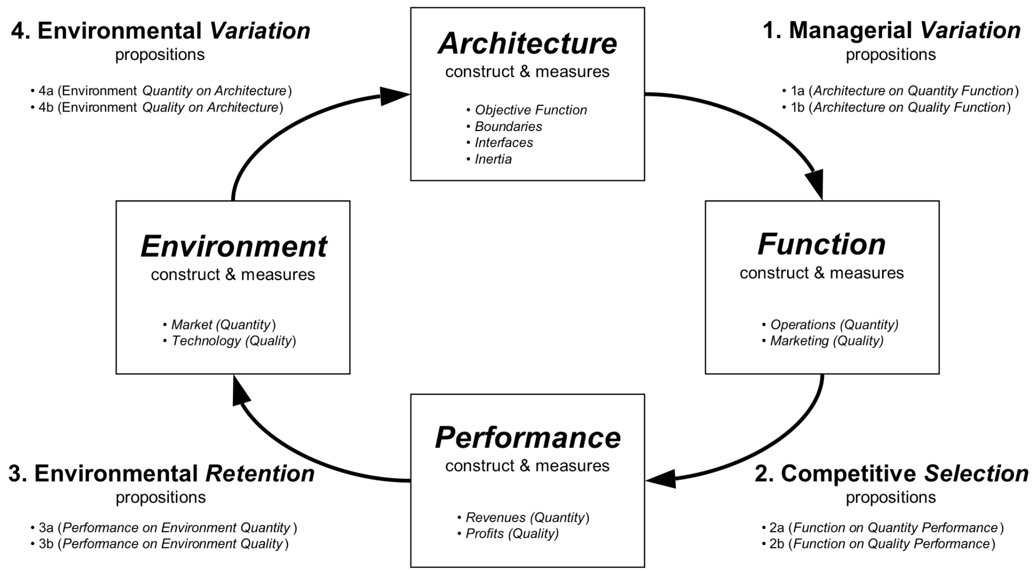
[13] Researchers using the organizational set level of analysis include: resource dependence theorist (Pfeffer and Salancik, 1978), transaction cost economists (Williamson, 1975 and 1985) and industry structural analysts in strategic management (Porter, 1980).

[14] Scott (2003) notes that "organizational field" has similar definitions within organization studies: "inter-organizational community" (Hawley, 1950; Warren, 1967), "organizational community" (Aldrich, 1999), "industry system" (Hirsch, 1985), and "societal sector" (Scott and Meyer, 1991).

**Framework Summary.** In the following section, the framework is decomposed into its four constitutive *construct sets* of enterprise architecture, function, performance and environmental maturity[15], which are linked by *proposition sets* as shown proceeding clockwise in Figure 5 below.[16] The theoretical framework captures the essential evolutionary processes of variation, selection and retention, as first expressed for *organisms* in evolutionary biology (Darwin, 1859), and subsequently for *organizations* in evolutionary sociology (Aldrich, 1979) and evolutionary economics (Nelson & Winter, 1982).

Figure 5: Overview of Theoretical Framework




The first construct set defines the construct of enterprise architecture, which describes how the focal firm interacts with its environment. A typology of ideal enterprise architectures will be defined along a continuum ranging from modular to integral network forms. In variance theory terms, this module captures the primary *explanatory* variables.

The second construct set describes the competitive dynamics between enterprise architectures. It describes how each type of enterprise architecture functions in terms of key high-level operations and marketing variables. A typology of ideal operations and marketing strategies will be mapped to the typology of enterprise architectures. In variance theory terms, this module captures the primary *mediating* variables.

The third construct set describes how the competitive dynamics of each type of enterprise architecture impacts long-term firm performance. A typology of ideal financial strategies will be mapped to the typology of enterprise architectures. In variance theory terms, this module captures the primary *dependent* variables.

The fourth construct set describes how long-term firm performance impacts the evolution of the industry, which in turn creates the conditions for future enterprise architectural development. In variance theory terms, this module captures the primary *moderating* variables.

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[15] This corresponds to the biological constructs of ecology, morphology and physiology.

[16] Each successive construct set assumes a longer time constant: the first defines the short-term static properties of enterprise architectures; the second and third define the mid-term dynamic - but non-evolutionary - process of competition, and the fourth defines the long-term co-evolutionary process of architectural change.

**Primary Construct:** ***Enterprise Architecture***

**Theoretical Background.** From the outset, we stated that seek a *systematic* explanation for long-term performance. We thus seek to characterize the firm-environment as a *system* of strategic complementarities (Milgrom and Roberts, 1990 & 1995), and as a typology of such complementarities (Hall and Soskice, 2001). The main construct of an *enterprise architecture* is introduced which originally emanates from architectural theory, which maps *form* to *function* (morphology to physiology) and specifies a typology of architectural forms ranging from *modular* to *integral*. Within design science, such an architectural typology has been developed for information (Simon, 1962), products (Ulrich, 1995; Baldwin and Clark, 2000), systems (Rechtin, 1991) and supply chains (Fine, 1998), but rarely to entire organizational sets.

Within organization science, *intra*-organizational typologies have been posited (e.g. Burns & Stalker, 1961; Lawrence & Lorsch, 1967; Miles & Snow, 1978). In addition, *inter*-organizational interactions have been proposed including: "the firm as a political coalition" (March, 1962), "theory of the firm" / "transaction cost economics" (Coase, 1937; Williamson, 1975), "resource dependence theory" (Pfeffer and Salancik, 1978), "five-forces analysis" (Porter, 1980), "stakeholder theory of the firm" (Freeman, 1984), "social network analysis" (Granovetter, 1985; Uzzi, 1997) and "varieties of capitalism" (Hall and Soskice, 2001). Finally, the evolution of isomorphic organizational forms has been posited in both neo-institutional theories (Meyer & Rowan, 1977; DiMaggio & Powell, 1983) and organizational ecology at the population- (Hannan & Freeman, 1977) and community levels (Astley, 1985). Typologies of "species" of organisms and organizations have arisen in biological ecology (MacArthur & Wilson, 1967) and organizational ecology (Brittain and Freeman, 1980) respectively. These species range from *r-strategists (opportunists)* to *K-strategists* (*equilibrium*-based) species. Table 2 below summarizes the typologies and configuration theories that have bee proposed in disciplines ranging from economics to sociology.

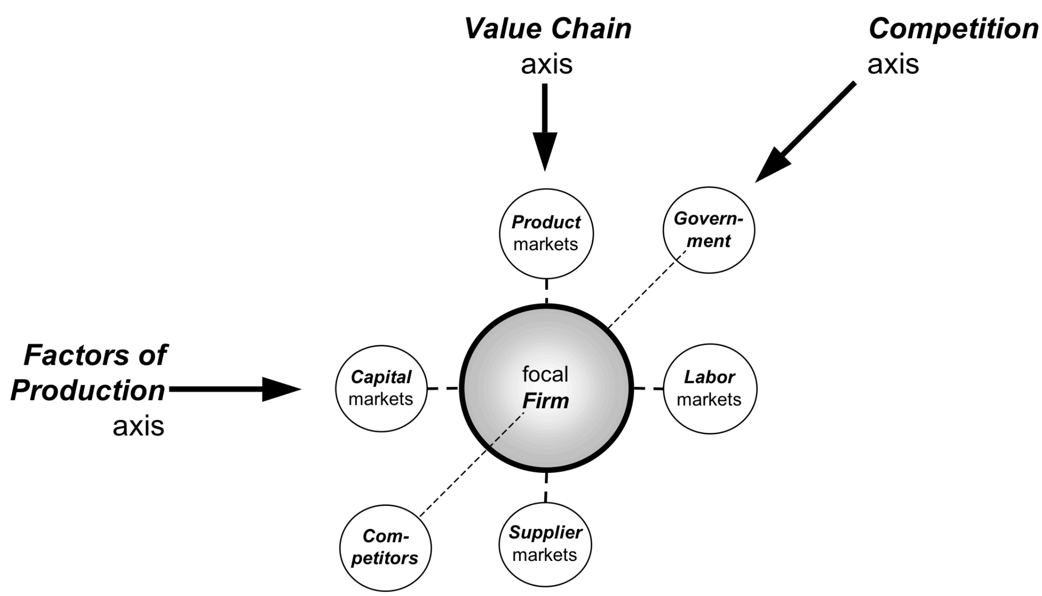
Table 2: Summary of Organizational and Economics-based Typologies

| Level | Typology (Disciplinary Basis) | Type 1 | Type 2 | Source |
|---|---|---|---|---|
| Micro | Organizational Structure (Structural Contingency Theory) | Mechanistic | Organic | Burns & Stalker (1961) |
| | Organizational Structure (Structural Contingency Theory) | Differentiation | Integration | Lawrence & Lorsch (1967) |
| | "Strategic Types" (Organizational Theory) | Prospector | Defender | Miles & Snow (1978) |
| | Organizational "Forms" (Organizational Ecology) | r-strategist | K-strategist | Brittain & Freeman (1980) |
| | Organizational Learning (Organizational Theory) | Exploitation | Exploration | March (1991) |
| | "Generic Strategies" (Economics) | Differentiation | Cost Leadership | Porter (1980) |
| | "Mixed Duopoly" (Economics) | Profit Maximizer | Labor Managed | Lambertini & Rossini, (1998) |
| Meso | Network Theory (Economic Sociology) | Underembedded | Overembedded | Granovetter (1985), Uzzi (1997) |
| | Inter-organizational "Architecture" (Complex Systems Theory) | Modular | Integral | Piepenbrock, Fine & Nightingale (2009) |
| Macro | Varieties of Capitalism (Political Economy) | Liberal Market Economy | Coordinated Market Economy | Hall & Soskice (2001) |

**Enterprise Architecture as *Organizational Set*.** An enterprise architecture is defined as the *form* of the organizational set.[17] An organizational set is a network comprising the firm and its key stakeholders. More specifically, the firm is seen to be the focal actor located at the center of a network of dyadic ties connecting the stakeholders to the firm. The extent of this network or enterprise is defined as including those stakeholders whose interactions with the firm significantly affect its performance (on a cost-benefit basis) over the time horizon of interest to the goals of the firm.

Before we can define an architectural typology of enterprises, we must first define the key modules or stakeholders of the organizational set, that is, we must first perform a functional decomposition or the enterprise. Each module is chosen for its relatively high internal interdependence and its relatively high external independence. For analytical simplicity, we decompose the enterprise along three dimensions or axes, with a pair of stakeholders associated with each axis: 1) the "value chain" of classical strategic management (Porter, 1985), which comprises customers and suppliers and captures classical demand and supply relationships; 2) the factors of production of classical economics which comprises providers of capital and labor; and 3) the competitive axis, i.e. those stakeholders which enable and constrain competition, (e.g. government and competitors). The primary modules of a generic enterprise architecture are summarized in Figure 6 below.[18]

Figure 6: Constituent Modules (Stakeholders) in a Generic Enterprise Architecture




[17] The architectural form of the organizational set (or morphology in organisms) represents an organization's "genotype", which may be common to both challenger (predators) and incumbent (prey). For example, the genotype of entrepreneurial radical innovators is an integral enterprise architecture – whether incumbent or late-entrant. A genotype's function and development within a specific environment, defines a richer concept of a "phenotype" or species, which is captured in the *ecology-morphology-physiology* framework.

[18] Note, for parsimony, the remainder of this paper focuses primarily on the first two dimensions of the enterprise, namely on customers, suppliers, investors and employees. For a fuller discussion of the broader organizational set, please refer to Piepenbrock (2009).

**Construct Definitions & Measures.** As Nohria and Gulati (1994) point out, no single unified perspective on organizations is shared between most major open systems schools of thought. For example, while contingency theorists, organizational ecologists and institutional theorists focus broadly on determinants of organizational *form*, resource dependence and transaction cost theorists focus on determinants of organizational *boundaries,* while resource dependence and network theorists focus on determinants of inter-organizational *relationships*.

The primary construct presented herein attempts to synthesize these theories, by proposing an integrated construct set which combines organizational *form, boundaries* and *relationships* in the notion of an inter-organizational or enterprise architecture.[19] These enterprise architectures are hypothesized to lie on a theoretical continuum ranging from *modular* to *integral* forms. These two extremes represent ideal types of architectures or archetypes, which can be defined in terms of three interrelated sets of properties: *objective functions,* enterprise *boundaries* and stakeholder *interfaces*.[20] Each will be briefly defined below.

*Objective Functions:* The objective function of the focal firm – within the classic corporate governance framework (Shleifer and Vishny, 1997) is defined by the way it appropriates residual profits to its enterprise, which ranges from maximization of *shareholder value* for the focal firm to maximization of *stakeholder surplus.* The former tends toward zero-sum *inter*-stakeholder competition, while the latter tends toward positive-sum *inter*-stakeholder cooperation. Intermediate objective functions are a weighted average of stakeholder claims.

*Enterprise Boundaries.* The objective function defines the spatio-temporal boundaries of the enterprise to be managed. "Spatial" refers to stakeholder space (not physical or geographic space), and "temporal" refers to the time horizon to which the enterprise is managed. For the shareholder value maximizer, the enterprise boundaries tend to be more *narrowly* defined both spatially around the firm, and temporally towards the short-term. For the stakeholder surplus maximizer, the enterprise boundaries tend to be more *broadly* defined both spatially around the entire extended enterprise, and temporally towards the long-term.[21]

*Stakeholder Interfaces.* The firm-stakeholder interfaces define the degree of complexity or functional in(ter)dependence. High functional *independence* is associated with narrow spatio-temporal boundaries, while high functional *interdependence* is associated with broad spatio-temporal boundaries. Interfaces can be divided into dimensions of quantity and quality of stakeholder relationships.[22] The *quantity* defines the number of providers within a stakeholder class and the *quality* defines the type of firm-stakeholder relationships, ranging from arm's-length, contract-based, market transactions to trust-based, relational coordination. The former tends toward zero-sum *intra*-stakeholder competition, while the latter tends toward positive-sum *intra*-stakeholder cooperation.

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[19] This new construct redirects emphasis from *formal* aspects of the organization towards more *informal* aspects. Schilling and Steensma (2001) employ different empirical measures for modular organizations.

[20] In organizational ecology, a similar definition of a "species" or "organizational form" consists of: *goals*, *boundaries* and *activities* (Aldrich, 1979, pg. 28.)

[21] The *spatial* and *temporal* dimensions are posited to be non-orthogonal, i.e., the broader the set of stakeholders, the longer the time frame that one must consider.

[22] The *quantity* and *quality* dimensions are posited to be non-orthogonal, i.e. with high quantity being coupled with low quality and low quantity being coupled with high quality.

**Architectural Typology: *Modular-Integral*.** The following three axioms, summarized in Figure 7 below, define the architectures of enterprises in terms of their *objective functions,* enterprise *boundaries* and stakeholder *interfaces*.

The first axiom relates architectural form to function. The form that an enterprise architecture assumes is driven to some extent by its *objective function*, which represents the weighted average of the interests of its constituent stakeholders.

> *Axiom 1: When modular enterprise architectures are observed empirically, the focal firm's objective function will tend toward singluar maximization of shareholder value. Conversely when integral enterprise architectures are observed empirically, the focal firm's objective function will tend toward pluralistic maximization of stakeholder surplus.*

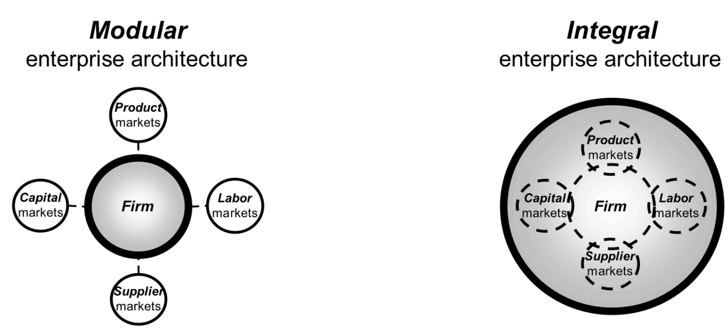
The second axiom relates architectural form to spatio-temporal boundaries. The form that an enterprise architecture assumes is driven to some extent by the boundaries within which the leader(s) of the focal firm manage(s) toward.

> *Axiom 2: When modular enterprise architectures are observed empirically, the spatio-temporal boundaries of the focal firm will be relatively narrow and coincident with the boundaries of the firm and the time expectations of its shareholders. Conversely when integral enterprise architectures are observed empirically, the spatio-temporal boundaries of the focal firm will be relatively broad and beyond the boundaries of the firm and its shareholders.*

The third axiom relates architectural form to the level of complexity of the stakeholder interfaces with the focal firm. The form that an enterprise architecture assumes is driven to some extent by the quantity and quality of stakeholder relationships with the focal firm.

> *Axiom 3: When modular enterprise architectures are observed empirically, the focal firm will tend to have a higher quantity of lower quality (i.e. contract-based) interactions within each stakeholder group. Conversely when integral enterprise architectures are observed empirically, the focal firm will tend to have a lower quantity of higher quality (i.e. relationship-based) interactions within each stakeholder group.*

Figure 7: Typology of Enterprise Architectures




| | | |
|---|---|---|
| ***Singular*** (Maximization of *Shareholder Value*) | **Objective Function** | ***Plural*** (Maximization of *Stakeholder Surplus*) |
| ***Narrow*** (*narrow* spatial, *short* temporal) | Enterprise **Boundaries** | ***Broad*** (*broad* spatial, *long* temporal) |
| ***Simple*** (*High* quantity of participants in a stakeholder class, *Low* quality of stakeholder relationships) | Stakeholder **Interfaces** | ***Complex*** (*Low* quantity of participants in a stakeholder class, *High* quality of stakeholder relationships) |

**Empirical Data.** The following representative qualitative data summarized in Table 3 below begins to support the above axioms of modular and integral enterprise architectural forms.

Table 3: Sample Qualitative Data Indicating Architectural Forms

| Industry | Firm | Quotation |
|---|---|---|
| Commercial Airplanes | *Boeing* (Modular) | "[Union President] Blondin recalls asking: 'I just don't understand why you always fight us.' Blondin says [*Boeing* HR VP] Calhoun replied: 'You just don't get it. We represent Corporate America. You represent labor. We are always going to be adversaries.'" (Source: *Business Week*, 26 Sept. 2005). |
| | *Airbus* (Integral) | "I am always a bit surprised by the speed with which Americans take decisions: that in three days (after 9-11) they announce 25,000 lay-offs at *Boeing* seems to me totally stupefying," (Source: Noel Forgeard, CEO, *Airbus*; *AFX*, 21 Sept. 2001). |
| Automobiles | *General Motors* (Modular) | "When the Japanese producers encounter these gigantic market waves, they will quickly become as mediocre as we are. They will have to start hiring and firing workers along with suppliers and will end us as mass-producers in short order." (Source: *GM* Executive; Womack, Jones & Roos, 1990). |
| | *Toyota Motors* (Integral) | "Under Japanese company law, shareholders are the owners of the corporation. But if corporations are run exclusively in the interests of shareholders, the business will be driven to pursue short-term profit at the expense of employment and spending on research and development. To be sustainable, corporations must nurture relationships with stakeholders such as suppliers, employees and the local community. So whatever the legal position, the corporation does not belong to its owners. It's not enough to serve shareholders." (Source: Mr. Okuda, Chairman, *Toyota Motor Corporation*; *Financial Times*, 1 Aug. 2001).<br>"*Toyota's* business philosophy is to realize stable, long-term growth by working hard to strike a balance between the requirements of people and society, the global environment and the world economy. Our goal is to grow with all our stakeholders, including customers, shareholders, employees and business partners." (Source: *Toyota Motors Corporation* Annual Report, 2003). |
| U.S. Airlines | *United Airlines, Continental Airlines* (Modular) | "We don't want to kill the golden goose,' Dubinsky...nicknamed Mad Dog... [head of the *Airline Pilots Association*] told Goodwin [*United Airlines* CEO]. 'We just want to choke it by the neck until it gives us every last egg." (Source: Roger Lowenstien, "Into Thin Air", *New York Times,* 17 Feb. 2002).<br>"I already hear labor leaders crying out, 'Let's go back to the old ways and let's get that again.' Do you know that a walrus isn't born fat and ugly – they become that way? So, if you want a date, you gotta kinda slim down and keep yourself in shape. So if you get fat and ugly again, someone's just going to take it away from you. Who are the big losers? The employees lost the most with pensions and incomes. Well, don't let that happen again! The guy that overeats is the one that dies. Where there's a management that says, 'Fine. We have to sign this contract, that we know that if we do will put us at a very non-competitive situation and will ultimately kill us'. Don't sign it! 'If we don't sing it they're going to strike and take the company out.' Well, take it! Shit, you're going broke anyway! It might as well be them that cause it and not you. How do you pull a band-aid off? If you do it fast, do it quick. On hair at a time or get that goddamn thing off – it's got to come off. Get it over with. *United, Delta, Northwest*, and others were a victim of compromise – another layer of fat, another deal they shouldn't have signed, another concession.." (Source: Gordon Bethune, former CEO *Continental Airlines*; *Airways*, July 2007). |
| | *Southwest Airlines* (Integral) | "We are willing to suffer some damage, even to our stock price, to protect the jobs of out people." (Source: James Parker, CEO, *Southwest Airlines*; *Business Week,* 8 Oct. 2001).<br>"We can't let investors guide the company. That's not to say that investors aren't smart and don't have good ideas, because they do. They just have different motives. We've got to say true to who we are as a company and build for the long term." (Source: Gary Kelly, CEO, *Southwest Airlines; The Dallas Morning News*, 20 Dec. 2007). |

**1. Managerial *Variation*: Architecture-Function Relationship**

**Construct Definitions & Measures**

Having defined a typology of enterprise architectures, the next step is to describe how these constructs function and interact over time in a competitive environment. Two primary variables are used which consider competition in terms of both *quality* or "what to offer?" and *quantity* or "how to offer it"? Porter (1980) frames this *quality* decision as a strategic position choice, which is broadly either *differentiation* or *cost-leadership*. Forrester (1961) frames this *quantity* decision as an operational stability choice, which is broadly either *unstable* or *stable* growth.

While organizational scholars have posited relationships between organizational form and competitive variables, for example that *intra*-organizational structure follows strategy (Chandler, 1962; Miles and Snow, 1978; Arthur, 1992; Delery and Doty, 1996), little research has shown which *inter*-organizational form delivers these strategic and operational choices the most effectively. Neither do they explain the conditions under which the converse is true, namely, when strategy follows structure.

Similarly, while organizational scholars have posited a tradeoff between the activities of exploration and exploitation (March, 1991), few have specified the *inter*-organizational forms that best deliver each activity.

Enterprise architectures can enable and constrain choice in competitive variables. The following two propositions serve to define the relationship between enterprise architectures and choices in strategic and operational variables.[23]

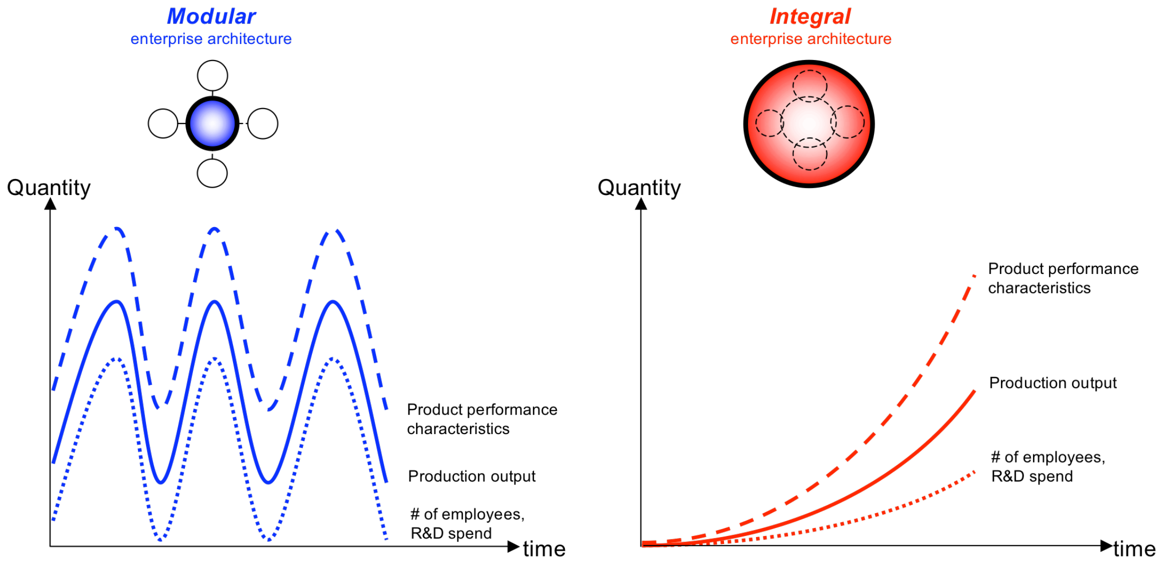
**Proposition 1a: *Quantity* of Firm Growth.** The first proposition relates enterprise architecture to *quantity*-type variables or operational stability choices. The choices that leaders of focal firms make are driven to some extent by their enterprise architecture.

Operations management scholars have advanced the construct of "stability" in the context of growth strategies (Forrester, 1961). The structure of growth can be characterized either as *unstable* which emphasizes reinforcing feedback and system delays, while de-emphasizing limits to growth; or as *stable* which emphasizes balancing feedback and limits to growth, while de-emphasizing system delays. As shown in Figure 8 below, the time histories of input variables (like number of employees or amount of R&D spend) and output variables (like number of units produced) reveal very different dynamic behaviors. Note that the rate of change of the inputs or outputs (i.e. the slope of the time histories) determines the "speed" of growth.

> *Proposition 1a: When modular enterprise architectures are observed empirically, the focal firm's operational strategy will tend toward unstable growth; it will have relatively high short-term speed, but relatively low long-term speed. Conversely when integral enterprise architectures are observed empirically, the focal firm's operational strategy will tend toward stable growth; it will have relatively low short-term speed, but relatively high long-term speed.*

[23] For a discussion of how strategic and operational variables interact, see Piepenbrock (2009).

Figure 8: Comparison of *Unstable* vs. *Stable* Growth




For *short* time horizons, the absolute value of the rate of change of output of the modular enterprises tends to always exceed the rate of change of output of integral enterprises. Mathematically, this can be expressed as:

$$|dQ_m/dt| > |dQ_i/dt| \qquad \text{(for small dt)}$$

For *longer* time horizons, the absolute value of the rate of change of output of the integral enterprises tends to always exceed the rate of change of output of long enterprises. Mathematically, this can be expressed as:

$$|dQ_m/dt| < |dQ_i/dt| \qquad \text{(for large dt)}$$

In addition, it appears that rate of change of output of integral enterprises tends to not go negative. In other words, integral enterprises are designed to grow at such a rate that they will not have to significantly shrink output. Mathematically, this can be expressed as:

$$dQ_i/dt < 0$$

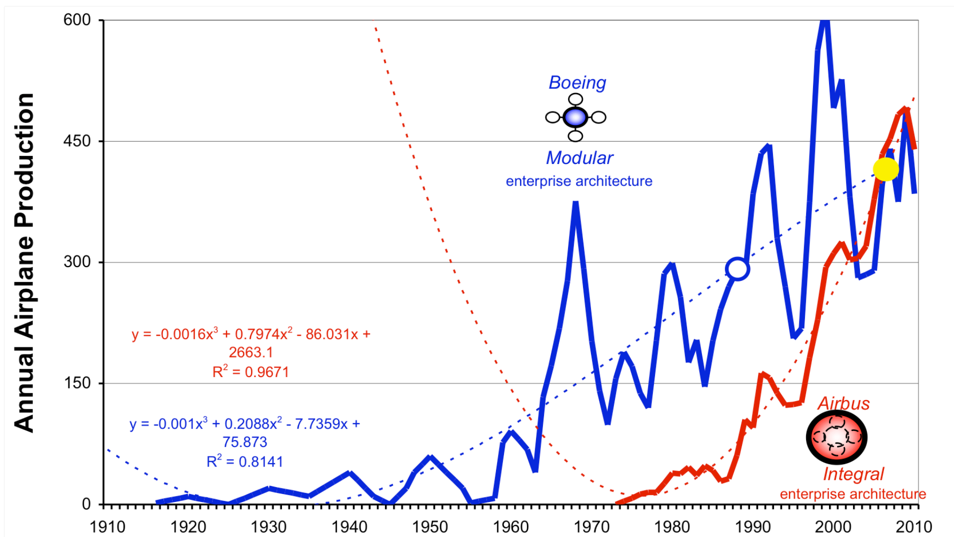
***Qualitative* Empirical Data.** Before presenting select quantitative date, we begin by reviewing select qualitative data as summarized in Table 4 below.

Table 4: Sample Qualitative Data Supporting Proposition 1a

| Industry | Focal Firm (Architecture) | Quotation (Source) |
|---|---|---|
| Com-mercial Airplanes | *Boeing* (Modular) | "Boeing quickly moved last week to cut commercial transport delivery estimates through 2002 in an announcement that surprised even some veteran Boeing-watchers by its swiftness and scope. At a hastily arranged news conference Sept. 18, one week after the terrorist attacks in the U.S., the company said it could also lay off up to nearly one-third of its commercial aircraft workforce. Alan R. Mulally, Boeing president and CEO of *Boeing Commercial Airplanes*, said the layoffs would begin during the last quarter of this year. 'When you order airplanes today, depending on the model, the lead time is anywhere from 10-14 months, so we need to make these decisions for production next year as soon as possible.'" (Source: Alan Mulally, President & CEO, *Boeing Commercial Airplanes*; *Aviation Week*, 24 Sept. 2001).<br>"History tells us that the quicker a company acts to counter adverse economic conditions, the better able it will be to work its way through a downturn and emerge stronger when the economy recovers." (Source: Jim McNerney, Chairman, President & CEO, *The Boeing Company*; memo to employees, 17 Feb. 2009). |
| | *Airbus* (Integral) | "We've always been much more careful about production rates. We do see peaks and troughs but we've always managed to limit the highs and lows better than they do in the USA." (Source: Philippe Camus, *EADS* Co-Chairman; *ATI*, 20 Sept. 2001). |
| Auto-mobiles | *General Motors* (Modular) | "When the Japanese producers encounter these gigantic market waves, they will quickly become as mediocre as we are. They will have to start hiring and firing workers along with suppliers and will end us as mass-producers in short order." (Source: *GM* Executive; Womack, Jones & Roos, 1990). |
| | *Toyota Motors* (Integral) | "In a high-growth period, productivity can be raised by anyone. But how many can attain it during the more difficult circumstances induced by low-growth rate? This is the deciding factor in the success or failure of an enterprise." (Source: Taiichi Ohno, *Toyota Motors Company* Executive Vice President; Ohno, T. 1978, pg 114).<br>"The Toyota Production System can be realized only when all the workers become tortoises. Speed is meaningless without continuity. Just remember the tortoise and the hare." (Source: Taiichi Ohno, *Toyota Motor Company* Executive Vice President; Ohno, T. 1978, pg. 63). |
| U.S. Airlines | *United Airlines* (Modular) | "I don't' want to take advantage of the situation, but we have to do what is right for the company… and events of September 11 have opened certain doors for the company that were pretty much closed before." (Source: Rakesh Gangwal, *US Airways President*; Hoffer-Gittell, 2003). |
| | *Southwest Airlines* (Integral) | "The 'experts' always think we need to expand at a more rapid pace. What these so-called experts express is their desire for Southwest to jump at opportunities at a more rapid clip. Apparently growth excites investors. [But] nobody is pushing us. That could never happen." (Source: Matt Hafner, Director, *Southwest Airlines;* Jody Hoffer Gittell, (2003), pg. 246). |

***Quantitative* Empirical Data.** Proposition 1a describes the rates of growth and associated enterprise stability in enterprise architectures within an ecosystem. One would expect *Boeing's* more modular enterprise architecture to grow at higher short-term rates, while lower long-term rates (i.e. with less stability). Conversely, one would expect *Airbus'* more integral enterprise architecture to grow at lower short-term rates, while higher long-term rates (i.e. with greater stability). Figure 9 summarizes the output quantities for the competing focal firms in the primary sample, after the emergence of the dominant product design.

Figure 9: *Quantity* Growth of Competing Enterprise Architectures in the *Airplane* Industry



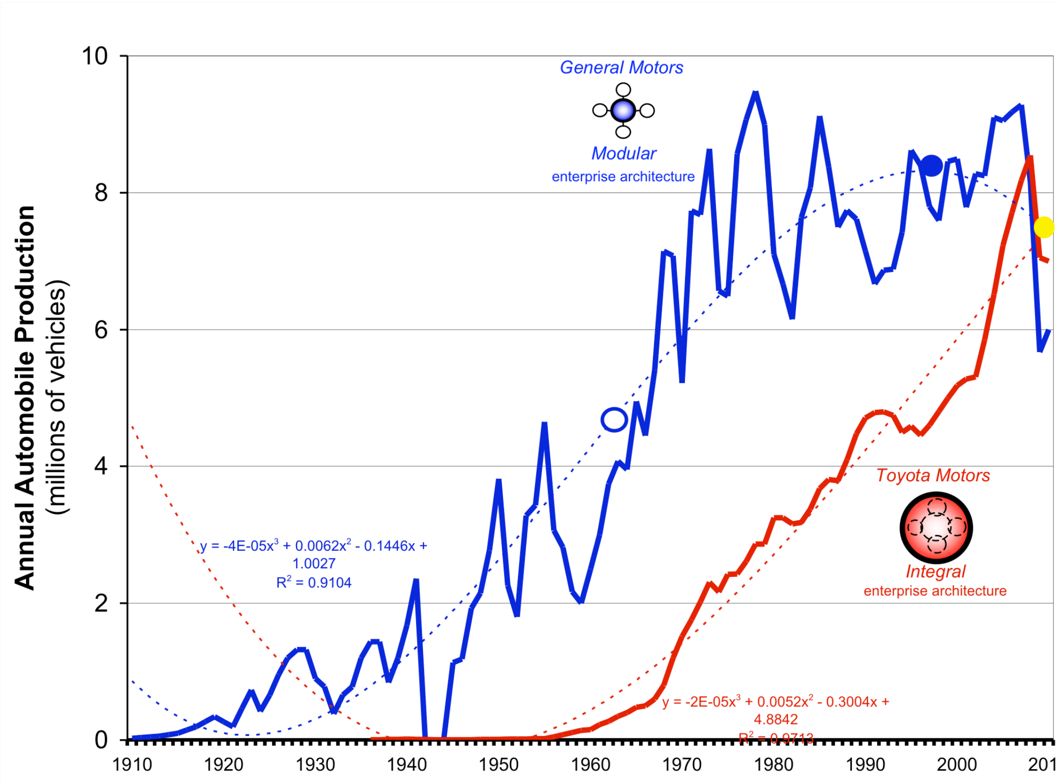

*Qualitatively*, after nearly 100 years of dominance, the market share-leading incumbent, *Boeing* is eventually overtaken by the late-entrant challenger, *Airbus*. Note that the late-entrant exhibits smoother growth (i.e. slow short-term growth, with fast long-term growth). Three observations can be made regarding quantity outputs: 1) during an upturn, the rate of change of output growth of a modular enterprise architecture generally exceeds that of an integral enterprise architecture; 2) during a downturn, the rate of change of output decline of a modular enterprise architecture generally exceeds that of an integral enterprise architecture; and 3) negative growth of an integral enterprise architecture is rare. These three observations combine to state that the long-term growth rates of integral enterprise architectures exceed those of modular enterprise architecture. Finally, note that the late-entrant appears to experience a prolonged incubation period of relatively low production, while capabilities are presumably built. This behavior might imply the need for patient capital.

*Quantitatively*, over the long-term since *Airbus* began production in 1974, its output CAGR is 12.5%, which is approximately seven times *Boeing's* output CAGR of only 1.8% over the same time period. A simple least squares fit regression analysis[24] using logistic, third order cubic polynomial trend lines, demonstrates both *Airbus'* higher long-term growth rate, as well as continued exponential growth. *Boeing* on the other hand has a lower long-term growth rate, and has begun to inflect towards downward concavity (i.e. industry exit).

[24] Note that for simplicity, the regression analyses shown use Ordinary Least Squares method. However, as the longitudinal time-series data are not independent, but autocorrelated, they require more advanced regression methods like Auto Regressive Moving Average (ARMA) models.

As illustrated in Figure 10 below, similar trajectories can be seen in the automotive industry.

Figure 10: *Quantity* Growth of Competing Enterprise Architectures in the *Automotive* Industry

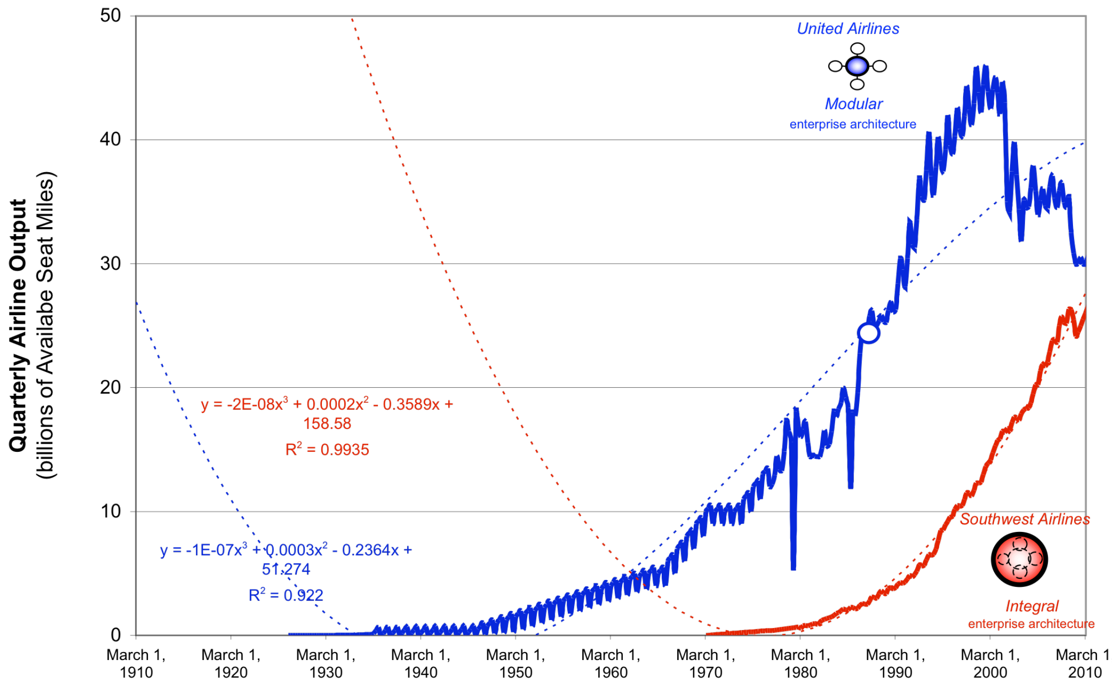



*Qualitatively*, after nearly 100 years of dominance, the market share-leading incumbent, *General Motors* is eventually overtaken by the late-entrant challenger, *Toyota Motors*. Note that the late-entrant exhibits smoother growth (i.e. slow short-term growth, with fast long-term growth). Note also that while *GM's* output is beginning to resemble an S-curve, with the inflection point occurring in the mid-1960s, *Toyota's* output is best described as exponential growth, with an inflection point not yet attained. Finally, again note that the late-entrant appears to experience a prolonged incubation period of relatively low production, while capabilities are presumably built. This behavior might imply the need for patient capital.

*Quantitatively*, over the long-term since *Toyota* began production in 1937, its output CAGR is 11.8%, which is approximately five times *GM's* output CAGR of only 2.6% over the same time period. A simple least squares fit regression analysis using logistic, third order cubic polynomial trend lines, demonstrates both *Toyota's* higher long-term growth rate, as well as continued exponential growth. *GM* on the other hand has a lower long-term growth rate, and has begun to inflect towards downward concavity (i.e. industry exit). Note also that the polynomials cross – i.e. competitive dominance switches – after the incumbent species has peaked in output growth rates, while before the challenger species has inflected.

As illustrated in Figure 11 below, similar trajectories can be seen in the airline industry.

Figure 11: *Quantity* Growth of Competing Enterprise Architectures in the *US Airline* Industry




*Qualitatively*, after nearly 100 years of dominance, the market share-leading incumbent, *United Airlines* is being overtaken by the late-entrant challenger, *Southwest Airlines*. Note that the late-entrant exhibits smoother growth (i.e. slow short-term growth, with fast long-term growth). The integral enterprise architecture's relative stability is evidenced by an absence of downward labor strikes, upward acquisitions and its ability general to dampen significant exogenous events like 9-11 terrorist attacks on the US, as well as the "noise" of minor seasonal fluctuation. Finally, again note that the late-entrant appears to experience a prolonged incubation period of relatively low production, while capabilities are presumably built. This behavior might imply the need for patient capital.

*Quantitatively*, over the long-term since *Southwest Airlines* began operation in 1970, its output CAGR is 20%, which is approximately six times *United Airline's* output CAGR of only 3% over the same time period. A simple least squares fit regression analysis using logistic, third order cubic polynomial trend lines, demonstrates both *Southwest's* higher long-term growth rate, as well as continued exponential growth. *United* on the other hand has a lower long-term growth rate, and has begun to inflect towards downward concavity (i.e. industry exit).

Table 5 below summarizes the empirical data supporting proposition 1a which captures the relationship between enterprise architectures and their function in *quantity* space.

Table 5: Summary of Data Supporting Proposition 1a

| Industry | Focal Firm | Enterprise Architecture | *Quantity* Growth During *Intra*-Species Competition | *Quantity* Growth During *Inter*-Species Competition |
|---|---|---|---|---|
| Commercial Airplanes | *Boeing* | Modular | 1916-1970 CAGR = **2**% | 1970-2010 CAGR = **3**% |
| | *Airbus* | Integral | | 1970-2010 CAGR = **13**% |
| Auto-mobiles | *General Motors* | Modular | 1908-1937 CAGR = **15**% | 1937-2010 CAGR = **3**% |
| | *Toyota Motors* | Integral | | 1937-2010 CAGR = **12**% |
| Airlines | *United Airlines* | Modular | 1926-1970 CAGR = **23**% | 1970-2010 CAGR = **3**% |
| | *Southwest Airlines* | Integral | | 1970-2010 CAGR = **20**% |

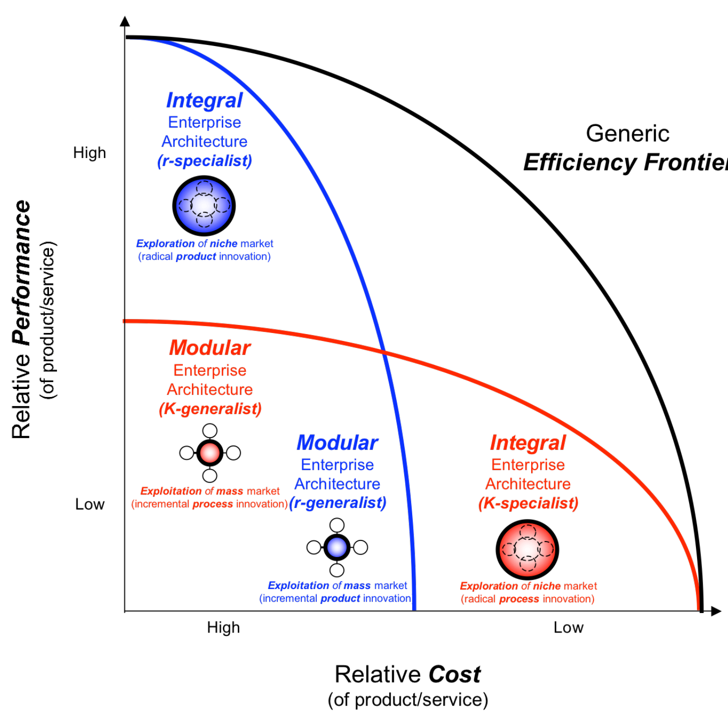
The question of how profitable this growth is will be covered in the next proposition set.

**Proposition 1b: *Quality* of Firm Growth.** Strategic management scholars have advanced the construct of an "efficiency frontier" in the strategic positioning space (Porter, 1996), which is defined by the orthogonal axes of differentiation and cost-leadership, or as specialist and generalists in ecological niche theory (Brittain & Freeman, 1980). As shown in Figure 12 below, a tradeoff between the two strategic positioning choices is posited to exist. *Efficiency* is defined as the distance of the firm from the frontier. Conversely, *effectiveness* is defined as the distance of the frontier from the origin. As the enterprise architecture enables and constrains performance, it defines the effectiveness potential of the enterprise (Pfeffer and Salancik, 1978). The shape of this efficiency frontier, while conceptually symmetrical at the industry level, is not symmetrical at a firm level. Firms that choose to focus on one strategy, develop capabilities and inertia around that choice, which makes switching to another strategy, while possible, lower in potential performance than a firm which chose to focus on it.

The second proposition relates enterprise architecture to *quality*-type variables or strategic positioning choices. The choices that leaders of focal firms make are driven to some extent by their enterprise architecture. When firms want to *explore* (March, 1991) or innovate radically in either products for differentiation or processes for cost-leadership, they will emphasize integration (Lawrence and Lorsch, 1967). Conversely, when firms want to *exploit* or innovate incrementally, they will emphasize differentiation as shown in Figure 12 below.

> *Proposition 1b: When integral enterprise architectures are observed empirically, the focal firm will be engaged in exploration (or radical innovation in either products or processes[25]) of niche markets. Conversely, when modular enterprise architectures are observed empirically, the focal firm will be engaged in exploitation of mass markets.*

Figure 12: *Exploration* and *Exploitation* in Strategic Position Space




[25] As will be discussed in Proposition Set 4, industries tend to evolve from product to process innovation.

***Qualitative*** **Empirical Data.** Before presenting select quantitative date, we begin by reviewing select qualitative data as summarized in Table 6 below.

Table 6: Sample Qualitative Data Supporting Proposition 1b

| **Industry** | **Focal Firm (Architecture)** | **Quotation (Source)** |
|---|---|---|
| Com-mercial Airplanes | *Boeing* (Modular) | "Forever New Frontiers" (Source: Philip M. Condit, Chairman and CEO, and Harry C. Stonecipher, President and COO, *The Boeing Company;* Annual Report, Message to Shareholders 2000). "Our products bring better value to our customers, and our pricing reflects that value. We also have a responsibility to our shareholders, and that means pricing that allows us to make our financial goals. Do I think that we will ever be the lower-price option? No. Do I think that should keep us from gaining more than 50 percent market share? I answer "no" to that as well. (Source: Scott Carson, Vice President of Sales, *Boeing Commercial Airplanes*, *Boeing Frontiers*, April 2005). "Fundamental, game-changing innovation like that we're pursuing on the 787 usually has a 'bleeding-edge' quality to it – meaning it goes beyond 'leading edge' into a realm where both the risks and the potential returns are high." "We're on the bleeding edge of taking a big, big step that was just a quarter step too far." (Source: James McNerney, Chairman and CEO, *The Boeing Company; Business Week*, 23 April 2008 and *The Chicago Tribune*, 22 May 2008). |
| | *Airbus* (Integral) | "Our strategy isn't a secret...we're called, 'Airbus', not 'Airlimousine'" (Source: anonymous *Airbus* executive, 2005). |
| Auto-mobiles | *General Motors* (Modular) | "Here's what's new about *GM's* strategy this year: Nothing. *GM* brought brand differentiation to the world in the 1920s. As the decades passed, and our product portfolio expanded, we slowly drifted away from that simple but effective strategy. Today the *GM* product revolution again is strengthening our brands, with more innovative marketing that better understands the customer." (Source: *General Motors* Annual Report, 2003, pp. 3 and 8). |
| | *Toyota Motors* (Integral) | "Cost Reduction is the Goal: At *Toyota*, as in all manufacturing industries, profit can be obtained only by reducing costs. Cost reduction must be the goal of consumer products manufacturers trying to survive in today's marketplace." (Source: Taiichi Ohno 1978). |
| U.S. Airlines | *United Airlines* (Modular) | "We have chosen to close our discount subsidiary, *Ted* in order to focus on our strengths in serving our premium customers – the historic source of our competitive advantage." |
| | *Southwest Airlines* (Integral) | *"Southwest's* business model, like that of *Toyota*, is to provide a low-cost product by utilizing its resources efficiently, while providing record levels of reliable service." (Source: Jody Hoffer Gittell, 2003 pp. 3-4.) |

***Quantitative*** **Empirical Data.** Proposition 1b describes the strategic position taken by enterprise architectures within an ecosystem. One would expect *Boeing's* more modular enterprise architecture (as well as that of its dominant competitive predecessor) to compete via a *differentiated* product strategy that stresses product capabilities based on product innovation. Conversely, one would expect *Airbus'* more integral enterprise architecture to compete via a *cost-leadership* product strategy based on process innovation. Figure 13, Figure 14 and Figure 15 below summarizes the quality of output for the firms in the airplane, automotive and airlines industries respectively.

Figure 13: *Quality* Space of Competing Enterprise Architectures in *Airplane* Industry

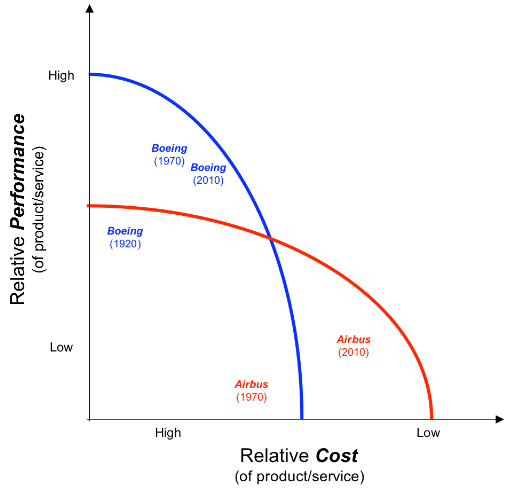



Figure 14: *Quality* Space of Competing Enterprise Architectures in *Automotive* Industry

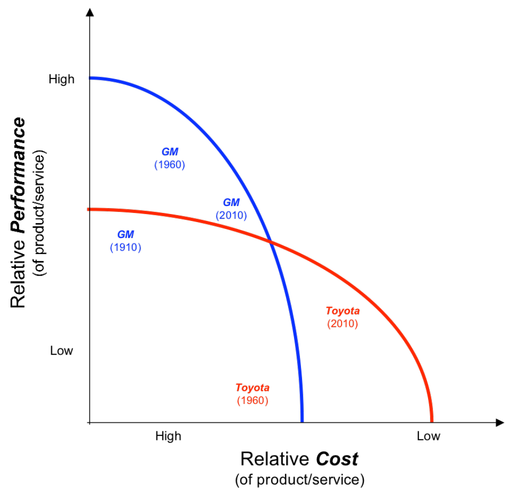
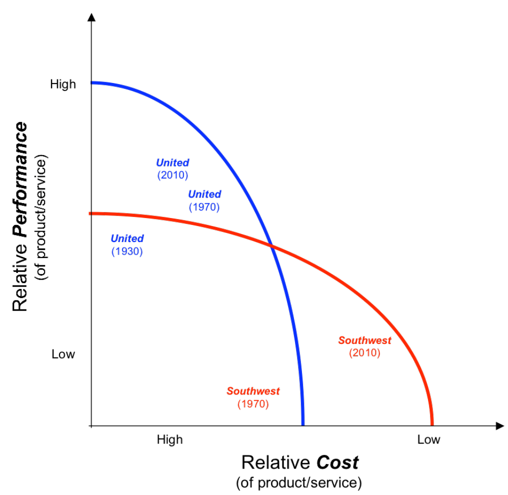



Figure 15: *Quality* Space of Competing Enterprise Architectures in *Airline* Industry



## 2. Competitive *Selection*: Function-Performance Relationship

### Construct Definitions & Measures

The dependent variable used in this research – which is typical for most research in strategic management – is long-term firm performance, defined specifically as *economic* or *financial* performance. As such, there are a vast number of measures and metrics upon which to base the research (McGrahan and Porter, 1997). This is made even more complicated given the fact that the spectrum of enterprise architectures represents a range of performance objective functions, making a direct comparison of performance difficult.

In order to reconcile this dilemma, the common performance metric that will be used for all enterprise architectures will be maximization of shareholder value as represented by market capitalization. Although this is the explicit goal of the *shareholder*-based enterprise architecture, and only an indirect and implicit goal of the *stakeholder*-based enterprise architecture, it allows crucial comparison of zero-sum vs. positive-sum outcomes, which reveal the conditions under which an integrated approach outperforms a modular approach to enterprise architectures.

Shareholder value has been demonstrated to be dependent upon both *past* financial performance and *future* growth prospects (Dobbs and Koller, 2005). These sub-variables will be important in understanding the distinction between enterprise architectures and their underlying mechanics. Past performance is reflected on the firm's income statement, and can be decomposed into *top-line* revenues and *bottom-line* net income or profits. Longitudinal time-histories of these two variables can help explain longitudinal trajectories of shareholder value.

Modular enterprise architectures assign a functional decomposition resulting in a clear separation and of ownership (by principals, typically shareholders) and management (their agents). This "efficiency" results in the classic principal-agent problem (Jensen and Meckling, 1976). *Agency Theory* posits that managers are typically interested in maximization of top-line revenues, as their pay and influence is tied to expanding the size of the firm, while investors are typically interested in maximization of bottom-line profits. Integral enterprise architectures on the other hand assign a less clear functional separation of ownership and management, alleviating some of the problems and costs of agency. Resolution of these functional conflicts occurs above at the enterprise architectural level. Researchers have referred to this as *Stewardship Theory* (Donaldson and Davis, 1990).

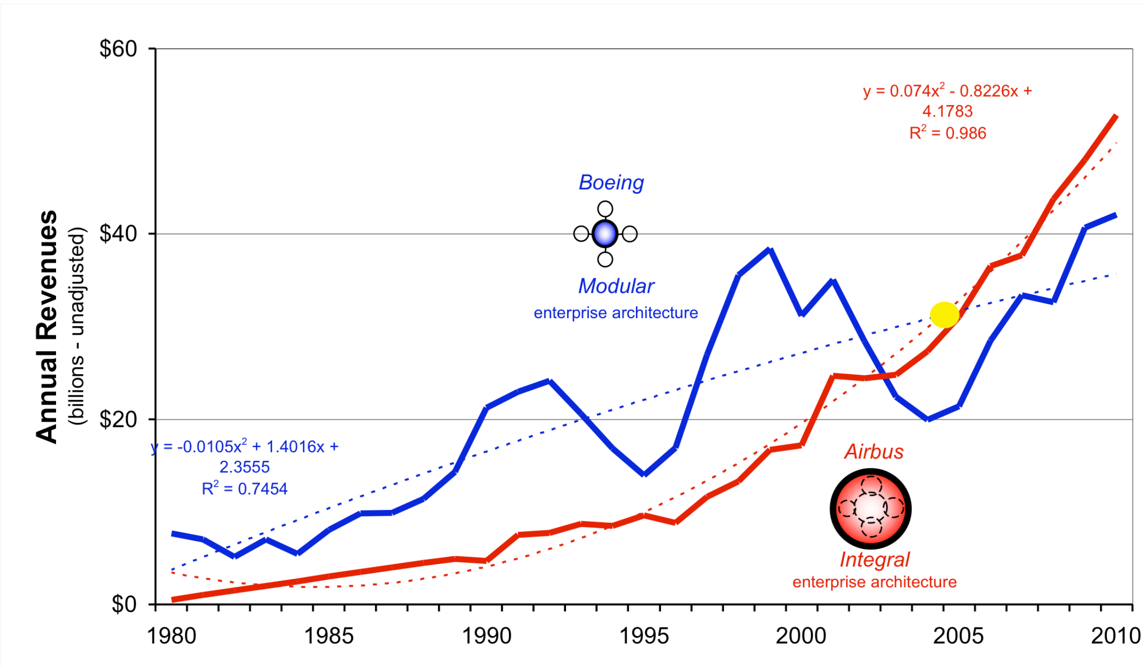
**Proposition 2a: *Quantity* of Firm Performance (Revenues).** Enterprise architectures, by enabling and constraining choice in key competitive variables, ultimately lead to firm performance. The following two propositions serve to define the relationship between enterprise architectures and key performance variables of growth in revenues, profits and shareholder value.

The first proposition relates enterprise function to firm performance expressed as long-term *quantity* growth or *revenues.*

> *Proposition 2a: When competing modular and integral enterprise architectures are observed empirically, the focal firm of the modular enterprise architecture will tend to have lower long-term rates of revenue growth, relative to the focal firm of the integral enterprise architecture.*

**Empirical data.** Proposition 2a describes the rates of growth of revenues in enterprise architectures within an ecosystem. One would expect *Boeing's* more modular enterprise architecture to grow at higher short-term rates, while lower long-term rates (i.e. with less stability). Conversely, one would expect *Airbus'* more integral enterprise architecture to grow at lower short-term rates, while higher long-term rates (i.e. with greater stability). Figure 16 summarizes the revenue quantities for the competing focal firms in the primary sample.

Figure 16: *Quantity* (Revenue) Growth in the *Commercial Airplane* Industry




Note that over the long-term since *Airbus's* founding (1974-2006), *Boeing's* revenue CAGR (unadjusted for inflation) was only 7.3%, while for *Airbus* it was more than double at 18.6%. While *Boeing* grows its revenues more quickly than *Airbus* during an upturn, it shrinks its revenues much more rapidly than *Airbus* during a downturn, with the net result being that the long-term revenue growth rates of *Airbus* are significantly higher than *Boeing*. The question of whether *Airbus'* higher long-term revenue growth is associated with higher profitability will be considered next.

As illustrated in Figure 17 and Figure 18 below, similar trajectories can be seen in both the automotive and airline industries respectively. Quantitatively, over the long-term (1980-2010), *Toyota's* revenue CAGR is 10%, which is approximately two times *GM's* revenue CAGR of only 4%. Similarly, *Southwest Airlines'* revenue CAGR is 14%, which is nearly three times *United Airlines'* revenue CAGR of only 5%.

Figure 17: *Quantity* (Revenue) Growth in the *Automotive* Industry

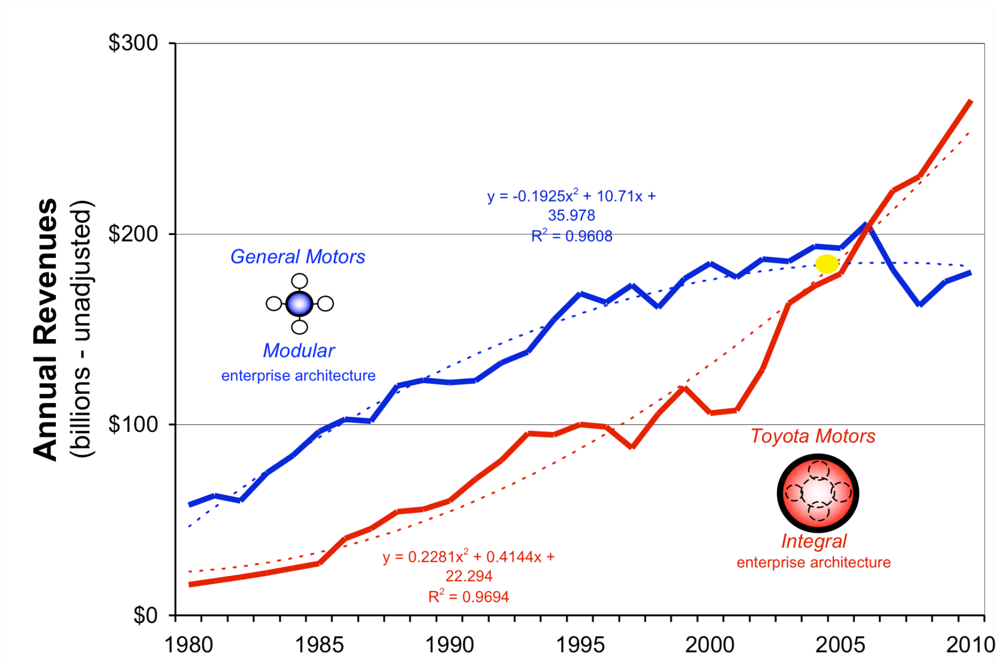
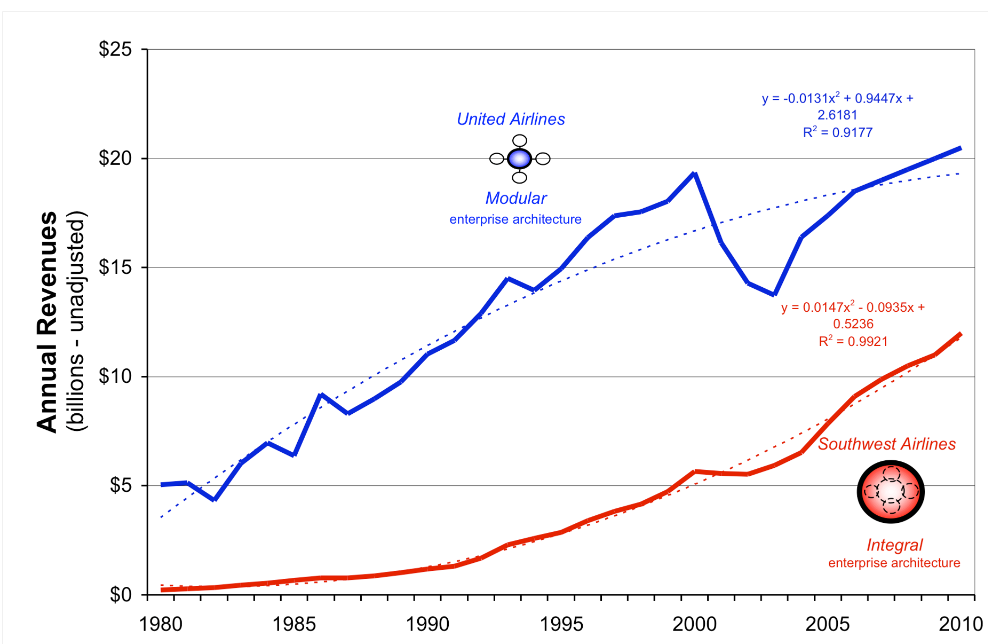



Figure 18: *Quantity* (Revenue) Growth in the *US Airline* Industry

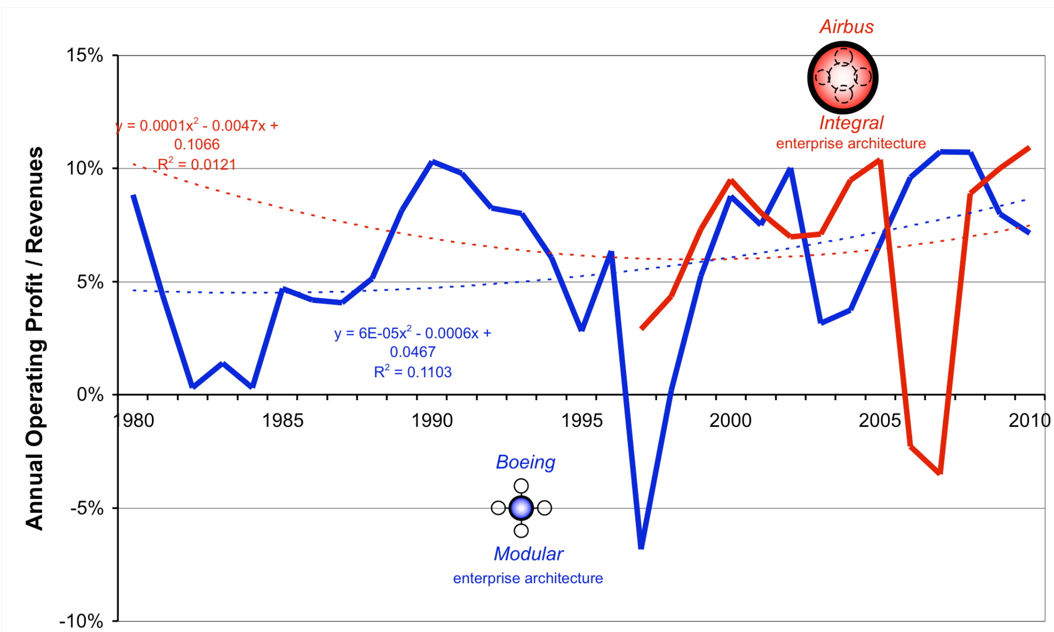


**Proposition 2b: *Quality* of Firm Performance (Profitability).** The second proposition relates enterprise function to firm performance expressed as long-term *quality* growth or *profits.*

> *Proposition 2b: When competing modular and integral enterprise architectures are observed empirically, the focal firm of the modular enterprise architecture will tend to have lower long-term rates of profit growth, relative to the focal firm of the integral enterprise architecture.*

**Empirical Data.** While the firm may be growing in terms of quantity of revenues, this does not speak about the quality of growth or the efficiency of converting such growth into residual cash flows or profits. Proposition 2b describes the rates of growth of profitability in enterprise architectures within an ecosystem. One would expect *Boeing's* more modular enterprise architecture to grow at higher short-term rates, while lower long-term rates (i.e. with less stability). Conversely, one would expect *Airbus'* more integral enterprise architecture to grow at lower short-term rates, while higher long-term rates (i.e. with greater stability). Figure 19 summarizes the profitability quantities for the competing focal firms in the primary sample, over periods for which data is publicly available.

Figure 19: *Quality* (Profitability) Growth in the *Commercial Airplane* Industry




*Qualitatively,* while *Boeing* grows its profitability more quickly than *Airbus* during an upturn, it shrinks its profitability much more rapidly than *Airbus* during a downturn, with the net result being that the long-term profitability growth rates of *Airbus* are significantly higher than *Boeing.* There is some evidence to support the proposition that high long-term revenue growth rates can be coupled with high long-term profitability rates by integral enterprise architectures.

*Quantitatively*, as both data sets show large variation, resulting in low $R^2$ values, only the most basic descriptive statistic is reliable. Over the period for which comparative data exists (1997-2008), both *Boeing* and *Airbus* have averaged 6% annual operating profits. This amount is in line with *Boeing's* longer term (1980-2008) average of 6%.

As illustrated in Figure 20 and Figure 21 below, similar trajectories can be seen in both the automotive and airline industries respectively. Quantitatively, over the long-term (1980-2010), *Toyota's* average profitability is 5% and increasing, while *GM's* average profitability is only -1% and decreasing. Similarly, *Southwest Airlines'* average profitability is 7% and stabilizing, while *United Airlines'* average profitability is only -1% and decreasing.

Figure 20: *Quality* (Profitability) Growth in the *Automotive* Industry

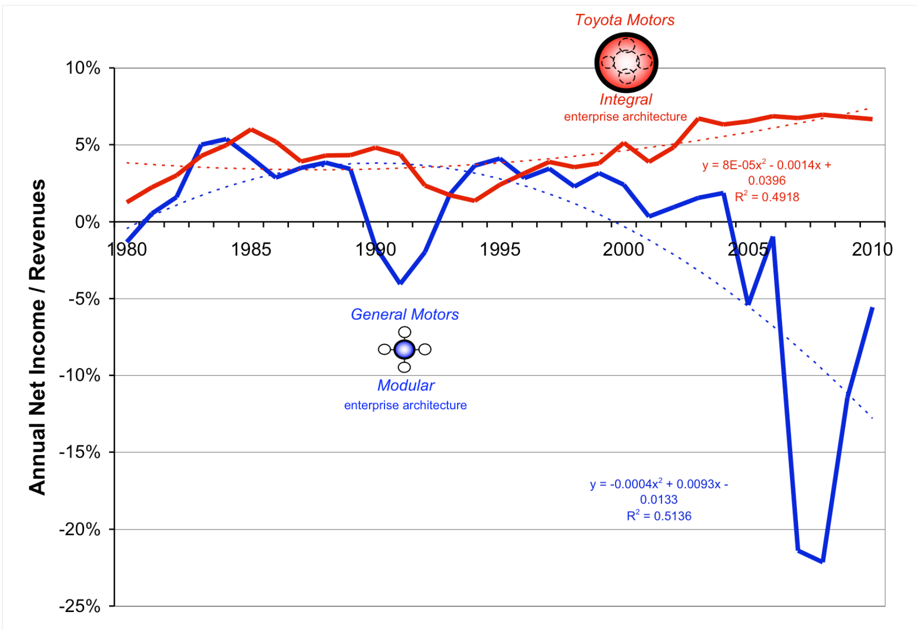
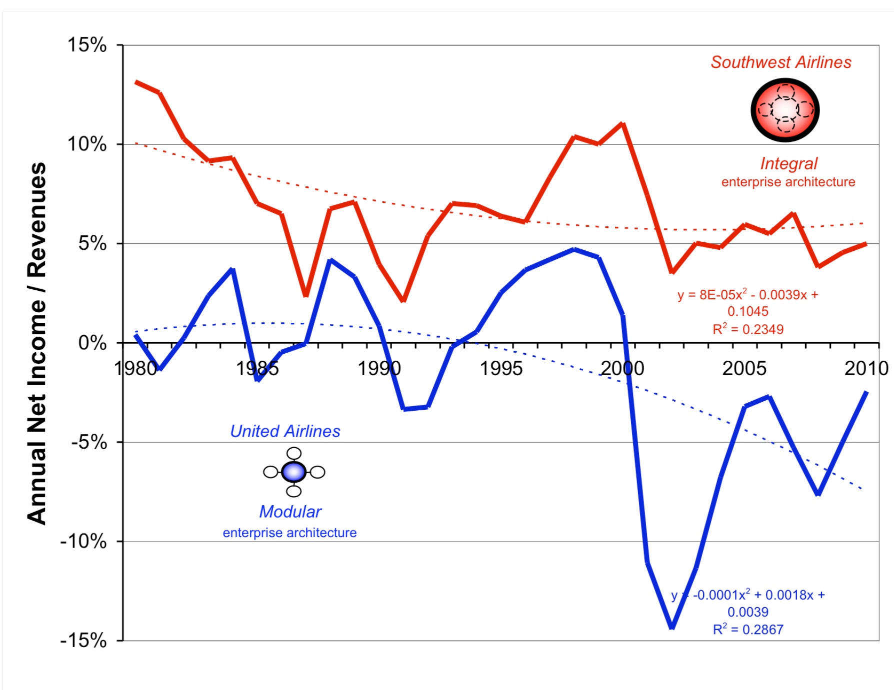



Figure 21: Quality (Profitability) Growth in the *US Airline* Industry



## 3. Competitive *Retention*: Performance-Environment Relationship

### Construct Definitions & Measures

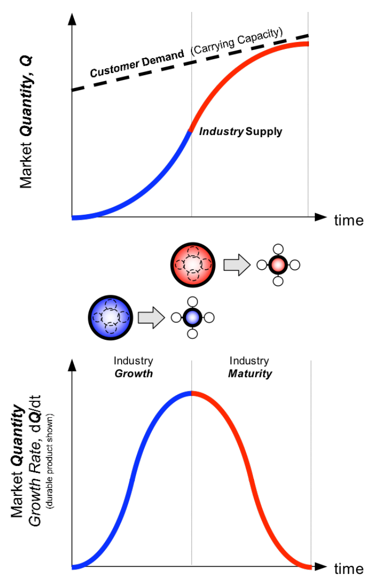
Both strategy (Porter, 1980, pg. 164) and organization (Lawrence and Lorsch, 1967, pg. 19) researchers have long recognized the importance rates of environmental change on competition and organizational forms. As far back as 1838, Cournot postulated a profit-maximizing firm which was subject to the constraints of *demand* and *technology*. This framework similarly distinguishes between two types of industrial evolution: *quantity* and *quality*, each possessing its own growth trajectories, which can be expressed stylistically as life cycle or S-curves. Just as the Architecture-Function relationship distinguished between quantity and quality at the firm level, the same distinction is made at the ecosystem level.

**Proposition 3a: *Quantity* of Environmental Growth.** The first proposition relates firm performance to environmental maturity in *quantity* terms, as summarized in Figure 22 below.[26]

*Quantity* space refers to the *amount* of products and services supplied and demanded in an ecosystem, which is influenced by such variables as population size, GDP growth, etc. This characterization of the environment is well-known in marketing research and has been modeled using Bass diffusion processes (Bass, 1969).

> *Proposition 3a: When considering the industry's rates of growth in customer demand, emerging industries, i.e. those that exhibit slow but increasing rates of quantity growth tend to be built by / reward integral enterprise architectures, which specialize in slow (equilibrium) behavior. Transitioning industries, i.e. those that exhibit high rates of quantity growth tend to be built by / reward modular enterprise architectures, which specialize in fast (opportunistic) behavior. Maturing industries, i.e. those that exhibit fast but decreasing rates of quantity growth tend to be built by / reward integral enterprise architectures, which specialize in slow (equilibrium) behavior.*

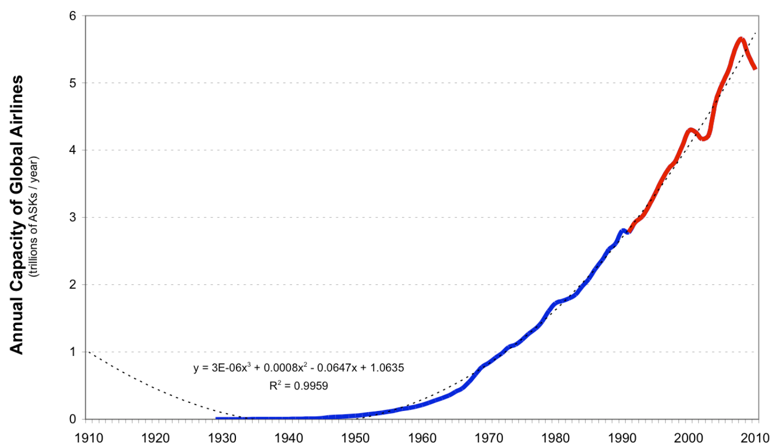
Figure 22: Co-Evolution of Firm Performance and Environment (*Quantity*)




[26] This "quantity" formulation captures organizational ecologists' construct of "*mass* dependence" (Barron, 1999).

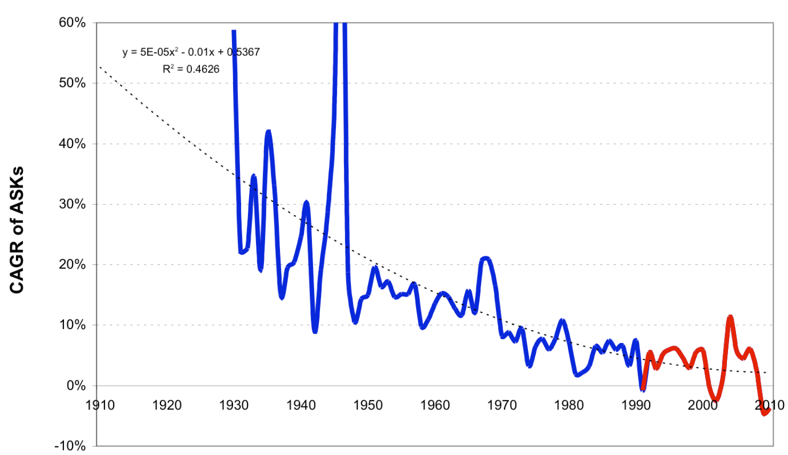
**Empirical data.** The carrying capacity of the ecosystem in *quantity* space can be defined by the underlying availability of critical environmental resources from any of the stakeholders in the organizational set. The data presented below[27] takes customer demand as the key ecosystem variable, which for the primary sample is the underlying market growth in the global airline industry. As can be seen in Figure 23 below, the exponential growth trajectory appears to be following the logistic S-curve.

Figure 23: *Market* Carrying Capacity of the *Global Airline* Industry




The critical question rate of change of this growth will reveal whether or not the market is beginning to saturate, creating the environmental conditions for re-integration of the dominant enterprise architecture. In order to determine if this ecosystem growth is speeding up or slowing down, Figure 24 below shows the compound annual growth rate (CAGR). While the industry is growing, the annual rate of change of this growth has been diminishing over time - signaling a "maturing" market – and is asymptotically approaching the CAGR of global GDP.

Figure 24: CAGR of *Market* Carrying Capacity of the *Global Airline* Industry




[27] Data source: Air Transport Association (ATA). Excludes data from the USSR prior to 1970.

As illustrated in Figure 25 and Figure 26 below, similar trajectories can be seen in both the global automotive[28] and US airline[29] industries respectively.

Figure 25: *Market* Carrying Capacity of the *Global Automotive* Industry

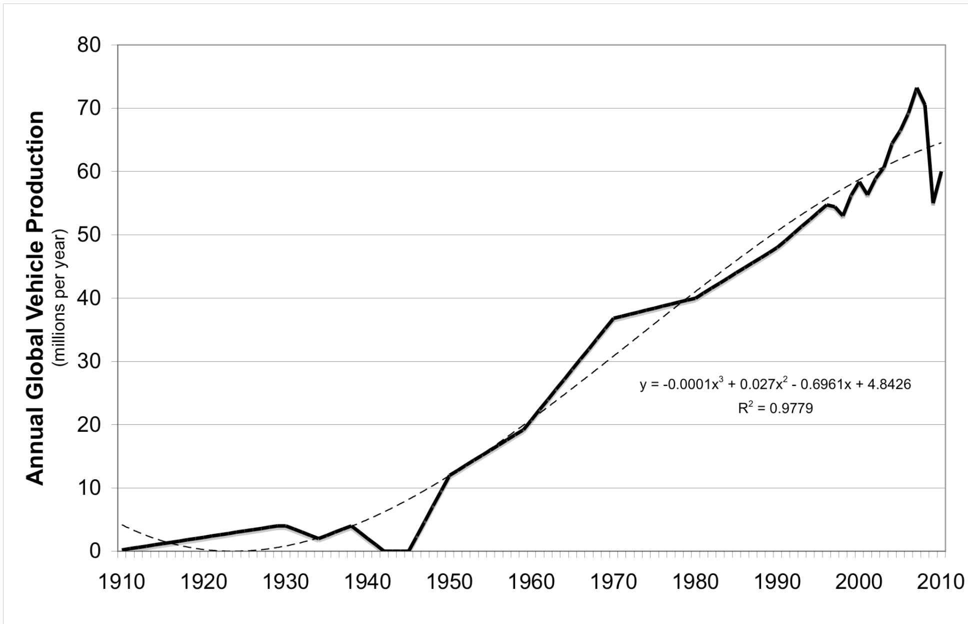
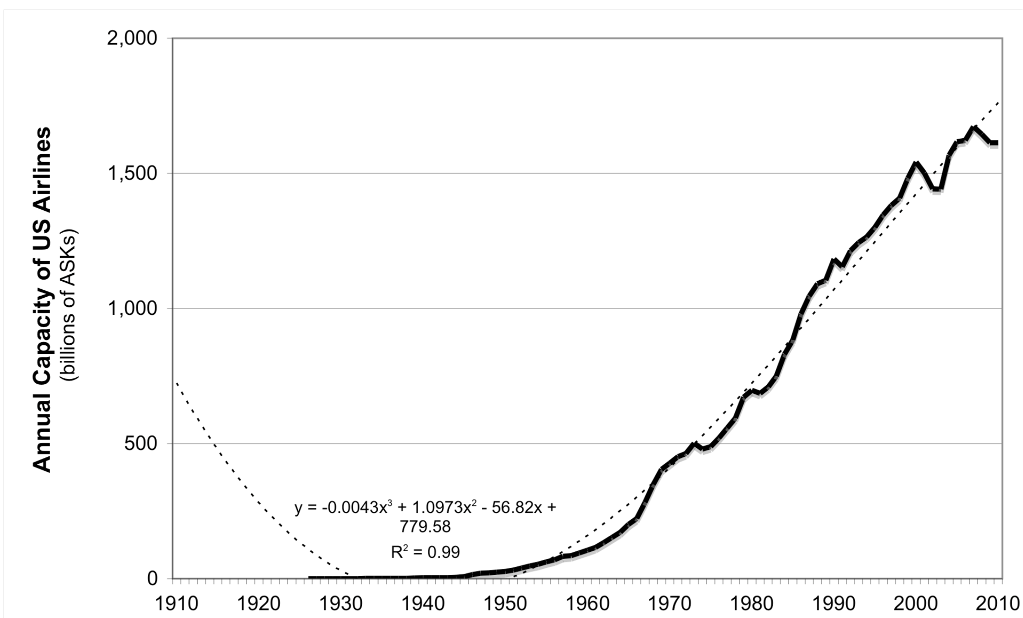



Figure 26: *Market* Carrying Capacity of the *U.S. Airline* Industry




[28] Automotive data source:s Organisation Internationale des Constructeurs d'Automobiles (www.oica.net) and Hirooka (2006), pg. 73.

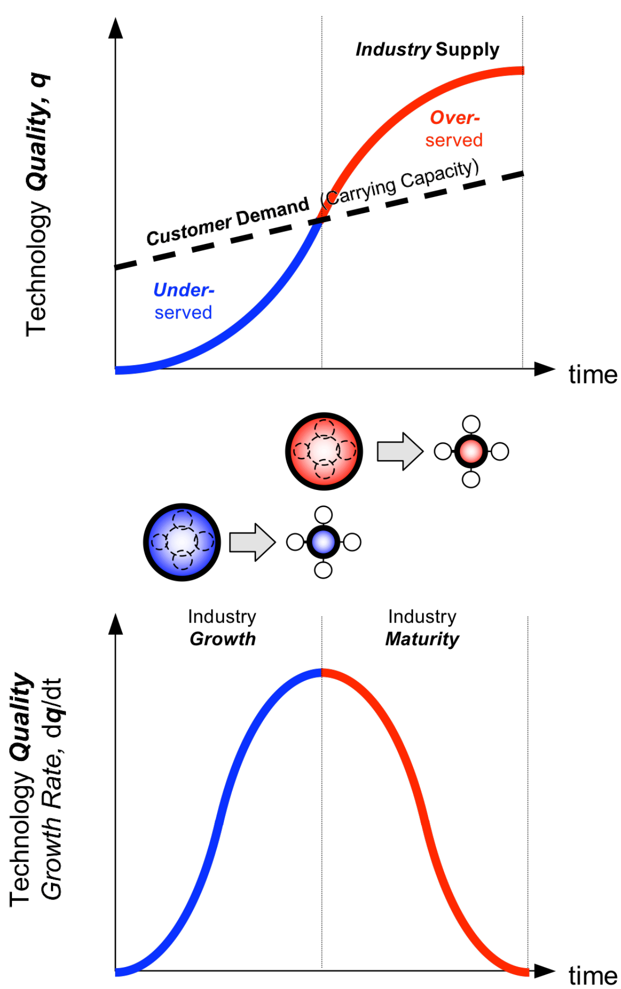
[29] Note, the data come from the Air Transport Association (ATA), and includes all US airlines passenger and cargo traffic for both domestic and international operations.

**Proposition 3b: *Quality* of Environmental Growth.** The second proposition relates firm performance to environmental maturity in *quality* terms and is summarized in Figure 27 below.

*Quality* space refers to the *type* of products and services supplied and demanded in an ecosystem, which is influenced by such variables as technological innovation, etc. This characterization of the environment is well-known in technology and innovation research (Christensen and Bower, 1996).

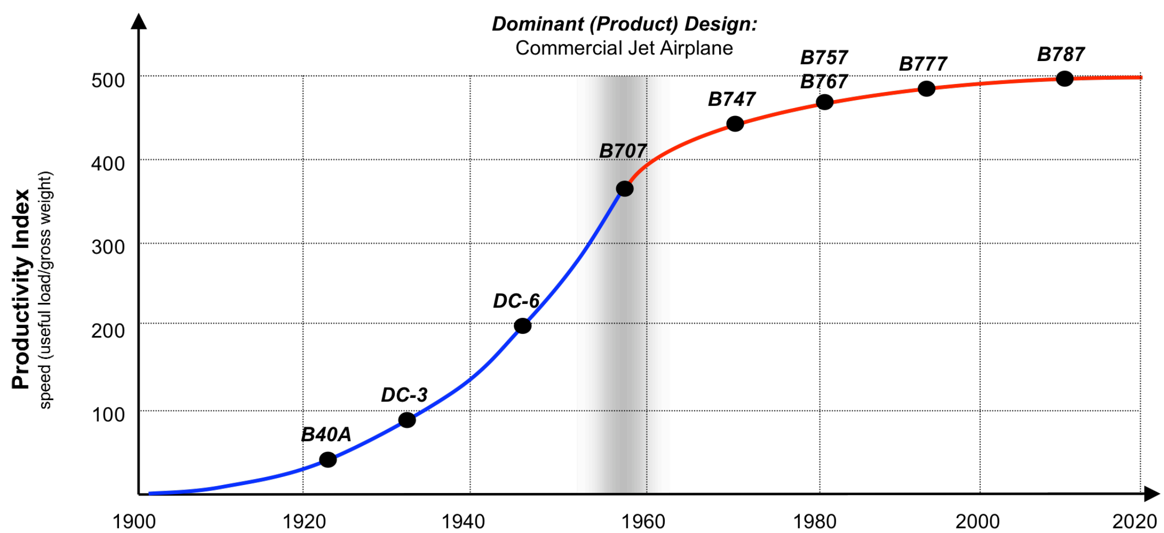
> *Proposition 3b: When considering the industry's rates of growth in technological innovation, emerging industries, i.e. those that exhibit slow but increasing rates of quality growth (i.e. under-served markets) tend to be built by and reward integral enterprise architectures, which specialize in radical product innovation (i.e. exploration). Transitioning industries, i.e. those that exhibit high rates of quality growth tend to be built by and reward modular enterprise architectures, which specialize in incremental product and process innovation (i.e. exploitation). Maturing industries, i.e. those that exhibit fast but decreasing rates of quality growth (i.e. over-served markets) tend to be built by and reward integral enterprise architectures, which specialize in radical process innovation (i.e. exploration).*

Figure 27: Co-Evolution of Firm Performance and Environment (*Quality*)



**Empirical Data.** The carrying capacity of the ecosystem in *quality* space can be defined by the underlying availability of critical environmental resources from any of the stakeholders in the organizational set. The data presented below takes supplier capability as the key ecosystem variable, which for the primary sample is the underlying growth in technological carrying capacity of the global airline industry as measured by an industry standard of airplane productivity (McMasters and Cummings, 2002). As can be seen in Figure 28 below, the growth trajectory appears to have followed the logistic S-curve, with the inflection point having occurred in the late 1950's with the emergence of the dominant product design of jet aircraft. Prior to this, competition existed in improving product performance, where rates of change in performance were increasing. After the emergence of the dominant design, when the rates of change of change in product performance began to diminish, competition is hypothesized to move toward other dimensions of cost, quality and delivery. The current state of technological carrying capacity is saturating around the asymptotic physical limits of speed, range, etc.[30]

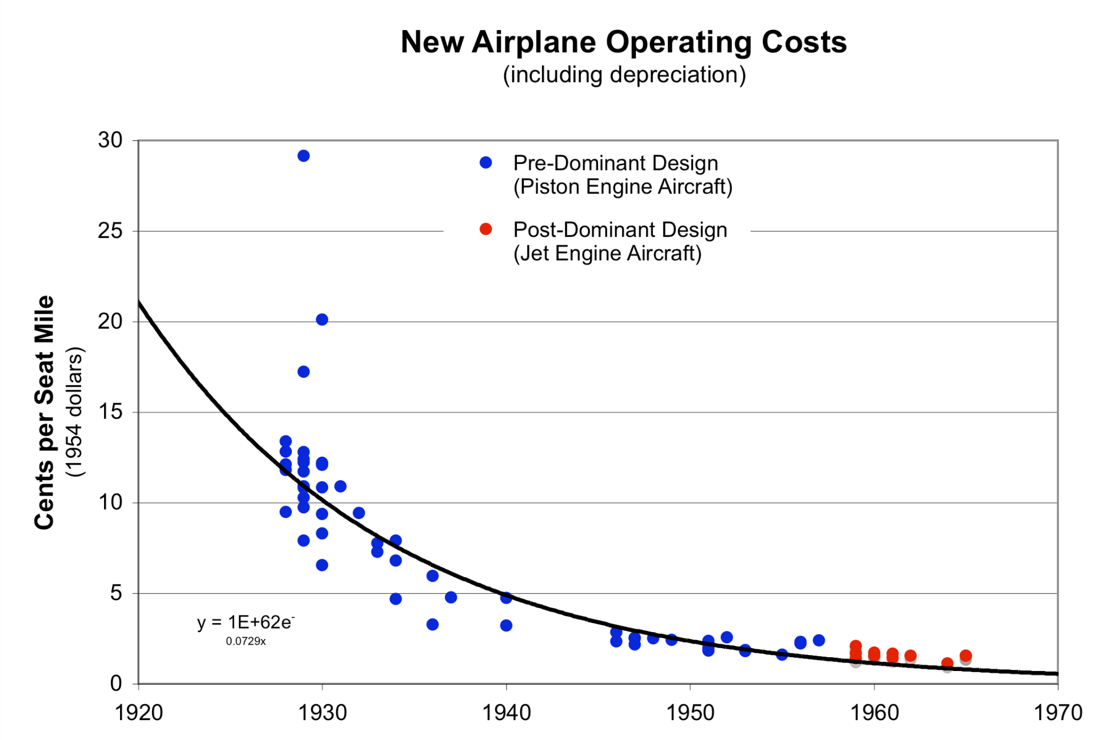
Figure 28: *Technological* Carrying Capacity of the *Global Airplane* Industry




In addition to saturation of product performance, the long-term trends in product operating costs have dropped asymptotically toward zero (Philips, 1971), as shown in Figure 29 below.

[30] Since the inception of the jet age, maximum speed (in economical mass transport) has been constrained to remain just below the drag divergence Mach number to avoid excessive fuel consumption. In addition, maximum range is confined to approximately half the earth's circumference.

Figure 29: *Technological* Limits of the *Global Airplane* Industry



## 4. Environmental *Variation*: Environment-Architecture Relationship

### Construct Definitions & Measures

Enterprise architectures, through their competitive interactions, reflexively shape and are crucially shaped by their environment. It is through this interaction between organization and environment, or more precisely between organizational set and organizational field (Scott, 2003), that both co-evolve.

Organizational ecologists (e.g. Hannan and Freeman, 1977) focus on macro-level constructs of organizational founding (entry) rates, failure (exit) rates, and inertial (change) rates. In particular, they observe that while organizational change does in fact occurs it tends to unfold at rates that are lower than change demanded by the environment. This organizational momentum is captured by the construct of structural inertia, which helps explain failure rates and founding rates.

Structural contingency theorists (e.g. Burns and Stalker, 1961; Lawrence and Lorsch, 1967), have long postulated that the environment is an important factor in defining the organizations within it. In particular, they have pointed to rates of change of key environmental factors like technology and customer demand as driving the optimum structure of organizations operating within these environment. For them, however, the environment is considered as a static exogenous variable moderating organizational structure and successful performance.

Technology and innovation theorists (e.g. Abernathy and Utterback, 1978) and affiliated organizational theorists (e.g. Anderson and Tushman, 1990; Henderson and Clark, 1990) have taken steps to advance structural contingency theory by endogenizing technological evolution and its effect on organizational evolution. These researchers posit the existence of "dominant designs" in products, which fundamentally change the nature of competition from pre-dominant design focus on *product* innovation, to the post-dominant design focus on *process* innovation. Later theorists (Suarez and Utterback, 1995; Klepper, 1996) in this vein have posited ecological firm entry/exit relationships to the evolution of industries.

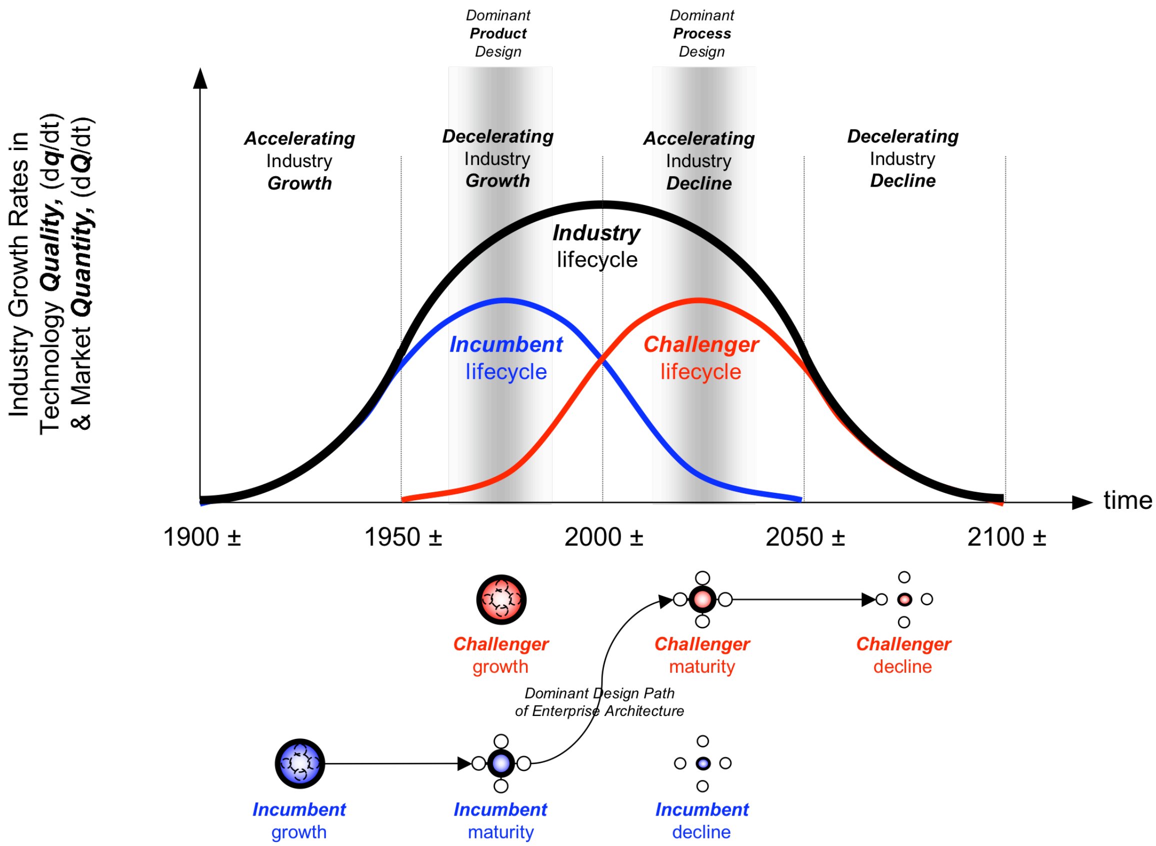
This framework, by co-opting more of the environment (i.e. the organizational set) into the causal explanation of organizational performance can begin to endogenize the dynamics of the evolution of the environment and the enterprises within it. In this sense it is contingency theory at a higher level of analysis than the organization, namely that of the organizational set, or *ecological* contingency theory. In addition, by formalizing "dominant designs" in an architectural framework, one can begin to integrate the organizational and environmental or technological evolution.

**Proposition 4a: *Dominant Designs* in Enterprise Architectures.** The first proposition relates environmental maturity to required levels of integration in enterprise architectures, which is summarized in Figure 30 below.

> *Proposition 4a: Dominant designs in enterprise architectures at the ecosystem level tend to oscillate between integral and modular states throughout the lifecycle of the industry.*

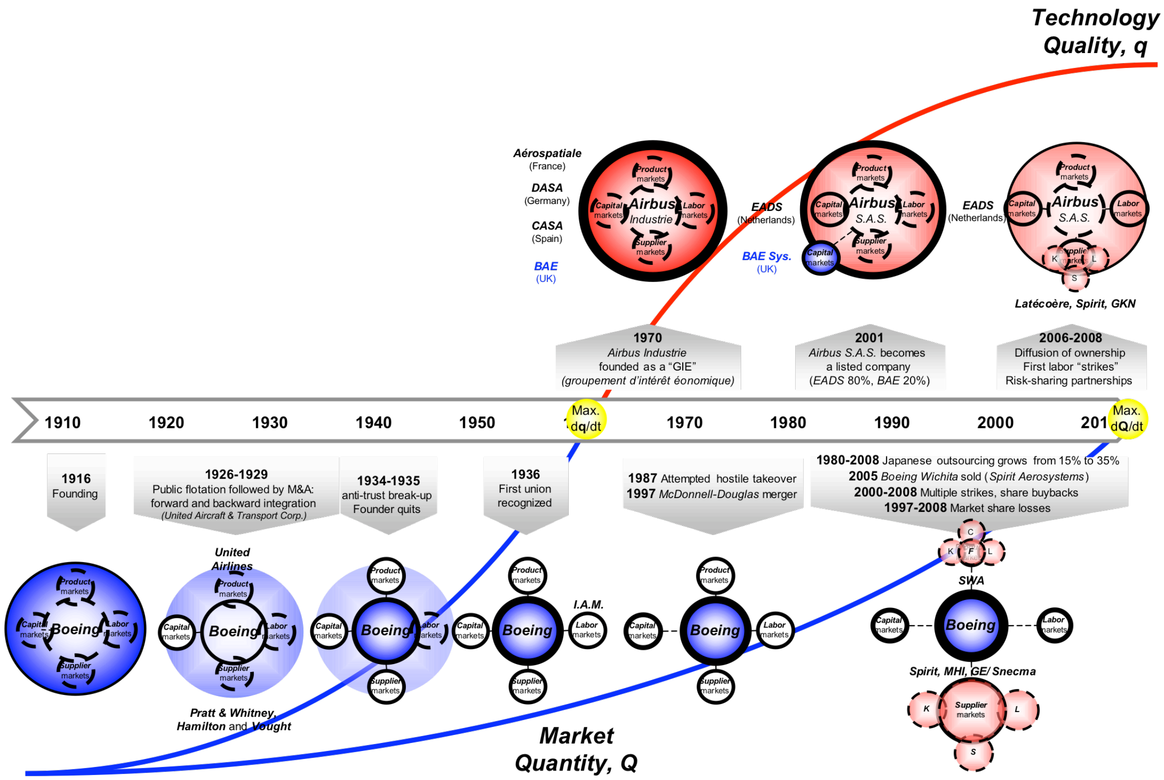
As the environment initially demands radical product innovation and patience, the dominant enterprise architectures tend to be integral. Subsequently, as the environment demands incremental product innovation, coupled with impatience, the dominant enterprise architectures tend to be modular. Then, as the environment demands radical process innovation and patience, the dominant enterprise architectures again tend to be integral. Finally, as the environment demands incremental process innovation, coupled with impatience, the dominant enterprise architectures tend to be integral.

Figure 30: Stylized Co-Evolution of Enterprises and Ecosystem



**Empirical Data.** Having established the birth dates and associated and founding conditions (e.g. population densities) of the two firms in the primary sample, Figure 31 below summarizes the qualitative evolutionary trajectories of the enterprise architectures of these firms.

Figure 31: Evolution of Dominant Designs in Enterprise Architectures: *Airplane* Industry:




The organizational *sets* appear to initially begin with an integral enterprise architectural form and subsequently disintegrate monotonically into a modular form over time. Note that this phenomenon appears to apply to both incumbent and challenger enterprises and be independent of the founding date of the enterprise.

At the ecosystem (or organizational *field)* level however, the dominant design in enterprise architecture appears to oscillate from integral to modular and back to integral forms. While re-integration of the incumbent enterprise architecture in order to achieve fit with the demands of the ecosystem is not theoretically precluded, empirically it is not observed. This suggests that in the theoretical sample analyzed, the incumbents reach a tipping point, whereby their reinforcing behavior tips from virtuous to vicious – that is, it is more efficient for the environment to *select* a new species, than for the existing species to be *retained* via managerial adaptation.

Superimposed on the evolutionary trajectories of the enterprise architectures, is a notional S-curve, representing the industry growth in both quantity and quality. One may begin to posit a relationship between the state of these key environmental variables and the states of the incumbent and challenger enterprise architectures. Empirical data will be offered in the following sections to refine this conceptual relationship.

As illustrated in Figure 32 and Figure 33 below illustrate similar trajectories in both the automotive and airline industries respectively.

Figure 32: Evolution of *Dominant Designs* in Enterprise Architectures: *Automotive* Industry

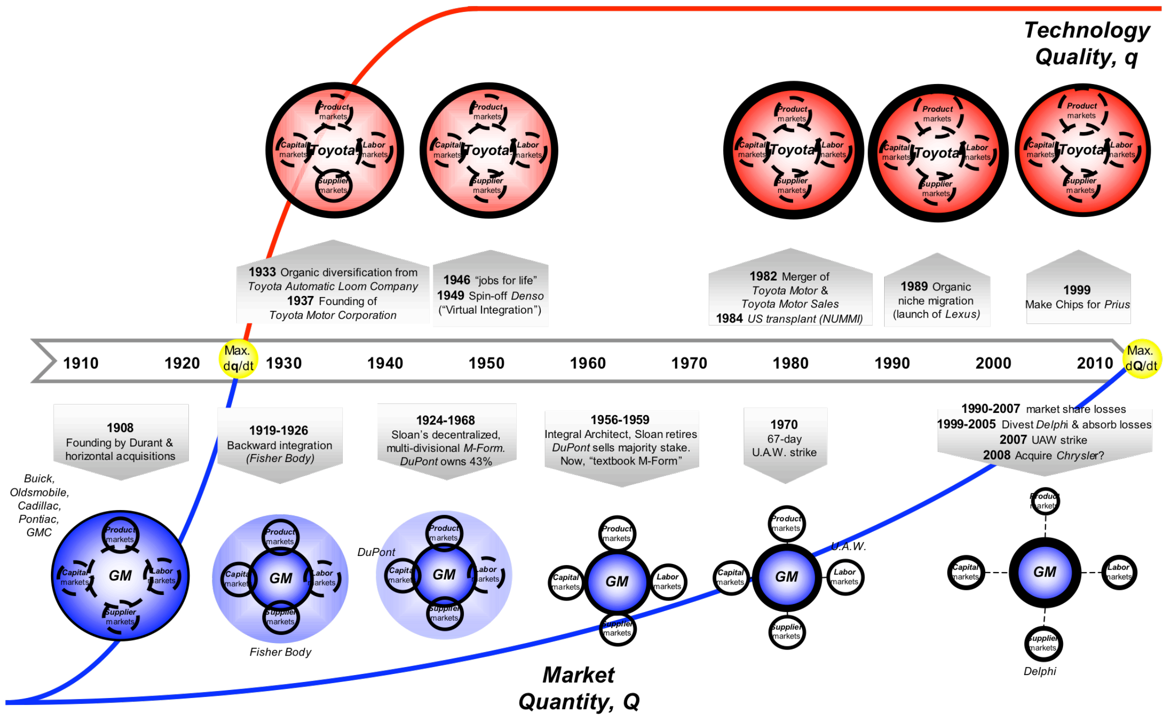
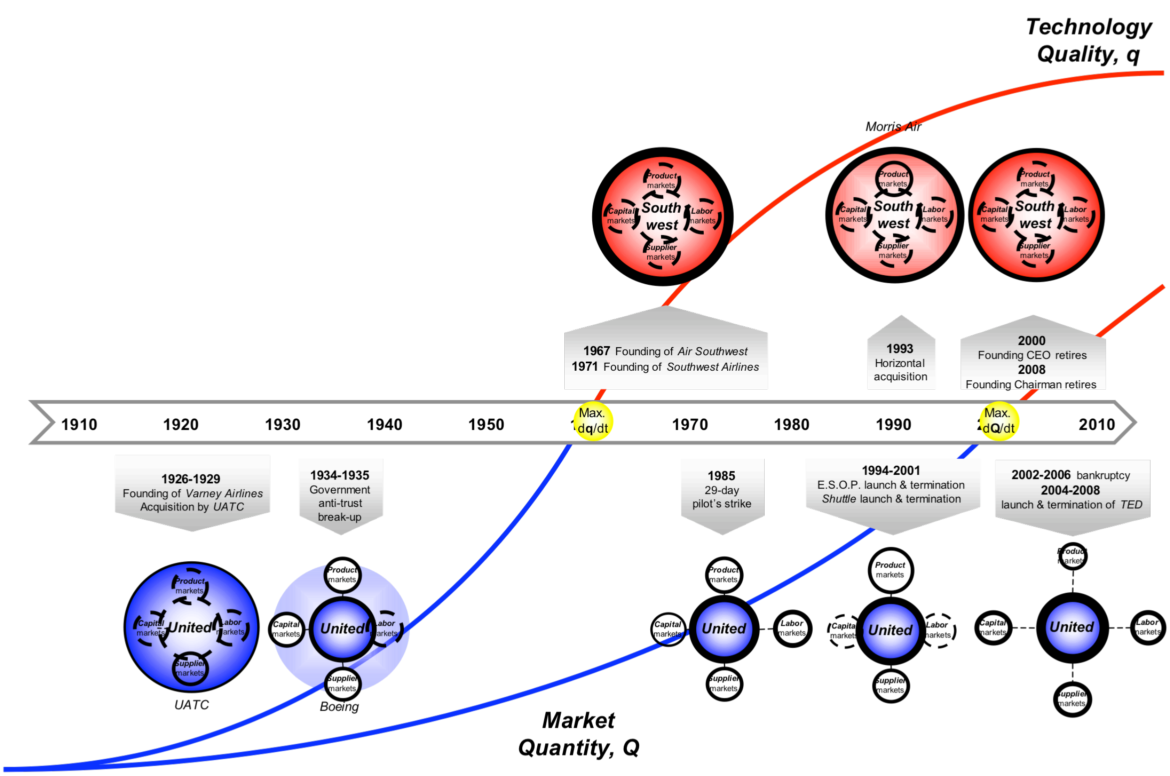



Figure 33: Evolution of *Dominant Designs* in Enterprise Architectures: *US Airline* Industry

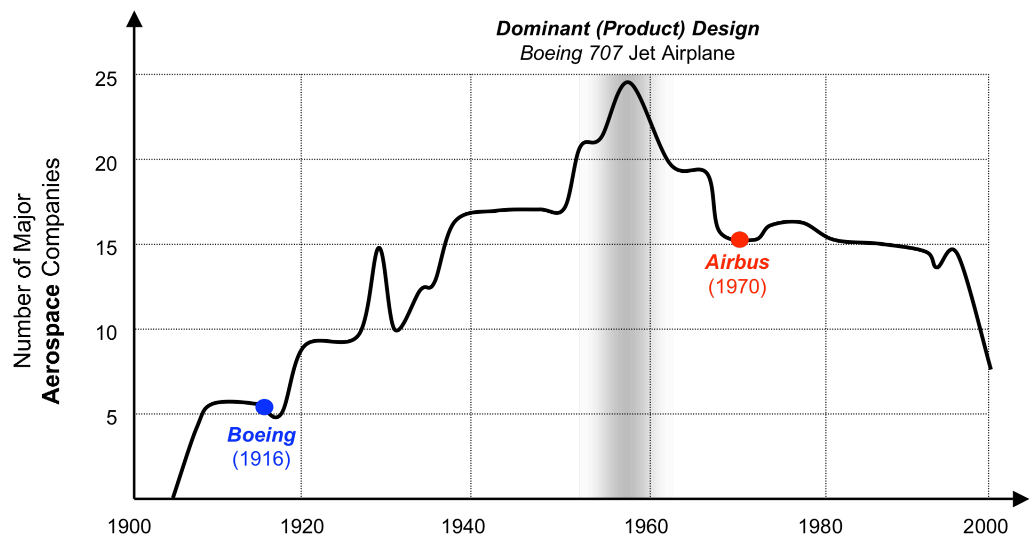


**Proposition 4b: *Entry and Exit* of Enterprise Architectures.** The second proposition relates environmental maturity to entry and exit of dominant enterprise architectures.[31]

> *Proposition 4b: Early entrant (incumbent) enterprise architectures tend toward monotonic disintegration, with increasing levels of architectural inertia inhibiting their reintegration. Thus it is easier for the environment to produce a new species of late entrant (challenger) enterprise architectures.*

**Empirical Data.** Figure 34 below summarizes the birth dates within the population densities for the firms in the primary sample.

Figure 34: *Commercial Airplane* Industry Concentration / Population Density




Soon after the invention of the airplane at the turn of the century, the number of firms in the aerospace industry grew for approximately fifty years during an era of ferment (Abernathy & Utterback, 1978) which was dominated by increasing product innovation resulting in improved product performance characteristics (i.e. "higher, faster, farther"). A "dominant design" in the product occurred in the late 1950's with the emergence of the commercial jet airplane[32], followed by a shake-out and consolidation of the industry, which continued for the next fifty years. Following the merger of *Boeing* with *McDonnell Douglas* in 1997, the large commercial airplane industry effectively became a global duopoly, with *Airbus* being the other producer.[33]

The founding dates of the two firms in the primary sample are also plotted in the figure above. *Boeing*, the incumbent was founded in 1916, well before the dominant product design and *Airbus* the challenger was founded in 1970, well after the dominant product design.

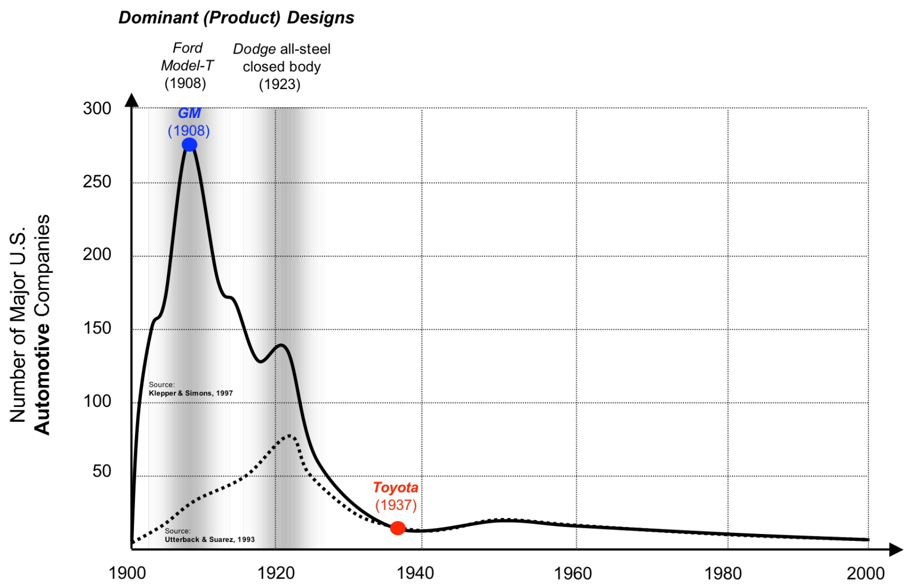
[31] Note: this "quantity" formulation captures the organizational ecologists' construct of "*density* dependence" (Barron, 1999).

[32] The *Boeing* 707 is considered representative of the "dominant design". Note however that other scholars (e.g. Tushman and Murmann, 1998) have cited an earlier "dominant design" in the *Douglas* DC-3 in 1936. See Piepenbrock (2008) for further discussion.

[33] As the market segment, "large commercial airplanes" is broadly defined as airplanes having over 100 seats, smaller airplane manufacturers (e.g. *Embraer*) have recently begun to enter this space.

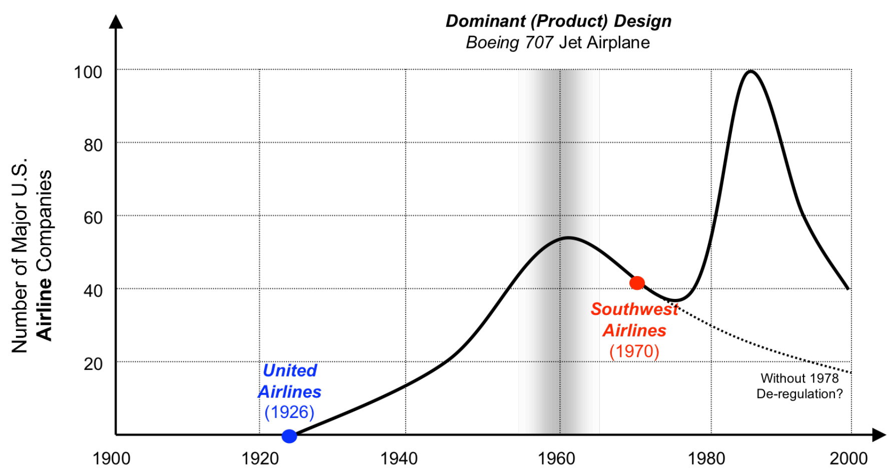
As illustrated in Figure 35 and Figure 36 below, similar phenomena in the trajectories in both the automotive and airline industries respectively are observed.

Figure 35: *Automotive* Industry Population Density, Dominant Design & Founding Dates




In the automotive industry, the dominant design was established in 1908 with *Ford's Model T*.[34] *General Motors*, the incumbent was founded in 1908, when the dominant design arrived and *Toyota* the challenger was founded in 1937, after the establishment of the dominant design.

Figure 36: *US Airline* Industry Population Density, Dominant Design & Founding Dates




In the airline industry, the dominant design was established around 1960 with *Boeing's* 707 jet airplane.[35] *United Airlines*, the incumbent was founded in 1926, well before the dominant design and *Southwest Airlines* the challenger was founded in 1970, after the dominant design.

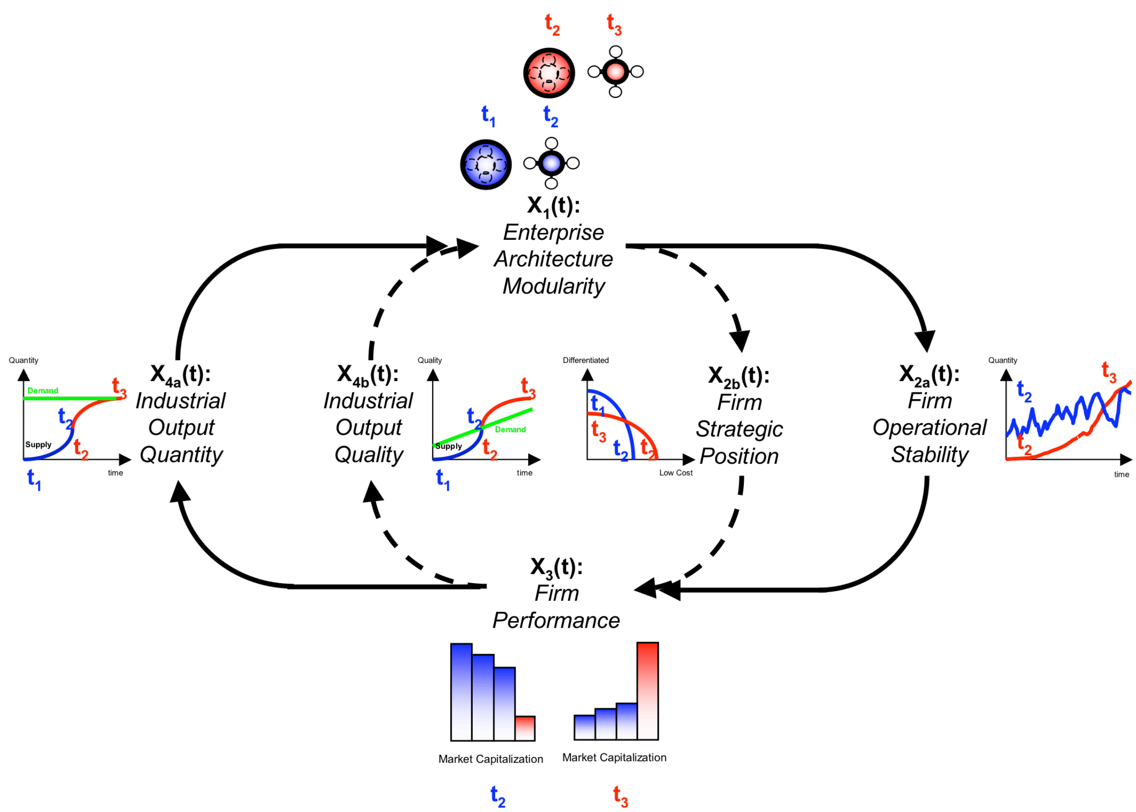
[34] Recent scholars (e.g. Klepper, 1997) argue that the US auto industry shakeout occurred in 1908, coincident with the arrival of the Ford Model-T as a candidate for dominant design. Utterback & Suarez (1993), citing a different data set, demonstrate shakeout in 1923 arguing that *Dodge's* all-steel, closed body automobile is the dominant design. See Piepenbrock (2009) for further discussion.

[35] See Tushman and Anderson (1986) and Kelly and Amburgey (1991).

**Summary of Theoretical Framework**

The theoretical framework, which traces the dynamic evolution of a generic business ecosystem is summarized in Figure 37 below.[36] Two main causal loops describe the co-evolution of the ecosystem and its constituent enterprises in terms of both product quantity (solid outer loop) and quality (dashed inner loop) that is demanded and supplied. Beginning with the industrial output variables $X_{4a}(t)$ and $X_{4b}(t)$ shown on the left of the figure, we will trace out two clockwise revolutions of the causal loop diagram to describe how the ecosystem grows and eventually matures[37], and how concurrently incumbent firms' enterprises build the industry and are ultimately overtaken by late-entrant challenger firms' enterprises.

Figure 37: *Simplified* Summary of Theoretical Framework




**Industry *Growth* Phase.** At time $t_1$, when an industry is born, a significant gap exists between the quantity and quality of a new product's supply and demand potential (shown in green). Firms that can bring higher performing products to market will gain early competitive advantage. In this phase of product innovation, integration is required in the product, firm and enterprise architectures. Such integral enterprise architectures have relatively low rates of growth due to their relatively "patient" capital, labor, customers and suppliers. Spatio-temporal boundaries begin as relatively broad, with the firm's relationship with its stakeholders being long-term, using trust-based relational contracts, and the resulting enterprise value being divided in a positive-sum cooperative game among stakeholders.

[36] A more detailed summary of the theoretical framework including the major balancing loops is discussed in Piepenbrock (2009).

[37] This framework traces the evolution of the business ecosystem from growth to maturity phases. For simplicity, it does not play out the evolution beyond maturity into the decline phase.

As the industry approaches time $t_2$, the gap between the quantity and quality of a new product's supply and demand potential diminishes at a faster rate as the rates of change of industry growth are rising. In order to meet the demands of the rapidly growing mass market, firms that can rapidly build capacity reap economies of scale. High rates of radical product innovation diminish, and are replaced by efficiencies of functional specialization. In this phase, disintegration (or modularization) of product, firm and enterprise architectures provide competitive advantage. Such modular enterprise architectures have relatively high rates of growth due to their relatively "impatient" capital, labor, customers, and suppliers. Spatio-temporal boundaries of the enterprise diminish, with the firm's relationship with its stakeholders becoming short-term, using arm's length contracts, and the resulting enterprise value being divided in a zero-sum competitive game among stakeholders.

**Industry *Maturity* Phase.** At time $t_2$, the industrial output S-curves are near their inflection points. After the industry reaches time $t_2$, the gap between the quantity and quality of a new product's supply and demand potential begins to diminish at a slower rate as the rates of change of industry growth begin to slow down. New customers are being added at slowing rates, and the appetite for higher performance products is now being dominated by a demand for cheaper products. At this inflection point in the industry's quantity and quality S-curves, two scenarios now occur.

Incumbent firms continue to over-serve the market by chasing smaller and smaller market segments consisting of higher and higher profit-margin customers (Christensen, 1997). Under new cost pressures, they continue to outsource, compete suppliers and unions harder and continue to attract more and more impatient capital. Although the industry is slowing down, the incumbent enterprise architectures continue to speed up, with their stocks of structural inertia and their impatient capital growing.

Challenger firms, having a different enterprise architecture can enter and take advantage of the industry's changing characteristics. Now, the rates of technological innovation begin to slow down, as the dominant product design has been established by the dominant enterprise architecture, which is now in a modular form. This slowing down of the industry, both in quantity and quality terms, provides the conditions for a new firm with a different enterprise architecture to enter and to bring supply and demand back in balance both in quantity terms (i.e. slower) and quality terms (i.e. *process* innovation for higher quality, lower cost, faster delivery). As in the birth of the industry, innovation requires integration of product, firm and enterprise architectures. Such integral enterprise architectures have relatively low rates of growth due to their relatively "patient" capital, labor, customers, and suppliers. Spatio-temporal boundaries of the enterprise increase, with the firm's relationship with its stakeholders becoming long-term, using trust-based contracts, and the resulting enterprise value being divided in a positive-sum cooperative game among stakeholders.

The competition to establish the dominant product architecture by the now-modular incumbent enterprise architectures has sown the seeds of their own destruction. The emergence of a dominant design in product architecture has established the conditions for the emergence of a new dominant design in enterprise architecture. The dominant enterprise architecture oscillated throughout the industry's lifecycle from integral to modular to integral.

## MATHEMATICAL MODEL and NUMERICAL SIMULATION

**Generic Equations of Motion.** The evolution of business ecosystems will be expressed formally by a system of simultaneous differential equations,[38] where the state variables, $X_n$ are stocks which accumulate net flows ($dX_n/dt$) over time.

$$
\begin{aligned}
dX_1/dt &= f_1(X_1, X_2, \ldots, X_n) \\
dX_2/dt &= f_2(X_1, X_2, \ldots, X_n) \\
&\;\;\vdots \\
dX_n/dt &= f_n(X_1, X_2, \ldots, X_n)
\end{aligned}
$$

Note that such equations form a feedback system that generates system dynamics endogenously, via information from the various state variables, which feed back to influence their own rates of change.

**Model Build-Up.** In the following subsections, the model will be constructed progressively, each time adding a higher level of sophistication in order to more clearly understand the underlying assumptions, parameters, structure and behavior of the model at each stage of complexity. The following stages will be discussed sequentially:

- Single Firm Growth in an *Infinite* Market
- Single Firm Growth in a *Constant* Market
- *Intra*-species Competition in a Constant Market[39]

- *Diffusing* Market (Quantity)
- *Intra*-species Competition in a Diffusing Market
- *Inter*-species Competition in a Diffusing Market

- *Commoditizing* Market (Quality)
- *Intra*-species Competition in a Commoditizing Market
- *Inter*-species "Competition" in a Commoditizing Market

- *Diffusing, Commoditizing* Market (Quantity and Quality)
- *Intra*-species Competition in a Diffusing, Commoditizing Market
- *Inter*-species Competition in a Diffusing, Commoditizing Market

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[38] In the traditions of the general system theory (e.g. Von Bertalanffy, 1950), cybernetics (e.g. Ashby, 1952), system dynamics (e.g. Forrester, 1961); as well as organizational ecology (e.g. Hannan and Freeman, 1977).

[39] We will not cover the case of *inter*-species competition in an unchanging environment here, because theoretically, significant sustained environmental variation is required in order to produce and sustain significant variation in organizational species. Inter-species competition in a constant market would be a special parametric study when exploring inter-species competition in a logistic growth market, in which the market diffusion rate is much greater than the competitor growth rates.

**Single Firm Growth in an Infinite Market.** First, we assume a monopolist operating under increasing returns to scale. This assumption captures a variety of business phenomena including economies of scale, learning curve effects, etc. Under this reinforcing feedback, the more market the firm accumulates, the faster it continues to be accumulated.

Second, we assume initially that the firm exists in a market of unlimited growth potential – unlimited carrying capacity. The firm then is able to grow at its maximum fractional rate, r which is assumed to be constant and is determined by a number of goals and constraints which might include the rate of return on residual cash flows promised to risk bearers.[40]

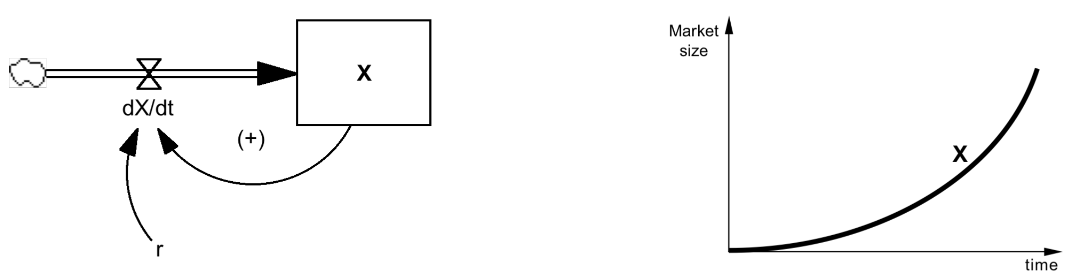
Most models in organizational ecology focus on population size or density - expressed as number of organizations - as the primary state variable, which accumulates net flows of organizational entries and exits (e.g. Hannan and Freeman, 1977). Population size is of lower importance in these formulations. This paper however focuses instead on organizational size as approximated by the amount of environmental resources an organization accumulates, or more specifically in the case of business ecosystems, the amount of a market a firm possesses. In this way, a population could consist of a spectrum of organizations ranging from a large number of equally sized firms, each possessing the same percentage of the total market; to a single firm operating as a monopolist possessing the entire market. We will derive equations of motion for a firm accumulating sales, X over time.[41]

The following differential equation captures this simple reinforcing feedback:

$$dX/dt = rX \qquad (1)$$

Figure 38 below illustrates the causal structure[42] and resulting behavior of this *linear* first-order formulation, which results in unrestrained exponential growth of the firm's market acquisition.

Figure 38: Structure and Behavior of Single Firm Growth in an *Infinite* Market




This equation also describes the early growth of a firm in a finite market, when its accumulated quantity of market, X is far from the carrying capacity of the market. This will be covered in the subsequent section.

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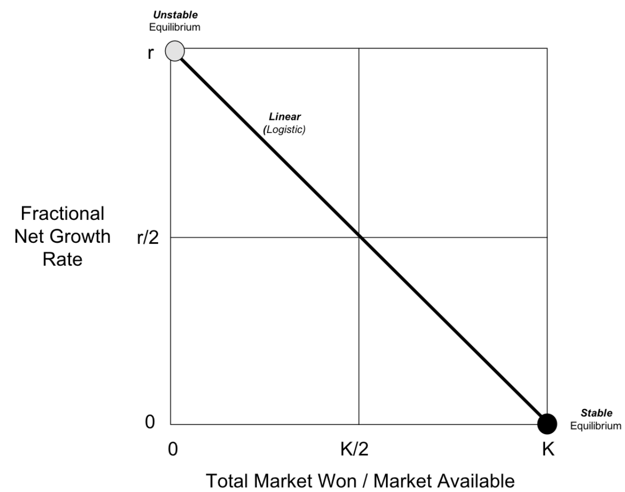
[40] This is actually the fractional net growth rate, and has the units of percent of market growth per unit of time.

[41] For the present discussion, we assume that the firm converts demand into supply instantaneously or without any delays associated with order backlogs, inventory backlogs etc. Such delays in a balancing loop can account for cyclical oscillatory behavior. As the time horizon of interest in this evolutionary research is measured in centuries, the oscillations which manifest themselves over timeframes of decades are of secondary importance.

[42] In the diagrammatic representations of the differential equations, the variables within "boxes" represent stocks or accumulations, while the variables below the "valves" represent rates or flows in and out of the stocks.

**Single Firm Growth in a *Constant* Market.** As no firm exists in an infinitely rich resource environment, we next constrain the model by imposing finite but constant market carrying capacity, K, which might represent the size of population of potential customers or sales. The assumption here is that, as the firm acquires more of the finite market, K, the rate of firm growth, r begins to reduce linearly[43], making the organization's rate of growth dependent upon the proportion of the carrying capacity that remains unexploited[44], as shown in Figure 39.

Figure 39: Fractional Net Growth Rate Assumption

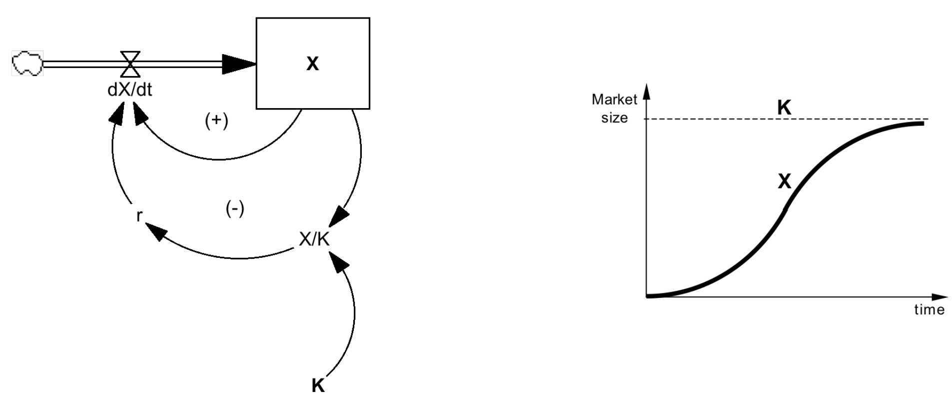



We therefore extend the previous differential equation (1) to capture the mode-switching from reinforcing to balancing feedback as the firm approaches the carrying capacity of the market. This new logistic equation is shown below:[45]

$$dX/dt = rX - rX^2/K \tag{2}$$

Figure 40 below illustrates the causal structure and resulting behavior of this *nonlinear* first-order formulation, which results in sigmoid or S-shaped growth of the firm's market capture.

Figure 40: Structure and Behavior of Single Firm Growth in a *Constant* Market



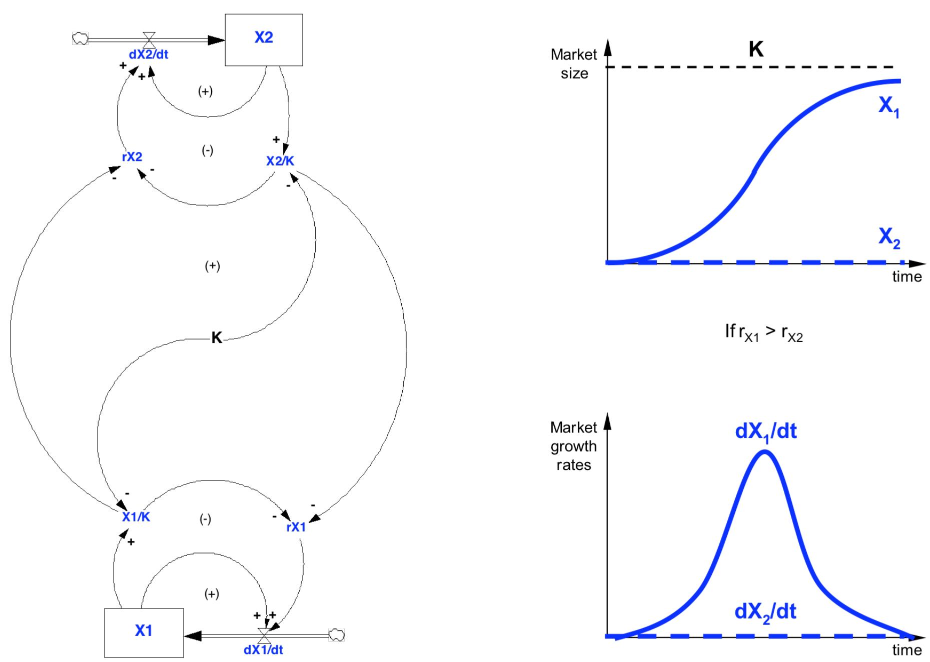

[43] This linear relationship, which produces logistic growth, will be relaxed in subsequent sections which explore interspecies competition.
[44] This is called "mass dependence" in the organizational ecology literature.
[45] This was first formulated in social systems by Verhulst (1838) in his logistic population growth model.

***Intra*-species Competition in a Constant Market.** In most markets, no firm exists without competition; we therefore need to next introduce competition between firms for customers in a common market. At this point, we assume two identical isomorphic competitors, $X_1$ and $X_2$ having homogeneous enterprise architectures occupying the same mathematical point niche. We therefore extend the previous differential equation (2) to account for the simple fact that the addition of sales to either competitor decreases the rate of growth of the other competitor.[46] Both competitors are now connected via a reinforcing loop that amplifies differences in market share resulting in an unstable equilibrium.[47] The new, coupled system of differential equations is shown below:[48]

$$dX_1/dt = r_{X1}X_1 - r_{X1}X_1^2/K - r_{X1}X_1X_2\alpha_{12}/K \quad (3a)$$
$$dX_2/dt = r_{X2}X_2 - r_{X2}X_2^2/K - r_{X2}X_2X_1\alpha_{21}/K \quad (3b)$$

Figure 41 below illustrates the causal structure and resulting behavior of this nonlinear *second*-order formulation, which results in sigmoid or S-shaped growth of each competitor's market capture. Provided that both firms have identical forms and occupy the same market niche, no two-firm (or more generally, two-population) equilibrium can be stable – any exogenous shock to the system will result in the elimination of one of the firms (or populations).[49]

Figure 41: Structure and Behavior of *Intra-species Competition* in a Constant Market

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[46] In ecology, this is called "exploitation" (vs. "interference") competition (Brian, 1956). Other dynamic models formulate competition using more operational variables (Sterman, Henderson, Beinhocker and Newman, 2007).

[47] This severe "winner-takes-all" competitive assumption is akin to Bertrand (price) competition, rather than the weaker form of Cournot (quantity) competition where the market is shared in proportion to relative firm growth rates. Under this assumption, the "competition coefficients", $\alpha_{12}$ and $\alpha_{21}$ equal 1.

[48] This system of equations formed the basis for modeling competition within the seminal organizational ecology framework (Hannan and Freeman, 1977: 942). It is based on the classic Lotka-Volterra equations for *competing* populations, after Lotka (1925) and Volterra (1931). Note that this is different from the classic Lotka-Volterra equations for *predator-prey* populations which generate chaotic oscillation due to a central *balancing* loop.

[49] This is known in ecosystem theory as the "principle of competitive exclusion" (Gause, 1934).

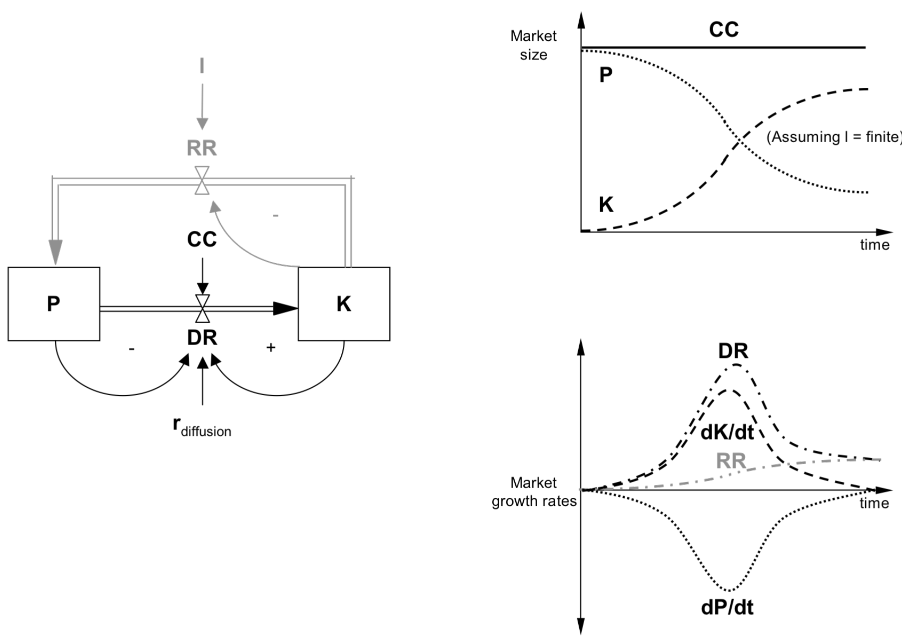
***Diffusing* Market (Quantity).** Next, we relax the assumption of a constant carrying capacity of the resource environment, K (Brittain, 1994). Instead, we permit sigmoid growth as it approaches its own inherent carrying capacity.[50] This assumption captures the scenario of a new product/service that either: 1) diffuses logistically throughout a constant population of potential consumers (Bass, 1969), or 2) diffuses instantaneously through a logistically-growing population of potential consumers (Verhulst, 1838), or 3) some combination of the two.[51]

The new, coupled system of differential equations is shown in its most simple form below:

$$dP/dt = RR - DR = K/l - r_d PK/CC \quad (4a)$$
$$dK/dt = DR - RR = r_d PK/CC - K/l \quad (4b)$$

Here, P denotes the *potential* market; K denotes the *adopting* market; CC denotes the carrying capacity of the system; DR denotes the *diffusion* rate; $r_d$ denotes the fractional *diffusion* rate; RR denotes the *replacement* or *repurchase* rate; l denotes the average product life. Figure 42 below illustrates the causal structure and resulting behavior of this nonlinear *first*-order formulation, which again results in sigmoid or S-shaped growth for the resource environment.

Figure 42: Structure and Behavior of a *Diffusing* Market




For simplicity, we will assume that the average product life, l approaches infinity (i.e. the market consists of durable goods)[52], making the replacement rate, RR approach zero. Noting that P = CC – K, the new differential equation which captures the dynamics of *diffusion* is:

$$dK/dt = r_d K\,(1 - K/CC) \quad (4c)$$

[50] For simplicity, we model a linear relationship between the diffusion rate and available carrying capacity, which results in logistic growth.

[51] The more general formulation of a resource environment comprising an interaction of logistic consumer population growth with logistic diffusion of an innovation is discussed in Piepenbrock (2009).

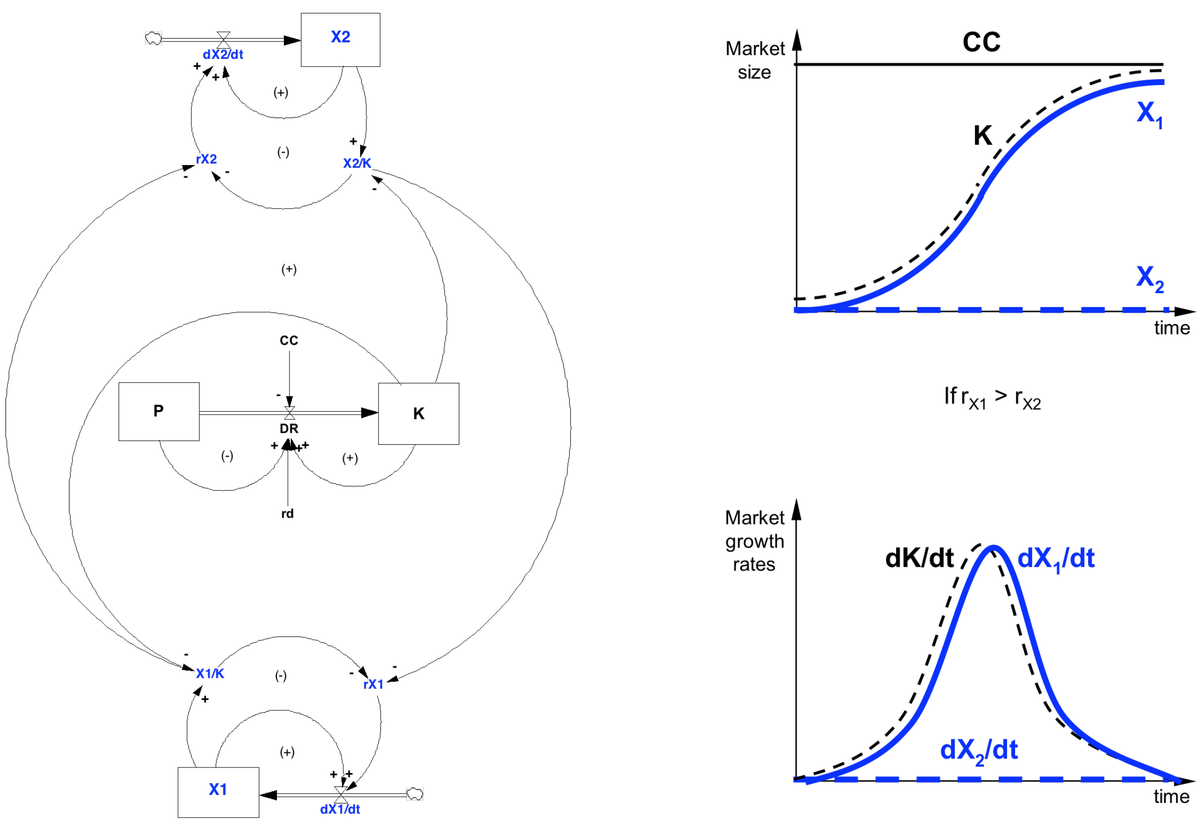
[52] This assumption is not an unreasonable approximation for the primary case study of large commercial airplanes, with average product lives ranging from 25-50 years.

**Intra-species Competition in a *Diffusing* Market.** Next, we reintroduce two members of the same species, competing for the logistically growing market. The new, coupled system of differential equations is shown in its most simple form below:

$$dX_1/dt = r_{X1}X_1 - r_{X1}X_1^{\,2}/K - r_{X1}X_1X_2\,\alpha_{12}/K \qquad (5a)$$
$$dX_2/dt = r_{X2}X_2 - r_{X2}X_2^{\,2}/K - r_{X2}X_2X_1\alpha_{21}/K \qquad (5b)$$
$$dK/dt = r_KK - r_KK^2/CC \qquad (5c)$$

Figure 43 below illustrates the causal structure and resulting behavior of this nonlinear *third*-order formulation, which again results in sigmoid or S-shaped growth for both the resource environment and the dominant firm (or population of firms) that created it.

Figure 43: Structure and Behavior of Intra-species Competition in a *Diffusing* Market

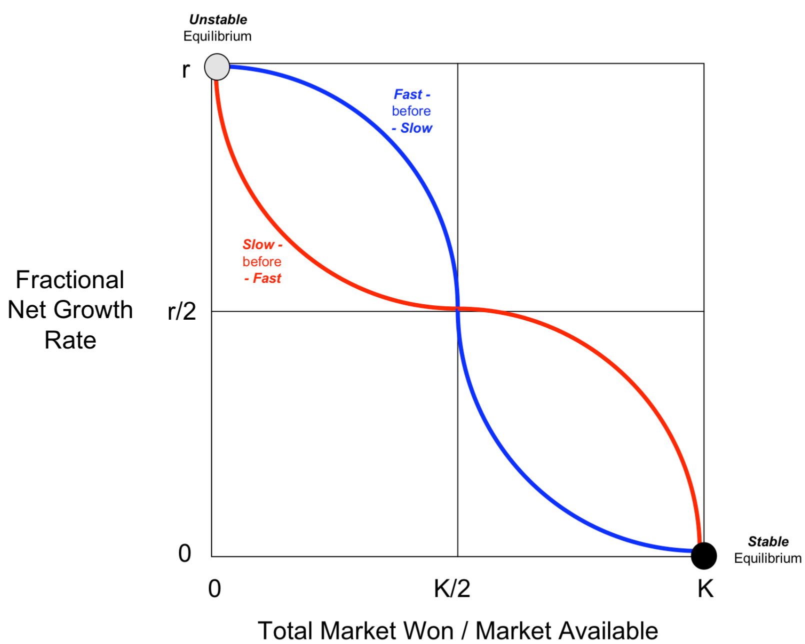



Although this refinement of Hannan and Freeman's (1977) classic does not itself add new insights into the behavior of competing organizations or populations, it is a necessary building block for the next step of the formulation of the evolution of business ecosystems, namely, it establishes the condition necessary for the establishment of interspecies competition, resulting in an extension of the theory of competitive exclusion (Gause, 1934).

***Inter*-species Competition in a Diffusing Market.** Since in the previous stage, we have allowed the environment to grow logistically, we can now acknowledge the possibility of variation in organizational forms as a consequence of variation in environmental rates of growth. This gives rise to the potential for dominance switching: i.e. the late entry of a new species of organization, and the associated early exit of the incumbent species. The two types of competing organizational species modeled therefore reflect either increasing rates or decreasing rates of environmental growth.

The incumbent species, X which builds the market is known in bio-ecology as an *r-strategist*, and the late-entrant challenger species, Y which takes the market is known as a *K-strategist* (MacArthur and Wilson, 1967). The primary difference between this formulation and the previous, is that each competitor's fractional net growth rates are no longer linearly density-dependent, with the (*Modular*) *r-strategist* growing faster when the environment is experiencing rapid growth, and the *(Integral) K-strategist* growing faster when the environment's rate of growth is slowing down, as shown in Figure 44 below.

Figure 44: Fractional Net Growth Rate Assumptions




The new, coupled system of differential equations is shown below:

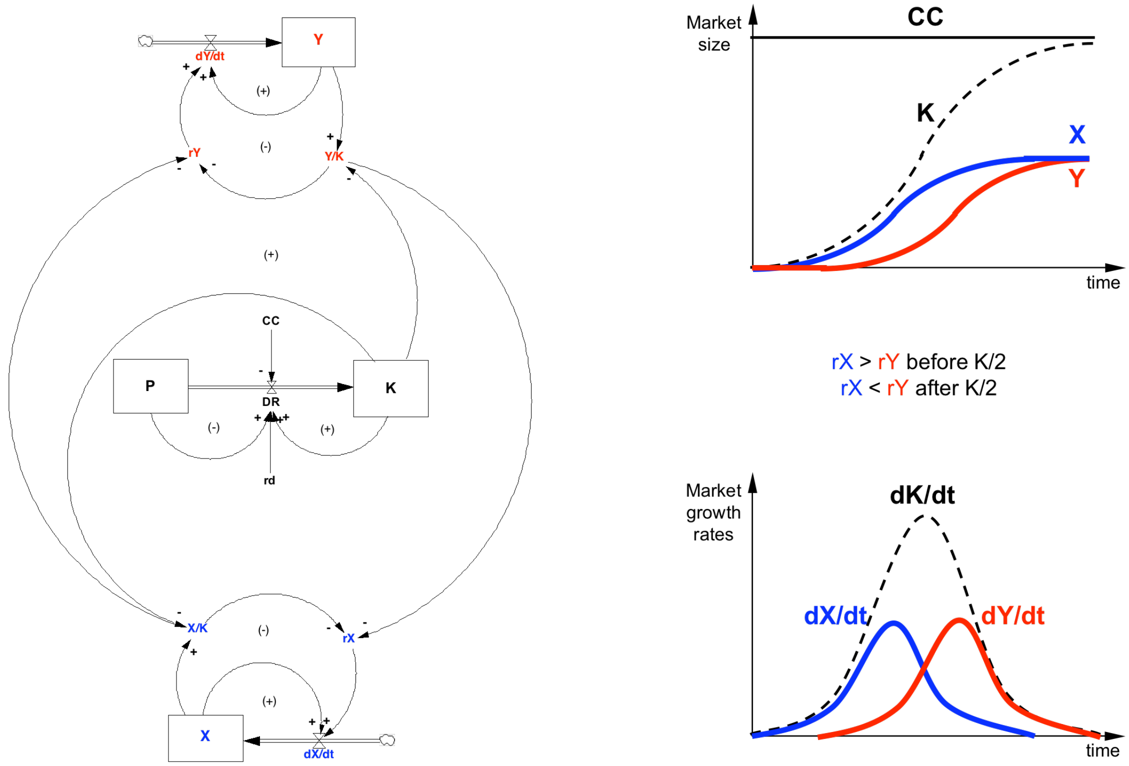
$r_X > r_Y$ when $(X+Y) < K/2$ $\quad dX/dt = r_X X - r_X X^2/K - r_X XY\alpha_{XY}/K$ (6a)

$r_X < r_Y$ when $(X+Y) > K/2$ $\quad dY/dt = r_Y Y - r_Y Y^2/K - r_Y XY\alpha_{YX}/K$ (6b)

$dK/dt = r_d K - r_d K^2/CC$ (6c)

Figure 45 below summarizes the causal structure and resulting behavior of this nonlinear *third-order* formulation which results in S-shaped (but no longer logistic) growth for the competitor's state variables. Crucially note that the r-strategist tends to exit when the growth rate of the market begins to drop below its own growth objectives. Environmental variance therefore produces variance in the architectures of the organizational sets, which creates symbiotic inter-species competition, with a more complex theory of competitive exclusion.

Figure 45: Structure and Behavior of *Inter*-species Competition in a Diffusing Market



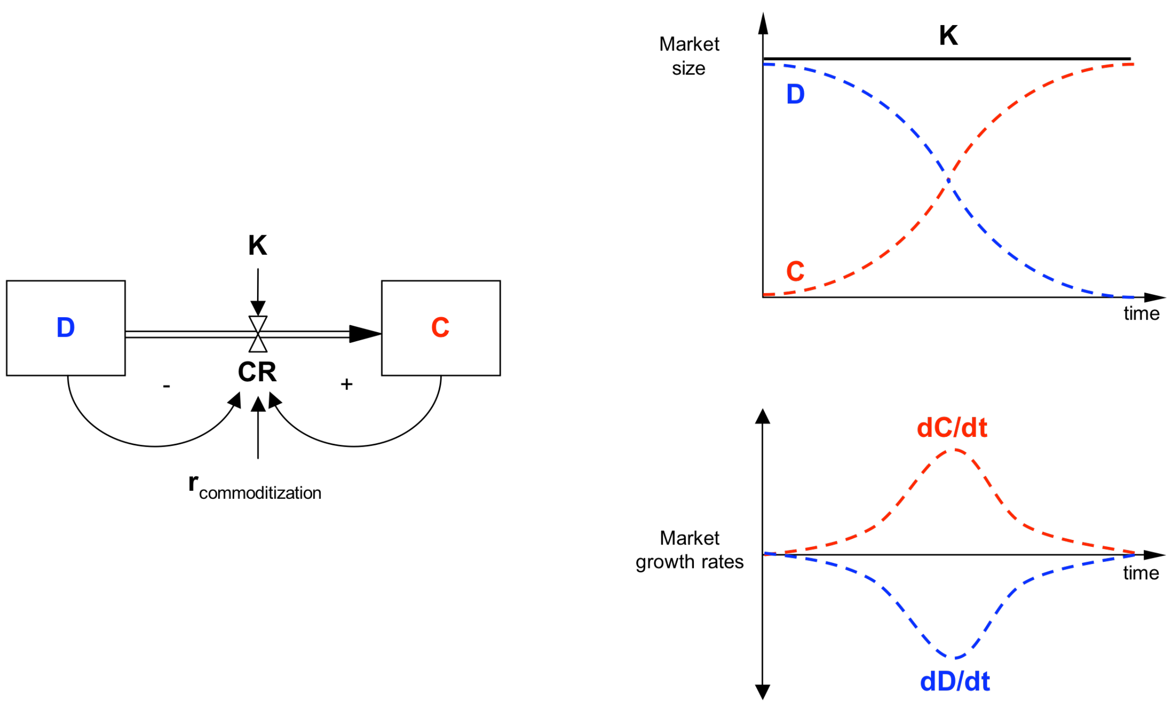
***Commoditizing* Market (Quality).** Having permitted the carrying capacity of the market, K to grow logistically, we now go back to a constant market assumption, but instead allow the *quality* of the market customer preferences to diffuse from high-performance *differentiated* products and services towards *low-cost* products and services (Abernathy and Utterback, 1978; Christensen, 1997). This in effect allows market niches to evolve, which has the potential to shape the entry and exit of different species of organizational sets.

The new, coupled system of differential equations is shown in its most simple form below:

$$dD/dt = - CR = - r_c DC/K \quad (7a)$$
$$dC/dt = CR = r_c DC/K \quad (7b)$$

Here, C denotes the *cost-based* market; D denotes the *differentiation-based* market; K denotes the adopting market's *capacity*; CR denotes the *commoditization* rate; $r_c$ denotes the fractional *commoditization* rate. Figure 46 below illustrates the causal structure and resulting behavior of this nonlinear *first*-order formulation, which again results in sigmoid or S-shaped growth for the transforming resource environment.[53]

Figure 46: Structure and Behavior of a *Commoditizing* Market




Noting that D + C = K, the new differential equations which capture the dynamics of *commoditization* is shown below:

$$dD/dt = r_c D\,(1 - D/K) \quad (7c)$$
$$dC/dt = r_c C\,(1 - C/K) \quad (7d)$$

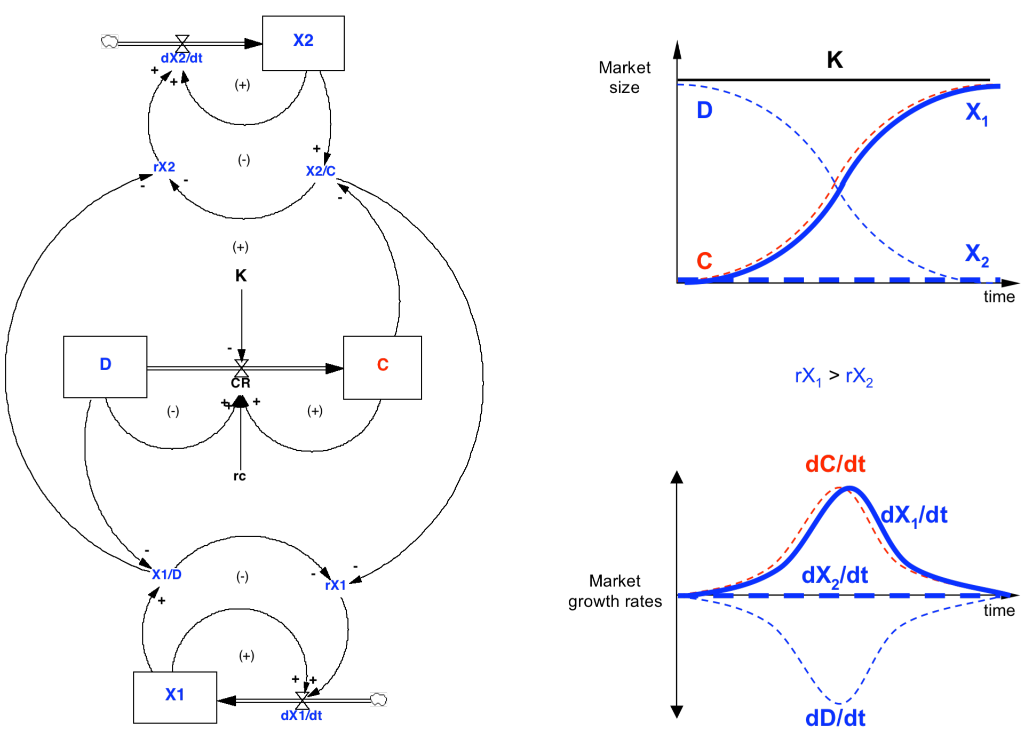
[53] Again, as in the characterization of the diffusing market, the commoditizing market's sigmoid growth is assumed to proceed logistically, for analytical simplicity.

***Intra*-species Competition in a *Commoditizing* Market.** In the previous stage, the resource environment was characterized as existing in one dimension: the rate of change of *market* growth, dK/dt. This formulation extends the model to include a second dimension: the rate of change of *technology* commoditization, dC/dt. This captures the construct of a *dominant design* in the product offering (Abernathy and Utterback, 1978), which marks the shift in market demand from increasing rates of change of improvement in product performance, where competition is based on *product* innovation, to increasing rates of change of improvement in product cost, where competition is based on *process* innovation.[54] In order to control for the previous effects of market growth, we hold the market size, K constant.[55] The new coupled system of differential equations is shown below:

$$dX_1/dt = r_{X1}X_1 - r_{X1}X_1^{\ 2}/D - r_{X1}X_1X_2\alpha_{12}/(D + C) \tag{8a}$$
$$dX_2/dt = r_{X2}X_2 - r_{X2}X_2^{\ 2}/C - r_{X2}X_2X_1\alpha_{21}/(D + C) \tag{8b}$$
$$dD/dt = r_cD\ (1 - D/K) \tag{8c}$$
$$dC/dt = r_cC\ (1 - C/K) \tag{8d}$$

Figure 47 below summarizes the causal structure and resulting behavior of this nonlinear *third* order formulation[56] which results in sigmoid or S-shaped transition from a market dominated by sales of products/services based on *differentiation*, D to a market dominated by sales of products/services based on *cost*, C. Note that this formulation represents *direct* competition between organizations within the environment.

Figure 47: Structure and Behavior of *Intra*-species Competition in a *Commoditizing* Market



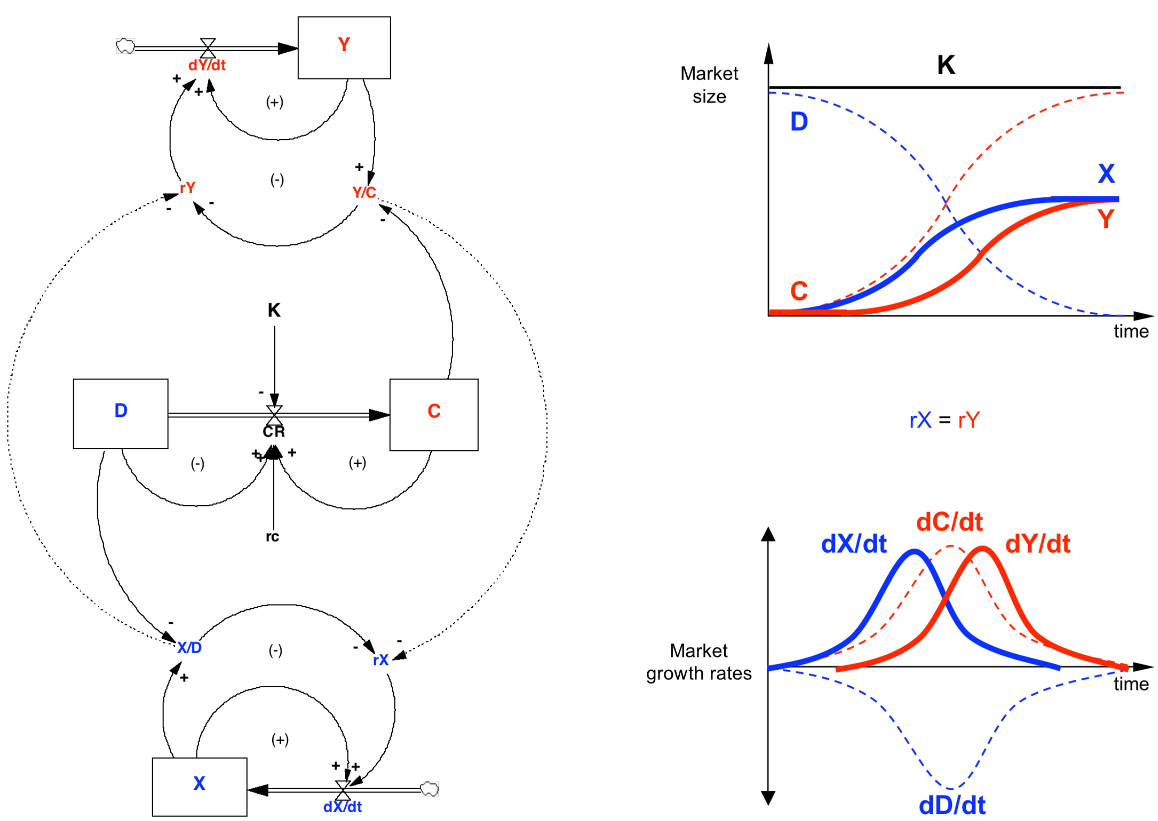

[54] Although a "dominant design" is often seen as a *discrete* event, the market is modeled as a *continuously* evolving.
[55] This control will relaxed in the next section, where both market size, K and type, C will grow logistically.
[56] The addition of two state variables is only a first-order addition as one is completely determined by the other.

**Inter-species "Competition" in a *Commoditizing* Market.** In the previous stage, both competitors were assumed to be of the same species, and therefore broadly able to compete in both the differentiation-based and cost-based niches (i.e. the competition coefficients α were at or near 1) – for example both intra-species competitors, *GM* and *Ford* can transition from a differentiated product focus towards a cost focus. However, the emergence of a new species, having an integral enterprise architecture (like *Toyota*) is much better suited towards cost-leadership, making their competition coefficient α approach zero. In this extreme case of interspecies competition, each species focuses on the niche that they are best suited to, and "competition" takes on a symbiotic nature, due to the presence of architectural inertia. The new coupled system of differential equations is shown below:

$$dX/dt = r_X X - r_X X^2/D - r_X XY\alpha_{XY}/(D + C) \qquad (9a)$$
$$dY/dt = r_Y Y - r_Y Y^2/C - r_Y XY\alpha_{YX}/(D + C) \qquad (9b)$$
$$dD/dt = r_c D\ (1 - D/K) \qquad (9c)$$
$$dC/dt = r_c C\ (1 - C/K) \qquad (9d)$$

Figure 48 below summarizes the causal structure and resulting behavior of this nonlinear *third* order formulation[57] which results in sigmoid or S-shaped transition from a market dominated by sales of products/services based on *differentiation*, D to a market dominated by sales of products/services based on *cost*, C. Note that this formulation represents *indirect* competition between organizations occupying different niches within the environment.

Figure 48: Structure and Behavior of Inter-species "Competition" in a *Commoditizing* Market



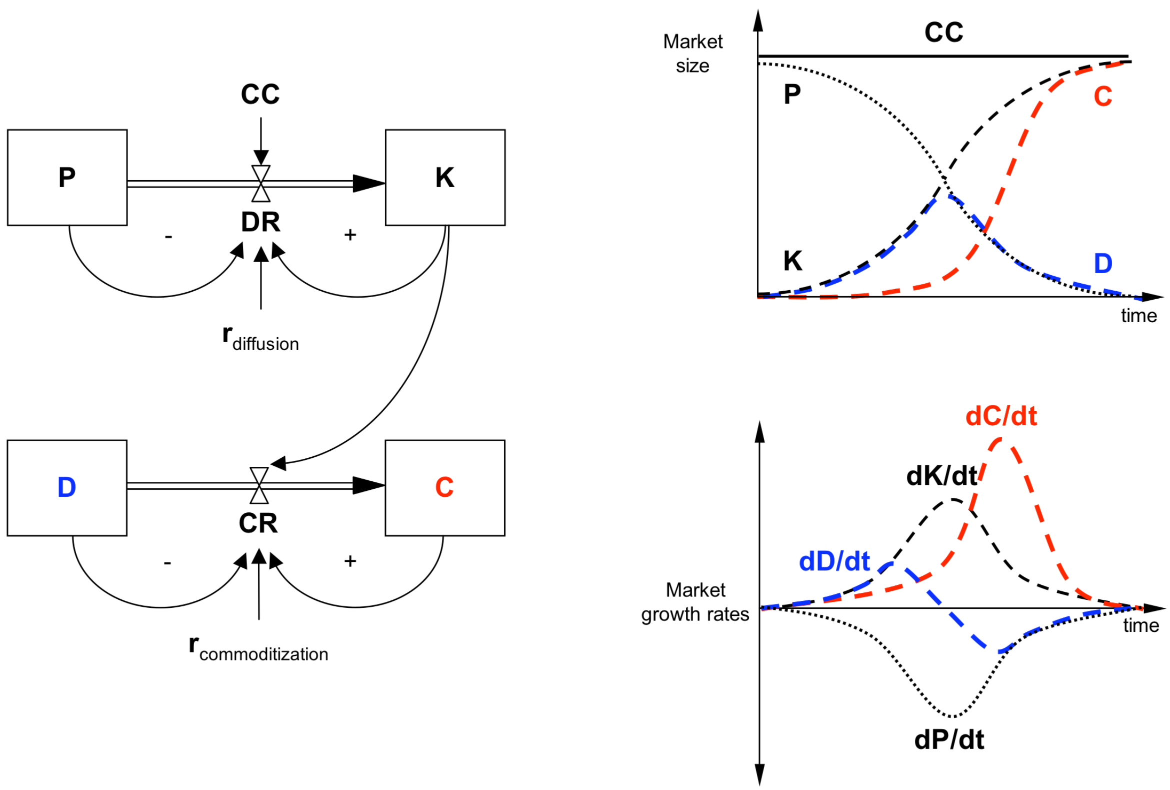

[57] The addition of two state variables is only a first-order addition as one is completely determined by the other.

***Diffusing, Commoditizing* Market (Quantity and Quality)**. We now combine the previous two descriptions of the market environment, where the *quantity* of the market, K grows logistically (Bass, 1969), while simultaneously, the *quality* of the market customer preferences diffuses from high-performance *differentiated* products and services towards *low-cost* products and services (Abernathy and Utterback, 1978). This allows the entry and exit of different species of organizational sets for two reasons: the rate of change in market *quantity* and the rate of change in technological *quality* enable market niches to evolve. The new, coupled system of differential equations is shown below:

$$dP/dt = -r_d P\ (1 - P/CC) \quad (10a)$$
$$dK/dt = r_d K\ (1 - K/CC) \quad (10b)$$
$$dD/dt = -r_c D\ (1 - D/K) \quad (10c)$$
$$dC/dt = r_c C\ (1 - C/K) \quad (10d)$$

Figure 49 below illustrates the causal structure and resulting behavior of this nonlinear *second-order* formulation. Although the total market, K again results in logistic sigmoid or S-shaped growth, niches D rises and falls, while niche C rises in S-shaped growth to eventually characterize the entire market. Note, however that if the fractional diffusion rate, $r_d$ >> than the fractional commoditization rate, $r_c$, then the behavior approaches that shown in Figure 43.

Figure 49: Structure and Behavior of a *Diffusing, Commoditizing* Market



***Intra*-species Competition in a *Diffusing, Commoditizing* Market.** The model now has two different ways of defining the state of evolutionary maturity of the environment: *quantity* and *quality* – that is, *how much* product is produced/consumed, and *what type* of product is produced/consumed. This section therefore combines these two characterizations of the market environment into one model, where two firms of the same species (characterized by the architectures of their respective extended enterprises) compete. The extent of competitive intensity is defined by the ability of each firm to overcome architectural inertia and transition from niche D to niche C as the market evolves. A summary of the coupled system of differential equations is shown below.

$$dX_1/dt = r_{X1}X_1 - r_{X1}X_1^2/D - r_{X1}X_1X_2\alpha_{12}/K - r_{X1}X_1X_2\alpha_{12}/(D + C) \qquad (11a)$$

$$dX_2/dt = r_{X2}X_2 - r_{X2}X_2^2/C - r_{X2}X_1X_2\alpha_{21}/K - r_{X2}X_2X_1\alpha_{21}/(D + C) \qquad (11b)$$

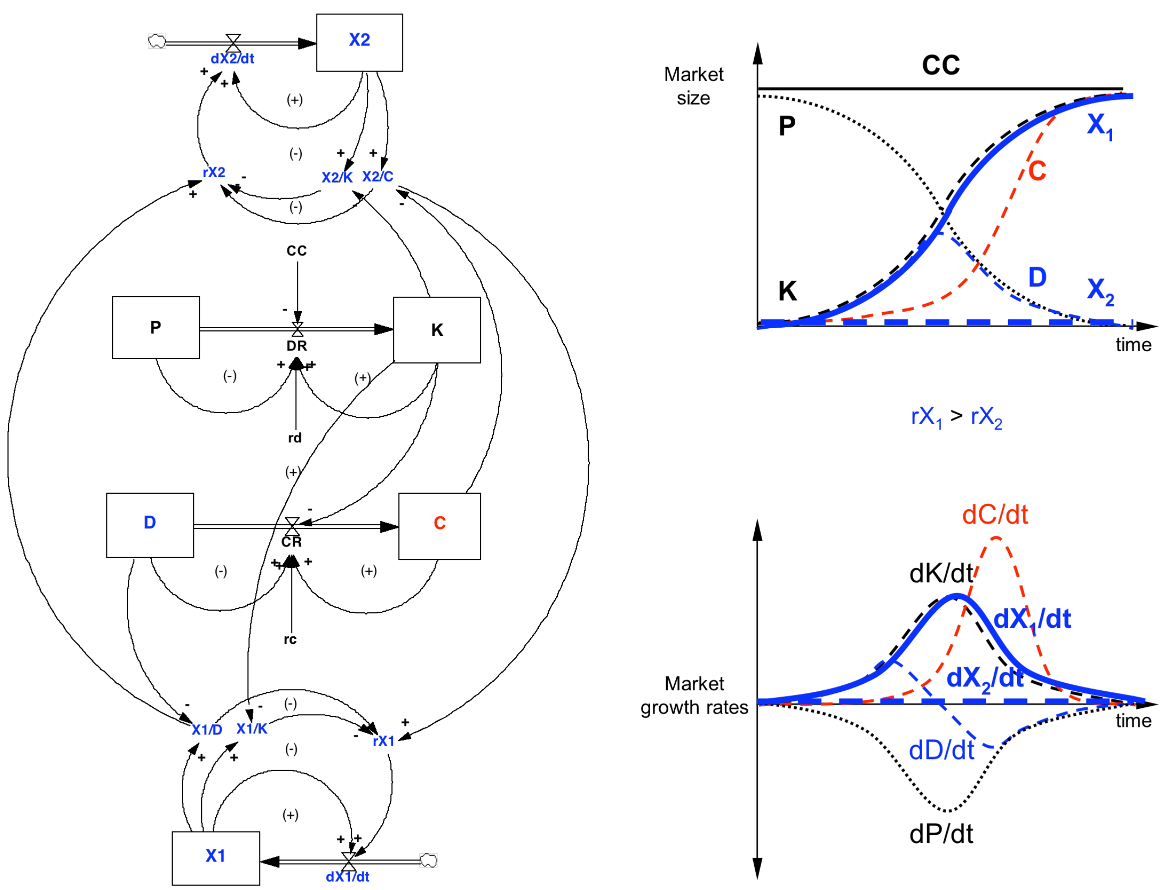
$$dK/dt = r_dK\ (1 - K/CC) \qquad (11c)$$

$$dD/dt = -r_cD\ (1 - D/K) \qquad (11d)$$

$$dC/dt = r_cC\ (1 - C/K) \qquad (11e)$$

Figure 50 below summarizes the causal structure and resulting behavior of this nonlinear *fourth*-order formulation which results in S-shaped growth of the general market K, and the niche, C. Due to architectural inertia, each species is constrained to its own niche resulting in early exit, late entry and dominance-switching throughout the life-cycle of the industry.

Figure 50: Structure/Behavior of *Intra*-species Competition in a *Diffusing, Commoditizing* Market



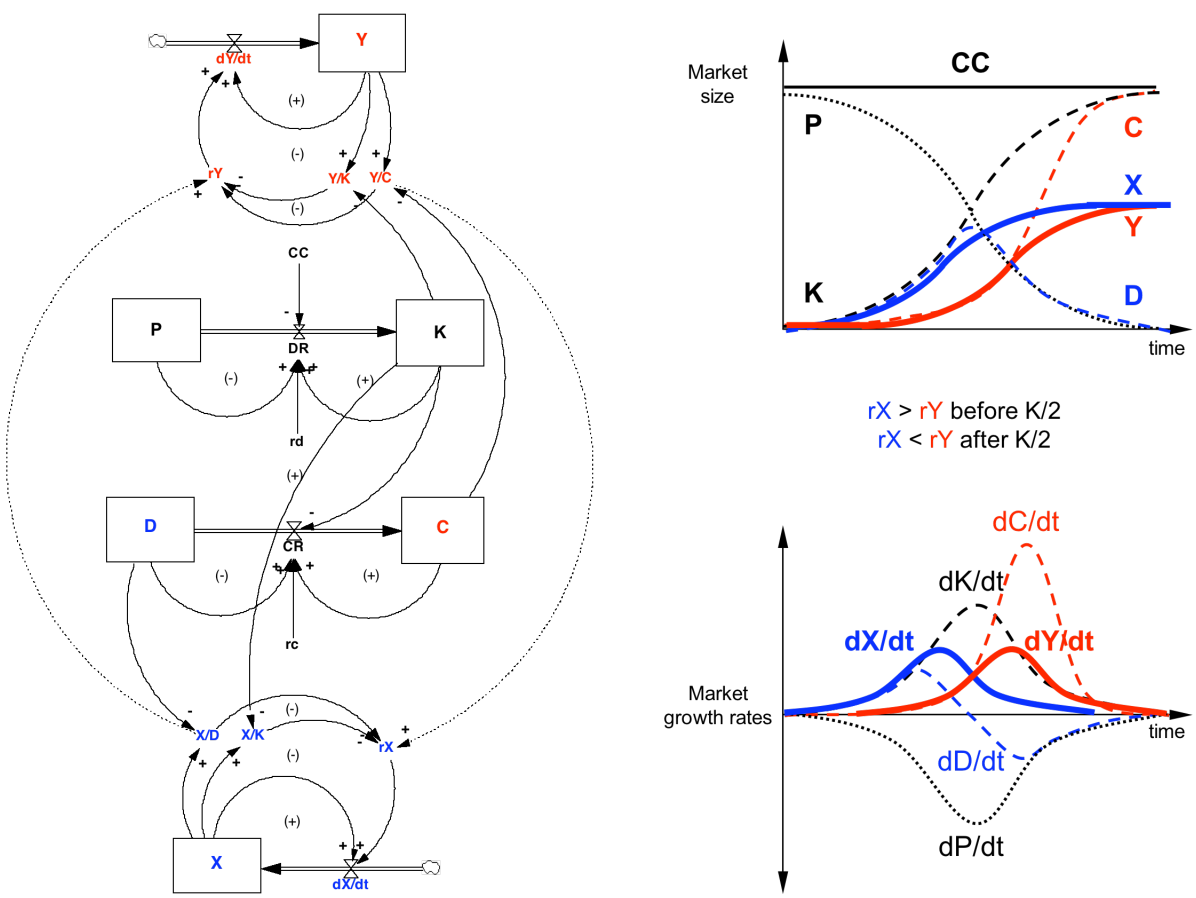
***Inter*-species Competition in a *Diffusing, Commoditizing* Market.** The model now has two different ways of defining the state of evolutionary maturity of the environment: *quantity* and *quality* – that is, *how much* product is produced/consumed, and *what type* of product is produced/consumed. This final section therefore combines these two characterizations of the market environment into one model, where two different species of firms (characterized by the architectures of their respective extended enterprises) compete. The extent of competitive intensity is defined by the ability of each firm to overcome architectural inertia and transition from niche D to niche C as the market evolves. A summary of the coupled system of differential equations is shown below.

$r_X > r_Y$ when $(X+Y) < K/2$
$r_X < r_Y$ when $(X+Y) > K/2$

$$dX/dt = r_X X - r_X X^2/D - r_X XY\alpha_{XY}/K - r_X XY\alpha_{XY}/(D+C) \quad (12a)$$
$$dY/dt = r_Y Y - r_Y Y^2/C - r_Y XY\alpha_{YX}/K - r_Y XY\alpha_{YX}/(D+C) \quad (12b)$$
$$dK/dt = r_d K\,(1 - K/CC) \quad (12c)$$
$$dD/dt = -r_c D\,(1 - D/K) \quad (12d)$$
$$dC/dt = r_c C\,(1 - C/K) \quad (12e)$$

Figure 51 below summarizes the causal structure and resulting behavior of this nonlinear *fourth*-order formulation which results in S-shaped growth of the general market K, and the niche, C. Due to architectural inertia, each species is constrained to its own niche resulting in early exit, late entry and dominance-switching throughout the life-cycle of the industry.

Figure 51: Structure/Behavior of *Inter*-species Competition in a *Diffusing, Commoditizing* Market



## DISCUSSION and CONCLUSIONS

### Summary of Findings and Results

Industry-leading firms like *Airbus*, *Toyota Motors*, and *Southwest Airlines* in the manufacturing and services sectors respectively while not trying to solely maximize shareholder value have ironically delivered significantly more of it than their competitors who are trying to maximize this metric. In the process, these late-entrant challengers have displaced significant market-making incumbents – in fact, the dominant competitors of their species – in *Boeing, General Motors* and *United Airlines* respectively. The key to this puzzle lies in understanding the how such firms interact with their environments – that is, in the *architecture* of their organizational sets. The theoretical sample revealed the integral enterprise architectures (or K-strategists) can be successfully grown in socio-economic environments as diverse as Europe, Japan and the United States.

### Discussion of Plausible Rival Hypotheses

At the outset of the is paper, we clearly stated that the objective of the research was to begin to answer a fundamental question in strategy and organization:

> "Why do firms in the same industry vary *systematically* in performance *over time*?"

The theory presented herein attempted to explicitly pose a *systematic* explanation for a *longitudinal* phenomenon: namely, how does a firm interact with its external stakeholders as a system, and how does this interaction evolve over time. Most plausible rival hypotheses concerning the explanation of long-term firm performance, however seem to be non-systemic and focused on short-term "noisy" data. Another way of stating this is that they tend not to focus on the evolution of the environment and the subsequent evolution of the competing species of competitors. Such explanations implicitly assume intra-species competition, which relies on explanations of *exogenous* events, simple *execution* problems or even *legitimacy*.

**Exogenous Events.** One of the most common non-systemic explanations is that *GM, United* or *Boeing* are experiencing events beyond their control, whether they are labor strikes, oil shocks or global credit crunches. This overlooks that their competitors *Toyota, Southwest* and *Airbus* experience the same events with fewer consequences, as their enterprise architectures endogenize or co-opt (Selznick, 1948) environmental constraints more effectively, for example by offering employment stability in return for year-on-year productivity improvements, thus avoiding labor strikes; by using a conservative hedging strategies to minimize the effects of high oil prices; or by maintaining conservative balance sheets with reserve cash to assist customers with financing of their products and services.

**Execution.** Another common non-systemic explanation frequently put forward by the leaders of their organizations is that *GM, United* or *Boeing* are simply experiencing execution problems. This class of plausible rival hypothesis, which focuses on poor execution of strategy, rather than on poor strategy itself or even more fundamentally, enterprise architectural misfit with environmental conditions is embedded in the focus on increasing *efficiency*, given a fixed strategy or enterprise architecture. A problem with this hypothesis may develop if longitudinal evidence demonstrates that such execution problems are persistent. Clearly, if a firm consistently and persistently is unable to execute its strategy successfully over the long term, then perhaps it has the "wrong" strategy, or an enterprise architecture which constrains its ability to pursue the most effective strategy.

**Legitimacy.** Another more ideologically-based non-systemic explanation is that *Toyota, Southwest* and *Airbus* are "cheating" due to their unusually close relationships with capital, labor and supplier markets or government and are therefore "illegitimate" forms of business systems. This is manifested by their competition referring to them as "Japan Inc.", Texas Inc.", or "Europe Inc." respectively. This explanation may in fact be defensible, provided that an external refereeing organization had the power to declare their illegitimacy and enforce rules systematically and longitudinally against their existence. The fact that such refereeing organizations do not exist, or are not able to enforce rules legitimating only one enterprise architecture, might seem to imply that a plurality of architectures may in fact exist and thrive empirically in real business ecosystems.

**Liability of Maturity.** One of the most common plausible rival hypotheses which attempts to explain firm success is that the younger the challenger firm, the lower its costs, and the easier it is to be the cost-leader; or conversely, the older the incumbent firm, the higher its costs (e.g. due to pensions for an aging work-force), and the harder it is to be the cost-leader.

This can be questioned for example by looking at the evolution of the US airline industry, which is currently populated by a collection of expensive "legacy" carriers who created the industry and the relative late arrival of the challenger, *Southwest Airlines*. *Southwest's* long-term cost leadership has sustained a thirty-year attack from a series of newer and therefore (potentially) less expensive competitors, who arrived nearly a decade after *Southwest's* founding, due to deregulation of the US market.[58] What distinguishes *Southwest*, is the relative integrality of its enterprise architecture relative to younger challengers. This supports the claims of the organizational ecologists, who contend that mortality rates should be high for late entrants.

It is interesting to note that organizational ecologists have determined across a broad range of industries that in populations of isomorphic organizations, late entrants have statistically higher mortality rates than early entrants. In these cases however, the late entrant not only survives, but it overtakes the incumbent. In other words, the explanation for *integral* enterprise architectures' success as late entrants is that the form of its enterprise architecture is more adapted to a maturing environment – it is a new species in an evolving environmental niche.

[58] See Kelly and Amburgey (1991, pg. 603) for their analysis of entry and exit in the US airline industry.

**Interest, Importance and Contributions**
As business ecosystems continually evolve, a framework exploring the co-evolution of organizations and their environment would be of theoretical interest to strategic management, organization science and complex systems researchers, as well as of practical interest to senior executives in industry, particularly those facing significant environmental change and potential lack of organization-environment fit, and those engaged in "inter-species" competition. By adapting organizational ecology's focus on multiple organization *density* to strategic management's focus on single organizations, we attempt to bridge the two domains.

***Firm-Industry* Debate in Strategic Management.** It was from this open-ended intensive, in-depth, longitudinal inductive study of both focal firms, that the data revealed something that the literature had not allowed for: a different species of organizational set which possessed fundamentally different architectural form, function, structure and behavior from its competitor. This allowed us to revisit and shed new light on Porter's (1996) classic construct of an *efficiency frontier* in light of heterogeneous enterprise architectures. Later analysis of the environment revealed fundamentally different conditions at the founding of each organizational set, which promoted their growth and development. In addition, the data revealed that both organizational sets served a symbiotic function for the other. While both were locked in conventional competition, one created the environmental conditions that enabled the other to grow and ultimately dominate. Concurrent analysis of the secondary samples confirmed that the same evolutionary processes and symbiotic inter-species competition occurred in a variety of settings ranging from manufacturing to services and across national boundaries from the US to Japan to Europe.

***Adaptation-Determinism* Debate in Organization Science.** The framework acknowledges the concurrent roles of managerial adaptation and environmental selection in the co-evolution of firms and industries through the construct of organizational set architecture, which simultaneously enables and constrains agency. Rather than diminishing the role of agency, the framework identifies an enhanced role of top management, namely CEO not as chief executive, but as "chief architect" who defines and maintains the objective function, boundaries and interfaces of the organizational set. These findings contribute to the understanding of *strategic leadership* as an architecting activity which focuses upward and outward of the organization (Durbin, 1979), as opposed to downward and inward. As such, these findings refocus the attention of strategic management scholars from their traditional focus on *efficiency* (i.e. doing things right) to a focus on *effectiveness* (i.e. doing the right things) for a broader set of stakeholders than just customers or investors. This in turn implies that new models firms and their leaders, may focus again on power (Pfeffer and Salancik, 1978) and politics (March, 1962).

Although the theoretical framework developed herein was constructed inductively from multiple case studies, it does confirm and support both theoretical propositions from the literature's illustrious past (e.g. Burns and Stalker, 1961 and Lawrence and Lorsch, 1967), as well as from its more recent cutting edge. For example, Lenox, Rockart and Lewin (2006 & 2007) recently developed numerical simulations of Kaufmann's (1993) NK model to demonstrate theoretically that for industries with high interdependency among activities, there will be only a few high performers earning profits well above the industry average and a relatively large number of laggards. The three pairs of case studies presented herein support not only this claim, but also present a theoretical model which describes how such interdependencies evolve at both the ecosystem and organizational levels.

***Modular-Integral* Debate in Complex Systems.** This research attempts to shed more light on the classic intra-organizational architectural forms implied in Lawrence and Lorsch's 1967 classic: *Organization and Environment: Managing Differentiation and Integration*. From the title, we can see clear references to modularity and integrality within organizations as reflected in the demands of their environments. Their proposition that when the environment demands increasing intra-organizational differentiation, this must be accompanies with associated increasing intra-organizational integration (no matter how difficult combining these two may be). The research presented in this paper however, demonstrates how such apparent difficulties of matching these two opposing activities actually occur in modular enterprise architectures, and how and why this can both lead to competitive advantage and competitive disadvantage.

The framework also engages the classic premises of theories of systems architecture, and in doing so, begins to expose an apparent contradiction regarding the relative "*evolvability*" of modular vs. integral systems. Architectural theorists from Simon (1962) to Baldwin and Clark (2000), have posited that modular (or loosely-coupled) systems create an "option value" which copes well with future environmental design uncertainties, resulting in a more adaptable system architecture.

However, this research begins to demonstrate that by applying the same principles of system architecture to the more complex settings of organisms - and crucially - organizations, one can begin to observe empirically from the case studies discussed herein, that integral (or tightly-coupled) systems may in fact have higher evolutionary capabilities than modular systems – the key being the time horizon over which design evolution occurs. If the environment is relatively stable and certain, requiring only continuous albeit incremental design changes, then wholesale system-wide change is possible, and it is the integrality of the architecture of the enterprise that creates the setting for such organizational learning. If, however, the environment is relatively unstable and uncertain, the potential for radical design changes over a relatively short period of time is beneficial, and it is the modular architecture that enables such short-term flexibility.

The establishment of a universal "design rule" of architectural evolvability, appears to be contingent therefore in the epistemological characterization of the system under consideration, with modularity apparently conferring adaptability in mechanistic systems in turbulent environments, while integrality appears to confer adaptability in organic systems in stable environments.

Finally, the framework also engages another classic premise of the theory of systems architecture, and in doing so, begins to expose an apparent contradiction regarding the relative "*performance*" of modular vs. integral systems. Architectural theorists like Ulrich (1995), whose research is confined to physical products, have posited that integral (or tightly-coupled) systems exhibit efficiency due to function-sharing, resulting in a higher performance system architecture. Our theory however demonstrates that "high-performance" is a relative property which is contingent upon the demands of the environment, whereby modular (or loosely-coupled) enterprise architectures can exhibit higher performance than integral, provided that the environment demands and rewards short-term speed and flexibility.

***Varieties of Capitalism* & *Mixed Duopoly* Research.** While most of the recent research in applying theories of the political economy to the firm (Hall and Soskice, 2000) has focused on descriptive models of macro-organizational forms, few have focused on firm performance as the dependent variable, explaining the environmental contingencies (e.g. market maturity) under which firms embedded in each of the national institutional archetypes (Liberal Market Economies vs. Coordinated Market Economies) tend to dominate.

This research empirically identifies a significant outlier (i.e. *Southwest Airline's* integral enterprise architecture), a Coordinated Market Economy-based firm, which is embedded within the archetypal US Liberal Market Economy. It has not only survived, but has grown to dominate the US airline industry comprising a population of incumbent LME firms. This case appears to offer significant counter-intuitive insights for both managers and a rich data set for researchers on how to create an inter-organizational architecture which does not utilize the apparent "natural" strengths of a national institutional archetype.

Similarly, in recent micro-economic research about mixed duopolies (e.g. Lambertini & Rossini, 1998), much has focused on theoretical models which determining equilibrium states, whereas this research attempts to demonstrate dis-equilibrium dominance-switching dynamics, and presents empirical evidence for such preliminary claims.

**Limitations of Theoretical Framework**

The framework presented herein aspires to initiate a theoretical basis for explaining the evolution of business ecosystems, by building from the foundations of the intellectual domains of strategic management and ecological-level organizational theory, and bridging across them with system architecture theory. Inevitably, such an endeavor will fall far short of its aims, some of the limitations of which are briefly discussed below.

**External (Spatial) Validity.** While the framework possesses reasonably strong internal validity, it is clearly limited in its external validity, i.e. in its generalizability or the scope of its applicability. This is due both to the small N theoretical sample size inherent in this initial exploratory study, as well as due to the rather narrow boundary around the environmental conditions for applicability: i.e. industries which exhibit product & process innovation (Klepper, 1996, pg. 565.). Such limited generalizability is likely to limit the utility of the framework, provided that the pursuit of greater generalizability is possible with such dynamically and functionally complex systems.

**External (Temporal) Validity.** The framework is limited temporally in its ability to explain the evolution of business ecosystems only from growth through maturity phases. Empirical data, upon which the framework was founded does not yet exist for industrial decline phases.

**Future Research**

As such a framework undoubtedly raises more questions than it answers, a rich research agenda can be developed which seeks to characterize the structure, function, and evolution of various species of organizational sets and their ecosystems. Some examples of this research might include the following:

**Increase External Validity.** The most important next steps would include additional longitudinal field-based case studies of competitors in other industries, exhibiting significant long-term variance in dependent and independent variables, enterprise architecture and firm performance respectively. This is needed not only to improve the external validity of the existing theoretical framework, but more importantly to begin to map out the key parameter ranges, which might alter the structure and behavior of the industry's evolution. For example, what is the effect of rapid changes to the exogenous variables like technology supply? Would *environmental selection* create a new enterprise architecture in such an environment, or would *managerial adaptation* evolve the incumbent firm due to the perpetually low levels of structural inertia?

**Expand Temporal Scope of Framework.** Additional empirical work is required in the case studies involved in this paper to determine what happens as industries evolve into later stages of maturity and eventually decline. Do all enterprise architectures begin as integral for exploration and eventually disintegrate for exploitation, creating a law of enterprise entropy? Conversely, do late entrants with integral architectures increase their integrality as the industry matures and declines, as the mathematical formalism would suggest?

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