MIS Quarterly

不同于Research notes和article

THEORY & REVIEW

不再强调对实践的指导意义

UNIFYING THE ROLE OF IT IN HYPERTURBULENCE AND COMPETITIVE ADVANTAGE VIA A MULTILEVEL PERSPECTIVE OF IS STRATEGY[1]

what is hyper-turbulence

Ning Nan
Management Information Systems Division, Sauder School of Business, The University of British Columbia,
2053 Main Mall, Vancouver BC V6T 1Z2 CANADA {ning.nan@sauder.ubc.ca}

Hüseyin Tanriverdi
Department of Information, Risk, and Operations Management, Red McCombs School of Business,
The University of Texas at Austin, Austin, TX 78712 U.S.A. {huseyin.tanriverdi@mccombs.utexas.edu}

While information technology (IT) serves as a new source of sustainable competitive advantage for firms, it also induces hyperturbulent environments (or hyperturbulence) that erode that sustainable competitive advantage. In this paper, we posit that these contradictions might be due to cross-level nonlinear causality between firm-level IT-based strategic actions and collective-level IT-induced hyperturbulence. We develop a multilevel perspective of IS strategy for theorizing this causality, and unifying novel with established research. Complex adaptive systems theory is employed as the overarching framework for its strength in formalizing cross-level nonlinear causal paths. Using literature-based theorization and agent-based modeling, we establish two bottom-up nonlinear causal paths by which IT drives hyperturbulence: IT can act as an external force (i.e., component IT innovation) to locally instigate firm strategic actions that aggregate to temporary hyperturbulence or as an internal force (i.e., architectural IT innovation) to drive pervasive firm strategic interactions that aggregate to persistent hyperturbulence. Each causal path produces varied amounts of reducible and irreducible uncertainties and thereby renders a top-down nonlinear effect that reshapes the opportunity for IT to contribute to competitive advantage. This multilevel theorization paves the way for new, IS-specific theory regarding IT's unique role in inducing nonlinear dynamics and in affording new business strategies in today's competitive environments.

① component

② architech

Keywords: IS strategy, IT innovation, hyperturbulence, generativity, uncertainty, complex adaptive systems, agent-based modeling, role of information, big data

Introduction

Information systems (IS) strategy research has shown both the promise and the challenge of information technology (IT). On one hand, IT is a new source of sustainable competitive advantage as firms can creatively combine IT and non-IT components into innovative business products and processes (Bharadwaj 2000; Nevo and Wade 2010; Wade and Hulland 2004). On the other hand, IT is a central catalyst in inducing hyperturbulence in business environments (hereafter referred to as *hyperturbulence*) (El Sawy et al. 2010). Such environments are characterized by the rarity of sustainable competitive advantage (Wiggins and Ruefli 2002).

The promise and challenge of IT taken together suggest the existence of nonlinear causality between firm-level IT-based strategic actions and IT-induced hyperturbulence in the

[1]Suzanne Rivard was the accepting senior editor for this paper.

The appendices for this paper are located in the "Online Supplements" section of the *MIS Quarterly*'s website (http://www.misq.org).

collective-level environment. The practical and theoretical significance of this nonlinear causality between phenomena at both the firm and collective levels has been highlighted by recent literature. For example, a comparison of growing companies such as Google and Amazon, and fading companies such as AOL and Nokia, reveals that a firm's success increasingly depends on whether it can continuously renew its strategy to exploit fissures in its business environment, which is jointly shaped by its customers, partners, and its own past strategy (Keen and Williams 2013). Such field observations have motivated calls for expanding IS strategy research beyond a firm's boundary to the level of a collective of interacting firms. Research in this expanded context can show the fundamental shift of IT's role from functional support to driver of business value (Bharadwaj et al. 2013; El Sawy et al. 2010). These research calls unveil a new research horizon: the need to explicate the cross-level nonlinear causality between individual firms and a collective of interacting firms, because phenomena at the collective level, such as IT-induced hyperturbulence, are enacted by but not reducible to individual firm strategy.

Our study approaches this new research horizon by theorizing (1) how firm-level strategic uses of IT can induce hyperturbulence in the competitive environment, and (2) how IT-induced hyperturbulence redefines IT-enabled solutions for a firm to cope with performance challenges. The essence of our theorization is a multilevel perspective that includes *bottom-up causal paths* from firm-level IT-based strategic actions to collective-level IT-induced hyperturbulence, and *top-down causal paths* of how an IT-induced hyperturbulent environment redefines the opportunity for IT to contribute to firm competitive advantage. Together, these cross-level causal paths can create nonlinear effects that unify linear segments of positive (the promise) or negative (the challenge) impacts of IT on hyperturbulence and competitive advantage. Furthermore, since the bottom-up and top-down causal paths bridge IS strategy phenomena at firm and collective levels, the paths can connect a traditional firm-centric view with a novel holistic view of IS strategy. This can facilitate a cumulative tradition in IS research.

Theoretical Foundation

Literature Review as the Foundation for Definitions and Research Boundary

Our theory development is positioned in the ongoing IS strategy research literature. We espouse the view that the central mission of IS strategy research is to "understand how capabilities and strategic advantage can be enhanced with the aid of IT in turbulent environments" (El Sawy et al. 2010, p. 836). Using this criterion for our literature search, we reviewed and synthesized several streams of work that either theorize about "turbulent environments" or formalize the nomological network from IT to firm capabilities and competitive advantage (see Appendix A for an overview of these literature streams). Given the multilevel nature of our theorization, we organized the literature review into collective-level and firm-level research.

内生和外生的区别：外生变量不受研究内变量的影响

Turbulent Environments: Collective-Level IS Strategy Research

In IS strategy research, turbulent environments refer to competitive business environments that are characterized by frequent competitive actions and short-lived competitive advantage (McAfee and Brynjolfsson 2008; Sambamurthy et al. 2003). Turbulent environments are traditionally modeled as exogenous moderators (e.g., Pavlou and El Sawy 2006) or control variables (e.g., Im and Rai 2008). However, this exogenous view is challenged by recent empirical findings and theory developments.

The endogeneity of turbulent environments was first suggested by the empirical finding that IT industries tend to have a fast clockspeed (defined by the rate of change in prices, duration of product life cycles, and "freshness" of product lines) (Fine 1998; Mendelson and Pillai 1998). More recent IS research has shown a noticeable correlation between levels of IT investment and yearly changes in firm performance rankings in both IT and non-IT industries (McAfee and Brynjolfsson 2008). In addition, business strategy research shows that sustainable competitive advantage is becoming extremely rare in almost all industries in the United States, particularly after the wide adoption of IT in business (Wiggins and Ruefli 2002). Both the fast rate of change and the rarity of sustainable competitive advantage manifest the rise of hyperturbulence (i.e., more persistent and intense forms of turbulence). These empirical findings suggest that hyperturbulence is more than an exogenous moderator or control condition in the impact of IT on competitive advantage. Hyperturbulence can be endogenously induced by IT-based firm strategic actions and interactions.

Empirical observations of IT and turbulent environments motivate the development of dynamic and nonlinear theoretical views in IS strategy research. IT–business alignment research (Chan et al. 1997; Chan et al. 2006) can best exemplify this development of new theoretical views. Early research on IT–business alignment adopted a punctuated equilibrium view to explain how turbulence in a competitive environment triggered episodes of revolutionary IS strategic

2] turbulance → Revolution

innovation → turbulance → reshape

alignment (Sabherwal et al. 2001). More recent IS strategy research began to highlight the persistent rather than the punctuated nature of turbulence in competitive environments, using analogies such as "dancing rugged competitive landscapes" (i.e., a firm's competitive environment is constantly reshaped by its own and its rivals' strategic actions) (Tanriverdi et al. 2010) and Red Queen competition (i.e., a firm has to evolve progressively faster in order to keep up with its rivals) (Agarwal and Tiwana 2015). Accordingly, a coevolutionary view of alignment has been proposed to capture continuous mutual influences of a firm's IT-based strategic actions and hyperturbulence (Benbya and McKelvey 2006; Vessey and Ward 2013).

IS strategy research refines our concept of hyperturbulence in three important aspects. First, hyperturbulence is an outcome produced by a collective of interacting firms as well as a condition that influences those firms. Therefore, we conceptualize hyperturbulence as a collective-level construct in the multilevel perspective of IS strategy. Second, prior research has defined a *turbulent environment* as changes in a firm's performance ranking over time (e.g., McAfee and Brynjolfsson 2008). Accordingly, *hyperturbulence, as a more persistent and intense form of turbulent environment*, can manifest as a nonlinear time path of firm performance ranking changes. Furthermore, a higher intensity of hyperturbulence is indicated by a more pronounced nonlinear time path where the per firm average jump in number of places up or down the rankings over time is greater (e.g., the turbulence chart in McAfee and Brynjolfsson 2008, p. 102). Third, although hyperturbulence is often examined at the industry level, recent IS research suggests that hyperturbulence can occur in digital ecosystems (Agarwal and Tiwana 2015). With increasing digitization of business products and processes, a digital ecosystem can form among firms across traditional industry boundaries. For example, the Android mobile platform has enabled strategic interactions among telecommunications, information, music, gaming, and banking industries. To ensure generalizability of our multilevel perspective, we broadly consider a collective of interacting firms as the context wherein hyperturbulence can occur. Examples of the collective include markets, industries, and digital ecosystems.

From IT to Competitive Advantage: Firm-Level IS Strategy Research

IS strategy is defined as "an organizational perspective on the investment in, deployment, use, and management of information systems" (Chen et al. 2010, p. 235). This definition reflects the predominant focus of IS strategy research on the nomological network linking IT, firm capabilities, and competitive advantage. Prior research has unpacked this nomological network into various constructs such as IT innovation, agility, and dynamic capabilities. Research on these constructs converges on two main themes: the changing nature of IT innovation holds the key to hyperturbulence, and hyperturbulence can reshape a firm's capabilities.

IT innovation: IS strategy research tightly couples the concept of IT with the notion of innovation (McFarlan et al. 1983; Tai and Phelps 2000). *Innovation* is defined as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers 2003, p. 12). Business strategy researchers see innovation as a key source of competitive advantage (Baregheh et al. 2009). Similarly, IS strategy researchers implicitly or explicitly conceptualize IT as codified new ideas, practices, products, or services that can produce competitive advantage. Chen et al. (2010, p. 243) have recently pointed out that "IS strategy can be operationalized in terms of a shared organizational perspective in which the firm seeks *innovation* through IS" (emphasis added). We explicitly recognize IT as innovation (hence the term *IT innovation*) so that our conception of IT is contextualized in the strategy research domain.

Early applications of IT systems were identified mainly as back-office support or standalone enterprise systems (El Sawy et al. 2010). Correspondingly, early IS strategy research tended to apply a resource-based view: conceptualizing IT innovation as instances of new assets (e.g., hardware, software, IT personnel) (Nevo and Wade 2010; Wade and Hulland 2004), or particular types of new systems (e.g., inventory systems, payroll systems) (Oh and Pinsonneault 2007). Recent digital innovation research recognizes that a new generation of IT innovation differs from traditional back-office support systems by its generativity (Yoo et al. 2010). *Generativity* refers to "a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" (Zittrain 2006, p. 1980). The new generation of IT innovation enables modularized productive means and standardized interfaces (Tiwana 2008; Tiwana et al. 2010; Yoo et al. 2010). As a result, business products and processes can continuously recreate themselves by combining modularized productive means via standardized interfaces. In other words, the new generation of IT innovation is a generative organizing logic that enables unprompted change driven by spontaneous strategic actions at the firm level (Tiwana et al. 2010; Yoo et al. 2010). Platforms such as Microsoft Windows and Apple iOS are examples of this new generation of IT innovation. Millions of independent developers are able to contribute content and applications to these platforms by using modularized development kits and standardized application programming interfaces.

广义了和狭义了

Traditional and recent views of IT innovation in IS strategy literature reflect the notions of component innovation and architectural innovation (Henderson and Clark 1990). *Component innovation* refers to the replacement of existing design elements with new ones while *architectural innovation* is the reconfiguration of interconnections among existing design elements (Henderson and Clark 1990). Past strategy research has gained insights into nonlinear causality from seemingly small firm-level strategic actions to unintentionally large industry or market-level competitive consequences through a comparison of component and architectural innovation (Henderson and Clark 1990). Likewise, we believe that the contrast of the traditional and new conceptual views of IT innovation holds the key to how firm-level creative uses of IT give rise to collective-level hyperturbulence, and how IT enables new solutions for firms to succeed in hyperturbulent environments.

Building on prior literature, our conception of IT includes both traditional and new views of IT and refers to them as *component IT innovations* (defined as the replacement of existing IT or business assets with new IT assets) (e.g., Nevo and Wade 2010; Oh and Pinsonneault 2007) and *architectural IT innovations* (defined as IT-enabled reconfiguration of interconnections among existing assets or systems) (e.g., Yoo et al. 2010) respectively. Although IT innovations are adopted by firms, the research on collective-level strategy phenomena reviewed earlier suggests that the impact of IT innovations can be observed on both firm and collective levels.

***Firm capability*:** IS researchers have recently pointed out that in hyperturbulent environments, firms must "rapidly innovate, adapt, and reconfigure themselves to match the changing environment" (El Sawy and Pavlou 2008, p. 139). According to the coevolutionary view of IT-business alignment, a firm's adaptive capabilities are applied to its recurrent efforts to coevolve with changes in competitive environments and business goals (Benbya and McKelvey 2006; Vessey and Ward 2013). This coevolving process has been visualized as hill climbing in a rugged landscape. The ruggedness of the landscape is determined by the number of factors in a firm's strategy and interdependencies among those factors (i.e., the NK model of strategy by Levinthal 1997). The recurrent applications of a firm's adaptive capabilities (also called dynamic or improvisational capabilities) have been conceptually broken down to agility, competition intelligence, flexibility, digital options, and absorptive capacity (for a review of these concepts, see Overby et al. 2006). Together, these concepts define what we call *firm adaptive capability* in this study. In particular, agility is a firm's ability to sense and respond to changes in the competitive environment (Overby et al. 2006). The sensing component of agility relies on a firm's competitive intelligence that converts data about the firm's interaction patterns to information about competitive relationships (Pant and Sheng 2015; Zheng et al. 2012). The responding component of agility includes a firm's strategic flexibility and operational flexibility to act on information regarding changes in a firm's interaction patterns (Grewal and Tansuhaj 2001; van Oosterhout et al. 2006). Digital options are IT-enabled work processes and knowledge systems that enable and coevolve with a firm's agility in sensing and responding to changes (Sambamurthy et al. 2003). The absorptive capacity (Cohen and Levinthal 1990) of a firm enables recurrent applications of agility and digital options to assimilate new information regarding firm interactions and the competitive environment, and to engage in new rounds of strategic action and interaction.

IS strategy research regarding firm capabilities has alluded to new opportunities for IT to contribute to competitive advantage. When the primary venue for IT to contribute to competitive advantage is planned firm capability, traditional IS research is primarily concerned with the opportunity for IT to provide information for rational decision making (for review, see Benbasat and Nault 1990). Today's hyperturbulence requires adaptive capabilities, which require IT to provide information for recurrent sensing and responding to the spontaneous strategic interaction of firms (El Sawy and Pavlou 2008).

Summary of Literature Review

IS strategy research suggests that hyperturbulence can result from IT-based firm strategic actions and interactions, while a firm's adaptive capabilities are the main venue for IT to afford competitive advantage in hyperturbulence. However, prior research has not proposed how these cross-level causal paths unfold. To effectively develop such propositions, we draw on Bacharach's (1989) widely cited criteria to define *the boundary of our study* in terms of implicit values, spatial restrictions, and temporal restrictions. Our implicit value is that IT innovations are important forces to instigate firm strategic actions and interactions; and that effects of IT innovations manifest as bottom-up and top-down nonlinear causality between firm strategic actions and hyperturbulence. The spatial restriction of our theory is a collective of strategically interacting firms, with markets, industry, and digital ecosystems as examples of this spatial context. The temporal restriction of our theory is after a firm has adopted an IT innovation.

为文章内容划分理论边界

复杂适应系统

动态更新系统 ↔ 注重info

agent对novel behavior作反馈

Complex Adaptive Systems (CAS) Theory as the Overarching Framework

CAS theory is an ideal overarching framework for our theory development. CAS theory arises from the study of changes caused by interactions among elements in a system (Arthur 2014; McKelvey 2001). CAS research embraces nonlinear dynamic changes and looks into interactions as the root of these changes. In addition to its dynamic and nonlinear perspective, CAS theory is well-suited because it explicitly focuses on the role of information. As Gell-Mann (1994, p. 23) points out, "in studying any complex adaptive system, we follow what happens to the information." Examining how information helps individuals to cope with uncertainties resulting from dynamic changes holds the key to potential enhancement of their adaptive capability.

The basic concepts of CAS theory come from physics. Seeing the limitation of Newtonian physics in explaining changes in physico-chemical systems, Nicolis and Prigogine (1989) developed the theory of "dissipative structures" to explain dynamic changes that occur when environmentally imposed energy fluctuations trigger a web of feedback loops. Some feedback loops then amplify the effect of the energy fluctuations (i.e., positive feedback loops) while other loops dampen the effect of the fluctuations (i.e., negative feedback loops). The aggregated effects of these positive and negative feedback loops produce nonlinear dynamics to "dissipate" the initial energy fluctuations.

The early complexity research in physics was subsequently extended to biology and social sciences (i.e., research on living systems) (Gell-Mann 2002). Theoretical insights gained from this line of work form the so-called complex adaptive systems theory. CAS theory relies on three key constructs for explaining nonlinear causality in a living system: *agents* (i.e., basic entities of actions), *interactions* (i.e., mutual adaptation) of agents, and an *environment* (i.e., a medium for agents to operate in and interact with) (Nan 2011). Compared with molecules in a physico-chemical system, agents in a living system have a distinctive property; they have a purpose to survive and thrive in their living systems (Holland 1995). This purpose is encapsulated in the *behavioral rules* by which agents convert information from their surroundings into actions that improve their likelihood of surviving and thriving in the system. Behavioral rules embody the agent's adaptive capability because they determine the ability of an agent to continuously reconfigure itself according to what is rewarded by its surroundings (Holland 1995). Interactions arise when agents adapt to information from one another via their interconnections. CAS theory recognizes that the source of behavioral variations lies in diversity of agent attributes and behavioral rules (Holland 1995). This diversity can not only generate novel behaviors in a system, but also lead to distinct responses to those novel behaviors (Miller and Page 2007). ~~If agents~~ perceive the novel behavior to be superior to their own, they may combine the novel behavior with their own. This recombination serves to amplify the novelty in a system, and manifests the *generativity* of a system. If agents feel the novel behavior will impair their likelihood of thriving or even of survival, they may try to eliminate the behavior. This elimination prevents generativity from causing harmful behavioral variations in a system (Kirschner and Gerhart 1998). Recurrent applications of these distinct responses produce positive and negative feedback loops that aggregate to nonlinear changes on the system level (Anderson 1999).

behavioral variation

反馈机制 ↔ nonlinear

With respect to adaptive capability (embodied by behavioral rules in CAS theory), CAS researchers recognize that dynamic changes and nonlinear causality defy deductive rationality because "there cannot be a logical solution to a problem that is not logically defined" (Arthur 2014, p. 4). Adaptive capability in a complex system proceeds by induction (Arthur 1994; Holland et al. 1986). CAS researchers focus on the impact of information on uncertainties in order to uncover opportunities to improve agent performance in a complex system. In CAS, uncertainties are situations (e.g., nonlinear changes in an agent's environment) that cannot be mapped definitively to superior performance via an agent's behavioral rules (Anderson 1999; Gell-Mann 2002). By tracing the impact of information on individual performance in tackling nonlinear changes in the environment, we can gain insights into the role of information.

信息的作用

Proposition Development

Building on the key construct definitions and the CAS framework described above, we develop our proposition by first mapping the key constructs (firms and their adaptive capability, IT innovation, and collective-level competitive environment) to CAS concepts of agent, interactions, and the environment. The CAS-based conception of hyperturbulence then enables us to draw on CAS theoretical insights to explicate bottom-up and top-down causal paths in hyperturbulence.

hyperturbulence 的定义

CAS Conception of Hyperturbulence

Our literature review indicates that hyperturbulence is a collective-level condition jointly created by a firm's strategic actions and interactions. Accordingly, firms represent *agents* (basic units of action) in a collective of firms. Arthur (2014) conceptualizes a firm as a combination of productive means. Although Arthur does not provide a definition of productive means, his theoretical arguments indicate that *productive means* (interchangeable with "means" hereafter) is a basic component in business products or a basic activity in business processes. Accordingly, the *attributes* of a firm are the bundle of means owned by a firm.

协同手段组合

Prior CAS research has conceptualized the main task of firms as managing synergies and conflicts between pairs of means (Allen 2001). Accordingly, *behavioral rules* of firms (i.e., their adaptive capability) govern their search for the combination and recombination of means that leverage synergies and avoid conflicts between pairs of means (e.g., arm's length relationships have synergy with a high level of dominance over suppliers, but have conflict with risk sharing; Allen et al. 2009). A combination of synergistic means yields greater firm performance gains than the sum of independent performance contributions by each means. This CAS notion of synergy reflects the economic concept of complementarity (Milgrom and Roberts 1995). A combination of conflicting means produces a lower return than the contribution of either one (Cavusoglu et al. 2009). Although conflicts are detrimental to firm-centric optimization, they can be constructive for adaptive behaviors because conflicts can destabilize a CAS and thereby encourage firms to jointly explore alternatives and compromises to resolve the disputed combinations of productive means (Albert et al. 2015). Information is conceptualized as input to a firm's behavioral rules for combining and recombining productive means. *Interactions* arise when firms recurrently apply their behavioral rules to improve their performance in the competition with other firms.

H1>2

A competitive *environment* is comprised of the collective of incumbent firms whose attributes are bundles of means. In this competitive environment, *component IT innovation* is represented by new productive means that are introduced to replace the existing means of incumbent firms. *Architectural IT innovations* are represented by reconfiguration of interconnections among productive means both within a firm and between firms. The CAS conception of hyperturbulence is illustrated in Figure 1. Our propositions are developed below in light of this illustration.

部分创新

Component IT Innovation and Hyperturbulence: A Bottom-Up Causal Path

自下而上

Schumpeter's notion of "creative destruction" has been commonly cited to explain the nonlinear impact of innovation on a firm's competitive advantage. *Creative destruction* refers to a process wherein a firm's incessant replacement of existing productive means with new ones can create continuous changes in the competitive environment (Schumpeter 1942). Via the CAS lens, creative destruction portrays *component IT innovations* as an external force that triggers both strategic actions and performance ranking changes in a collective of firms. Although a new productive means can be created by an incumbent firm as well as by a newcomer to the collective of firms, this new means is "outside" the existing set of means possessed by incumbent firms and is therefore perceived as an external force. Like a slight solar energy influx instigates significant global climate changes (Nicolis and Prigogine 1989), new IT-enabled consumer goods, new IT-based production methods, and other forms of component IT innovations are an influx to the environment of incumbent firms. Via existing interconnections, these new means disturb the combinations of means possessed by incumbent firms.

While a component IT innovation can contribute higher performance than the displaced means, its impact on firm performance depends on how a firm recombines the component IT innovation with remaining means. The overall impact of a component IT innovation on firm performance can be either positive or negative. Multiple firms' decisions to embrace the new component IT innovation form positive feedback loops that amplify the uncertain performance impact of this component IT innovation. Meanwhile, some incumbent firms may try to reject a new component IT innovation if they perceive the innovation as detrimental to their sustainable competitive advantage (Arthur 2009). Reject decisions can form negative feedback loops that allow firms to preserve their existing combinations of means in the short term, but can accumulate sufficient disadvantages for the rejecting firms to eventually adopt the new component IT innovation or go out of business (Boisot and McKelvey 2010). Over time, these positive and negative feedbacks enact a nonlinear bottom-up causal path leading from firm efforts to environmental turbulence (see P1 as a bottom-up effect in Figure 1). A greater number of component IT innovations represents a stronger external force that instigates firm efforts to obtain sustainable competitive advantage from IT innovation. This in turn can strengthen the nonlinear effect of a firm's strategic actions on dynamic changes in firm performance rankings.

Proposition 1 (P1): *Individual firm efforts to gain sustainable competitive advantage from component IT innovations will aggregate to produce nonlinear changes in firm performance rankings over time. This nonlinear effect is more pronounced (indicating a higher intensity of hyperturbulence) when greater numbers of component IT innovations are introduced.*

组件组合→业绩（由企业→环境 turbulence
自下而上）

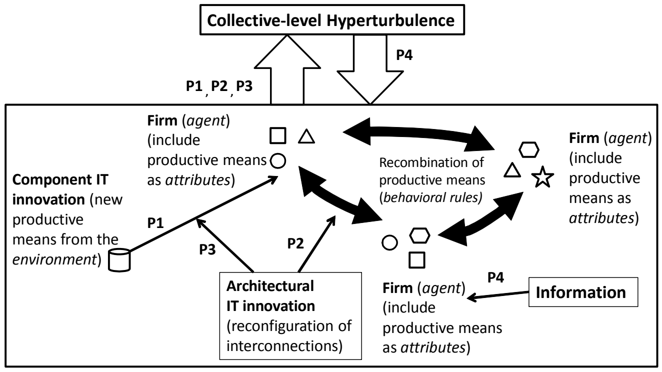

Figure 1. Overview of Our Theoretical Model

Architectural IT Innovation and Hyperturbulence: A Bottom-Up Causal Path

Architectural IT innovations differ from component IT innovations in that they lead to modularized productive means and standardized interfaces (Tiwana 2008; Tiwana et al. 2010; Yoo et al. 2010). They represent a generative organizing logic that increases the scope, scale, and speed of strategic interactions of firms (Tanriverdi et al. 2010). Modularization of components and standardization of interfaces enable extensive interconnections of business products and processes both within a firm and between firms. These intra- and interfirm interconnections expose each firm to a greater number of recombination opportunities. Meanwhile, modularization and standardization enable firms to rapidly recombine productive means in response to strategic interactions centered on each firm. Firms are liberated from path dependency and granted the freedom to explore many strategic options. For example, a layered modular architecture (an architectural IT innovation) enables firms to source reusable components from different design hierarchies (device, service, network, content) and quickly combine these components into new products via standardized interfaces (Yoo et al. 2010).

Prior strategy research shows that even when the search for an ideal combination of means is confined within a firm (i.e., intra-firm), the increased interconnection of means makes finding the desired combination more difficult (Levinthal 1997; Porter and Siggelkow 2008). Architectural IT innovation aggravates the situation by interconnecting the means owned by different firms (i.e., interfirm interconnections). A firm's desired combination of means is dependent on synergies or conflicts of means that reside in other firms as well as those in its own. Even if a firm achieves a desired combination, this combination can be quickly disrupted by other firms' recombination of means. For example, while firms from previously separated industries can now connect and recombine their products and processes via the Android mobile platform, their firm performance is often impaired after an upgrade of the Android platform (e.g., compatibility problems). When firms recurrently apply their behavioral rules to gain sustainable competitive advantage from architectural IT innovations, both positive feedback loops that lead to new combinations and negative feedback loops that maintain existing combinations can occur. Together these feedback loops create nonlinear changes in firm performance rankings (see P2 in Figure 1 for a depiction). These nonlinear changes become more pronounced when architectural IT innovation is more pervasive in a collective of firms, because greater interconnections of business products and processes can escalate strategic interactions.

Proposition 2 (P2): *Individual firm efforts to gain sustainable competitive advantage from architectural IT innovations will aggregate to produce nonlinear changes in firm performance rankings over time. This nonlinear effect is more pronounced (indicating a higher intensity of hyperturbulence) when architectural IT innovations are more pervasive.*

hypothesis后面要验证
proposition后面不用验证

Joint Effect of Component IT Innovation and Architectural IT Innovation

Like biological systems that are subject to external forces such as climate changes and internal forces such as mutual adaptations of species, hyperturbulence in a collective of firms can be driven simultaneously by component IT innovations as an external force and architectural IT innovations as component太直接,

企业 → turbulence

bottom up

architectural 可打破这一影响到整体

an internal force. The disruptive effects of a component IT innovation are mostly contained within those firms whose means are directly or indirectly replaced by component IT innovation. Architectural IT innovations, however, can scale up the disruptive effects of component IT innovations to the entire collective of firms, because they enable interconnections and mutual adaptations of the previously firm-centric combinations of means. A cascade of changes can ripple through the entire collective of firms via interfirm interconnections. Thus, architectural IT innovations are likely to positively reinforce the nonlinear effects instigated by component IT innovations on hyperturbulence. For example, a cloud computing service called Clio (an architectural IT innovation) develops, curates, and integrates digital tools for lawyers (e.g., documentation and billing tools). By increasing the affordability and availability of digital tools (i.e., component IT innovations), Clio helps to disseminate new legal practices enabled by these digital tools, such as Lawyers on Demand (see P3 in Figure 1). New legal practices in turn send shockwaves through firm performance rankings in the legal industry (Financial Times 2015).

Proposition 3 (P3)*: Architectural IT innovations can increase the prominence of the nonlinear changes instigated by component IT innovations on firm performance rankings.*

Hyperturbulence and IT Strategic Value: A Top-Down Causal Path

As conceptualized earlier, an important opportunity for IT to contribute to competitive advantage in hyperturbulence is enabling informational input (intelligence) to reduce uncertainties during strategic interaction with other firms. This theoretical focus on IT-enabled intelligence is directed at how the frontier of IT-enabled business solutions, namely big data (Goes 2014), can enable firms to better deal with challenges of hyperturbulent environments.

The inductive nature of agent behavioral rules (i.e., adaptive capability) in a CAS speaks to the critical impact of information on a firm's competitive advantage. Holland (1995) compares agent behavioral rules to hypotheses that gain power from additional observations. With additional information, an agent is more likely to separate regularity from randomness in a CAS (Gell-Mann 1994, 2002). The regularity perceived by the agent can then be converted to competitive advantage through this agent's behavioral rules. In a hyperturbulent environment, nonlinear changes require firms to engage in a continuous search for desired combinations and recombinations of means. Information related to the combination of means—such as the nature (synergy or conflict) of interconnection links among means—is particularly important for firms to detect combinations that could improve competitive advantage. A firm's competitive intelligence (Pant and Sheng 2015; Zheng et al. 2012), which converts data about the firm's online interaction patterns to information about competitive relationships, is an example of IT-enabled intelligence regarding the nature of interconnection links.

Proposition 4 (P4)*: IT can provide information related to combinations of productive means, and thereby contribute to competitive advantage in an environment characterized by nonlinear changes in firm performance rankings (i.e., a hyperturbulent environment).*

By conceptualizing hyperturbulence via the CAS lens, we are able to apply CAS theoretical insights to the development of a multilevel perspective of hyperturbulence. This multilevel perspective breaks down the nonlinear causality between firm-level IT-based strategic actions and collective-level IT-induced hyperturbulence. The result is bottom-up effects of two types of IT innovations and a top-down effect of hyperturbulence on IT's strategic value.

Quantitative Theorization via Agent-Based Modeling

To this point, the qualitative nature of our literature-based theory development prevented us from quantitatively characterizing the proposed causal paths between IT, hyperturbulence, and competitive advantage. *Agent-based modeling* (ABM) is an ideal quantitative theory development tool that allows researchers to precisely "walk through" the bottom-up and top-down causal paths proposed by our literature-based theorization. The value of ABM as a quantitative theory development tool is demonstrated by prior management theory development (e.g., Almirall and Casadesus-Masanell 2010). By coding the theoretical premises into parameters and algorithms of a computer program, ABM serves as a flexible tool for researchers to conduct "what if" analyses (i.e., counterfactual conditionals) and obtain implications of theoretical propositions that are not easily envisioned in literature-based theorization (Simon 1996). Furthermore, researchers can statistically analyze numeric data generated by ABM simulations to verify whether the patterns of our causal paths are distinguishable from the patterns of random effects. This ensured the logical rigor of our reasoning. Our application of ABM is theory-building in nature because data for our quantitative analysis is generated by the computational representation of theory rather than from real-world observations.

相当于对理论做一个 μ+σ 的推理

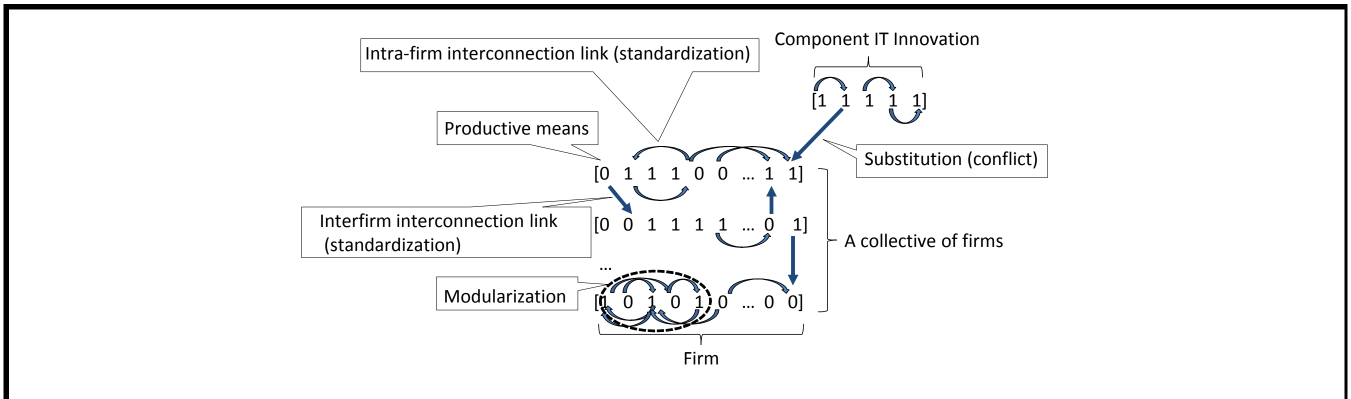

Figure 2. Overview of Agent-Based Model Design

Agent-Based Model Design

Our agent-based model design is based on a well-established approach that uses strings of digits to represent the agents and environment of a CAS (e.g., Levinthal 1997; Rivkin and Siggelkow 2007). Figure 2 depicts the key components in our agent-based model, which are described in detail below (see Appendix D for the model pseudo code).

In our CAS conception of hyperturbulence, *firms* are defined as agents that have strategic interactions with one another. A firm's *attributes* are characterized by a bundle of means that it possesses. Correspondingly, our agent-based modeling of hyperturbulence includes 20 firms that together form a collective where hyperturbulence can occur. There are 40 productive means represented by 40 digits in each firm. The number of firms and number of means in each firm are not meant to represent reality in a strict quantitative sense; instead, they are chosen for their effectiveness in generating theoretical insights (see Appendix B for sensitivity analysis). Each digit is initialized randomly with equal probabilities associated with 0 and 1, and then changed by the firm's applications of behavioral rules during a simulation session. A value of 0 indicates the firm's divestment from a productive means while a value of 1 indicates the firm's investment in a productive means.

Our conception of *architectural IT innovation* uses standardization and modularization as essential aspects. Standardization makes it easier to combine and recombine productive means (Tiwana et al. 2010; Yoo et al. 2010). In the agent-based model, the standardization of architectural IT innovations is represented by intra-firm interconnection links between means owned by the same firm, and interfirm interconnection links between means possessed by different firms. These intra-firm and interfirm interconnection links denote potential opportunities for firms to actualize combinations of means. An interconnection link can be synergistic or conflicting. This nature (synergy or conflict) is randomly assigned to each interconnection link with equal probability at the beginning of a simulation session and remains constant throughout the session. The actualization of combinations of means is determined by firm investment/divestment decisions (i.e., 0 or 1 of a digit value). An increase in the pervasiveness of architectural IT innovations leads to each digit's creation of two additional intra-firm interconnection links and one additional interfirm interconnection link.

Our agent-based model represents a module as a cluster of five means that have denser interconnection links among themselves than with those means outside the cluster (Baldwin and Clark 2000; Ethiraj and Levinthal 2004). With every increment in the pervasiveness of architectural IT innovations, each firm will form an additional cluster of means with five digits in the module. Each means first builds interconnection links with other digits in the same module according to the standardization implementation. Only when a digit exhausts all potential contacts in the same module will it build interconnection links with digits outside the module.

Firm performance is the average performance contribution of its productive means, consistent with firm performance calculation in prior research (e.g., Levinthal 1997). The complexity of firm performance is captured by the calculation of each means' performance contribution. To take into account intra-firm and interfirm interconnection links, each productive means' performance contribution is determined by its value, by the values of those other means in the same actualized combinations with the original means, and the nature of their interconnection links. Given the variations in digit values and interconnection link nature, each productive means has a multitude of potential performance contributions. Table 1 provides an example of the performance contributions of a means with respect to one interconnection link. In this table,

Table 1. Potential Performance Contributions of a Digit with Respect to One Interconnection Link

Focal Digit Value	Nature of the Interconnection Link	Alter† Digit Value	Performance Contribution	Interpretation
0	Synergistic	0	0	Neither the focal nor alter productive means receives investment. Thus, contribution to performance is zero.
		1	a random number from [0,1] distribution	Only the alter productive means receives investment and contributes independently to performance.
1		0	a random number from [0,1] distribution	Only the focal productive means receives investment and contributes independently to performance.
		1	a random number from [0,3] distribution	Investments in the focal and alter productive means are coordinated. Due to the synergy of the two productive means, the focal and the alter productive means together contribute synergistic performance over and above the sum of independent contributions of each productive means.
0	Conflicting	0	0	Neither the focal nor alter productive means receives investment. Thus, contribution to performance is zero.
		1	a random number from [0,1] distribution	Only the alter productive means receives investment and contributes independently to performance.
1		0	a random number from [0,1] distribution	Only the focal productive means receives investment and contributes independently to performance.
		1	a random number from [-2, 0] distribution*	Investments in the focal and alter productive means are uncoordinated. Due to the conflict of the two productive means, the focal and alter productive means together incur a negative return (i.e., a loss of investment).

†Alter digit connects to the focal digit. Alter digit and alter productive means are interchangeable terms.
*The range of the negative performance value [-2, 0] is chosen so that a firm's indiscriminate investment in all its productive means yields lower payoff than deliberate investment in a subset of productive means.

focal digit refers to the means whose performance contribution is being calculated. Alter digit is the means that the focal digit connects to via an intra-firm or interfirm link. The performance contributions exemplified in Table 1 ensure that combinations of synergistic, independent, and conflicting means make the highest, moderate, and lowest contributions respectively. Here "independent" refers to the cases that either the focal or alter productive means receives investment, but not both. Firms do not know the potential performance contributions of their means. They only observe the performance outcome of an actualized combination of productive means.

Behavioral rules govern a firm's search for the desired combination of means by preserving or changing values of digits in its string. In other words, to improve their performance firms decide which means to invest in or not, and to actualize a combination of synergistic and conflicting means. *The opportunity for IT to afford competitive advantage* is provided as the informational input regarding the synergistic or conflicting nature of interconnection links. We implemented three behavioral rules that integrate this role of information: internal search, external imitation, and responding to innovations.

Internal search represents a firm's attempts to improve its performance by adjusting its investment in or divestment from its means. To maximize the contribution of its bundle of means, a firm explores which combinations of means are likely to increase its performance outcome. Specifically, we allow a firm to flip the values of a pair of digits that are connected through an intra-firm interconnection link. If the new digit values result in performance improvement, the firm preserves the change. Otherwise, the pair of digits reverts to their previous values. Firms that are endowed with IT-enabled informational input (intelligence) can flip the values of the pair of digits according to the synergistic or conflicting nature of their interconnection. Firms without this intelligence flip the values of the pair of digits randomly. For example, Amazon continuously tests and adjusts combinations of its website features to improve performance. This website optimization is guided by the intelligence gained from data analytics.

External imitation concerns observing the combinations of productive means used by other firms, and imitating those with high performance. It involves replacing a firm's own module of productive means with an equivalent module from a higher-performing firm (Ethiraj and Levinthal 2004). Because modules are the basic unit of imitation, the imitation approach applies only when firms have at least one module. External imitation unfolds through several steps. First, a firm randomly chooses one of its own modules as the one to be replaced. Second, this firm identifies all equivalent and superior modules in other firms as the modules for imitation (exemplar modules). Here, *equivalent* denotes that digits in the two modules occupy the same node positions in their respective strings. *Superior* refers to two requirements: that the exemplar modules perform better than the module to be replaced, and that firms that own the exemplar modules have better performance than the focal firm. Third, if the focal firm has IT-enabled intelligence regarding the synergistic or conflicting nature of interconnection links, this firm would choose the exemplar module that has the largest number of similar interconnection links (in terms of nature and distribution) as the module to be replaced. Firms without this intelligence would choose randomly from the exemplar modules. Finally, the focal firm replaces digit values in its own module with those values in the exemplar module. These steps represent the transfer of best practices (Ethiraj and Levinthal 2004) such as the transfer of social media marketing practices from one firm to another.

Responding to incoming component IT innovations embodies a firm's effort to adapt to "creative destructions" caused by component IT innovations (Schumpeter 1942). When a new bundle of IT-enabled means enters the collective of firms, incumbent firms need to decide whether and how to combine these new means with their own. A wrong decision can reduce performance. In our implementation, if a firm has IT-enabled intelligence, we allow the firm to correctly understand the nature of the interconnection link between its own digits and those in the bundles of component IT innovations. If the firm lacks this intelligence, it randomly guesses the nature of the interconnection link between its means and the incoming component IT innovations.

We represent *component IT innovations* as new bundles of productive means entering the collective of incumbent firms and triggering recombination of means in the collective. Each bundle of component IT innovations is represented by a string of five digits. To simplify the representation, we gave all digits in a bundle of component IT innovations a value of 1 to represent coordinated investments in innovative productive means (our sensitivity test shows that randomly assigning 0 or 1 to the digits does not change the result). Each digit in the bundle builds one conflicting interconnection link with a randomly selected digit in one randomly selected firm. Prior research suggests that IT-enabled standardization and modularization of products and processes facilitate rapid recombination and reconfiguration of resources; this in turn can substantially increase the development rate of component IT innovations (Brynjolfsson and Saunders 2010). Therefore, if architectural IT innovation is in effect during a simulation, a new batch of component IT innovations will be introduced at each tenth clock tick during a simulation session that lasts for 100 clock ticks. The number of component IT innovations introduced is determined by the experimental condition (specified later).

The collective-level outcome is indicated by the time path of the average number of position changes per firm in the collective's performance rankings from one time clock tick to the next, consistent with the environmental turbulence indicator in previous empirical research (McAfee and Brynjolfsson 2008). A time path that portrays a large number of changes in firm performance ranking indicates high intensity of *hyperturbulence*.

Procedure of a Simulation Session

At the beginning of a simulation session, a population of 20 firms was created to represent a collective of incumbent firms. Ten randomly selected firms were endowed with IT-enabled intelligence, representing the opportunity for IT to contribute to competitive advantage by providing information regarding the synergistic or conflicting nature of each interconnection link. A simulation session runs through 100 clock ticks. A clock tick represents a strategic decision cycle. During each clock tick, every firm has an opportunity to pursue sustainable competitive advantage by executing its behavioral rules: internal search, external imitation, and responding to incoming component IT innovations (if component IT innovations are introduced). The order in which a firm executed these three rules was randomized. Digit values in a firm's string could change as a result of the firm's adaptations. However, the number, nature, and distribution of interconnection links remain constant throughout a simulation session. Firms could observe the performance outcome of their efforts, but did not know the performance payoff schedule of their means. At the end of a clock tick, the average number of position changes per firm in the performance ranking was calculated. As the agent-based model ran through a sequence of clock ticks, we obtained a time path of performance ranking changes. The agent-based model was implemented using the NetLogo toolkit (Wilensky 1999).

Model Validation and Proposition Testing

Before submitting our agent-based model design to proposition testing, we took three actions to ensure its validity. They include choosing conservative parameter values, conducting sensitivity tests of simulation results, and ensuring consistency between simulation findings and previous theory and evidence on hyperturbulence (see Appendix B for details).

Table 2. Experimental Treatments (Each experimental condition includes 30 simulation sessions)

Proposition	Experimental Treatment	Computational Representation
P1: component IT innovation → firm efforts to sustain competitive advantage → nonlinear firm performance ranking changes	9 conditions: • Number of bundles of component IT innovations increases from 0 to 8 • Pervasiveness of architectural IT innovation is 0	With each increment in the number of component IT innovations, an additional bundle of productive means was introduced at the beginning of a simulation session.
P2: architectural IT innovation → firm efforts to sustain competitive advantage → nonlinear firm performance ranking changes	9 conditions: • Pervasiveness of architectural IT innovation increases from 0 to 8 • Component IT innovation is 0	With each increment in the pervasiveness of architectural IT innovation, a digit built 2 additional intra-firm interconnection links, and 1 additional interfirm link; a firm formed an additional module.
P3: architectural IT innovation * component IT innovation → nonlinear firm performance ranking changes	81 conditions: • Number of bundles of component IT innovations increases from 0 to 8 • Pervasiveness of architectural IT innovation increases from 0 to 8	Component IT innovations and architectural IT innovation were manipulated as in experiments for P1 and P2.
P4: IT-enabled informational input (intelligence) → firm competitive advantage	2 conditions: • Firms with or without the intelligence	Half of the firms were endowed with the intelligence regarding the synergistic or conflicting nature of interconnection links.

Once we gained sufficient confidence in the validity of our model, we performed four "what if" analyses corresponding to the four propositions in our theoretical model. Table 2 provides an overview of experimental treatments implemented in the ABM.

Findings

Component IT Innovation and Hyperturbulence (P1)

Figure 3 shows the time path of changes in firm performance rankings resulting from the ABM experiment where varied numbers of component IT innovations are introduced. Since each firm has an opportunity to pursue sustainable competitive advantage in a clock tick, the contour of firm performance ranking changes over time indicates a nonlinear effect of recurrent firm efforts on collective-level outcome. Figure 3 also juxtaposes the time paths from the experiments where one and eight component IT innovations were respectively introduced. The time path associated with eight component IT innovations is generally higher than the time path of one component IT innovation, indicating the more pronounced nonlinear effect of a higher number of component IT innovations.

To verify the nonlinearity of the time paths depicted in Figure 3, we compared the goodness of fit for a few common nonlinear models and a linear model (see Figure 4 for the fitting of a linear model and a polynomial model). Since the linear and nonlinear models were not nested, we used Akaike's Information Criterion (AIC) to compare them (Motulsky and Christopoulos 2003). Lower AIC scores indicate less information loss and thereby a better fitting model. As shown in Table 3, nonlinear models have lower AIC scores than the linear model. Based on the AIC scores, a probability was calculated that a nonlinear model is the correct model for the given data compared with the linear model. All nonlinear models show high probabilities. This analysis supports the nonlinear effect of firm efforts on collective-level competitive outcomes.

In Figure 3, the prominence of nonlinear effects is indicated by the average height of a time path. To quantify the prominence of nonlinear effects of varied numbers of component IT innovations, we calculated the average changes in firm performance rankings for each experimental condition (see Table 4). OLS regression revealed a statistically significant positive relationship between the number of component IT innovations and average performance ranking change (β = 0.07, $p < 0.001$). This confirms that the nonlinear effect is more pronounced with a greater number of component IT innovations. Overall, P1 is supported by our simulation results.

The nonlinear effects prompted by component IT innovations can be illustrated by the turbulence in the photographic equipment industry. Component IT innovations such as digital imaging and digital printing replaced silver halide film and paper. These innovations instigated varied strategic responses by photographic equipment makers such as Kodak and Fuji,

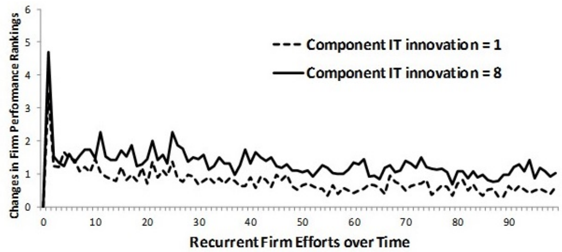

Figure 3. Nonlinear Effects Associated with Different Numbers of Component IT Innovations

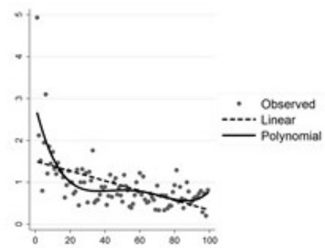

Figure 4. Effects of Recurrent Firm Efforts on Changes in Firm Performance Rankings

Table 3. Comparing Nonlinear Models with a Linear Model (Linear Model's AIC = 147)

	Polynomial	Quadratic	Cubic	Logarithmic
AIC	112	128	118	105
Probability of being the correct model compared with the linear model	99%	99%	99%	99%

Table 4. Impact of Component IT Innovations on Hyperturbulence

	Number of Component IT innovations								
	0	1	2	3	4	5	6	7	8
Average firm performance ranking changes per clock tick	0.57	0.68	0.82	0.79	0.93	1.07	1.10	1.11	1.22

Note: The analysis was done on a randomly selected sample from simulation data (2707 sample data points from a total of 540,000 simulation data points) due to concern that, "a key issue with applying small-sample statistical inference to large samples is that even minuscule effects can become statistically significant" (Lin et al. 2013, p.1).

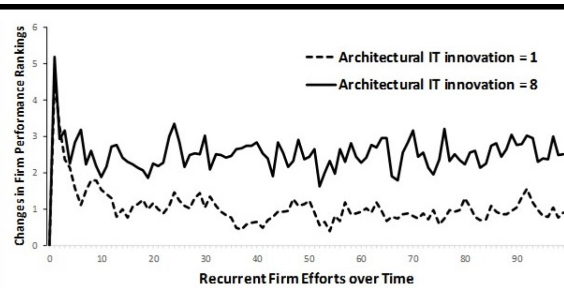

Figure 5. Nonlinear Effects Associated with Varied Pervasiveness of Architectural IT Innovations

Table 5. Comparing Nonlinear Models with a Linear Model (Linear Model's AIC = 205)

	Polynomial	Quadratic	Cubic	Logarithmic
AIC	201	201	203	198
Probability of being the correct model compared with the linear model	88%	88%	73%	97%

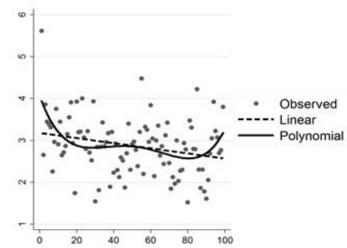

Figure 6. Effects of Recurrent Firm Efforts on Changes in Firm Performance Rankings

and these responses in turn aggregated to produce a substantial shift in performance ranking of these firms (e.g., the rise of Sony as a camera maker and the decline of Kodak).

Architectural IT Innovation and Hyperturbulence (P2)

Figure 5 shows nonlinear time paths resulting from the ABM experiment, with varied pervasiveness of architectural IT innovation. The path for high pervasiveness of architectural IT innovation is more pronounced than that for low. To verify this observation, we performed the same statistical analyses as used for P1.

AIC scores for the tested nonlinear models are consistently lower (better) than the scores of the linear model (see Table 5 for results and Figure 6 for depiction of linear and polynomial model fitting). The probabilities of nonlinear models being correct are high, indicating the high goodness of fit of nonlinear models compared with the fit of the linear model.

The average performance ranking changes that resulted from the nine experimental conditions are summarized in Table 6. The OLS analysis result shows that the prominence of nonlinear changes in firm performance ranking increases with the pervasiveness of architectural IT innovation (β = 0.37, p < 0.001). These results support P2. The rapid performance ranking changes in the mobile phone market exemplify P2. In recent years, mobile phones have evolved from standalone communication devices to interfaces to an ecosystem of millions of apps. The architectural IT innovation in the mobile phone market caused the decline of Nokia and Motorola and the rise of Apple, Samsung, Huawei, and Xiaomi.

Joint Effect of Component IT Innovation and Architectural IT Innovation (P3)

We test an OLS model with the interaction term of component IT innovation and architectural IT innovation, as well as the linear term of each. From the full dataset generated by the ABM experiment (4,860,000 observations), approximately 0.0006% of data (3025 data points) were selected for this analysis. Contrary to P3, the interaction term of component IT innovation and architectural IT innovation has a significant negative association with the average performance ranking change (β = -0.02, p = 0.046) (see Appendix C for full results). In other words, architectural IT innovation seems to dampen the effect of component IT innovation rather than amplify it. P3 is not supported by our simulation results. We will explore this surprising finding further, in the next section.

Opportunity for IT to Afford Competitive Advantage (P4)

In our agent-based model, IT-enabled intelligence was given to 50% of firms so that firms with this intelligence understood the synergistic or conflicting nature of interconnection links. By comparing performance of firms with and without this input, we could infer the opportunity for IT to contribute to a firm's competitive advantage. We reused the randomly selected sample (3025 data points) from the third experiment to evaluate P4.

A 3D graph with two performance surfaces was plotted to visualize the impact of IT-enabled intelligence on firm performance in conditions with varied numbers of component IT innovations and different degrees of architectural IT innova-

Table 6. Impact of Architectural IT Innovation

	Pervasiveness of Architectural IT Innovation								
	0	1	2	3	4	5	6	7	8
Average firm performance ranking changes per clock tick	0.56	2.02	2.34	2.71	3.05	3.25	3.43	3.64	3.91

Note: the analysis was done on a randomly selected sample from simulation data (2702 sample data points from a total of 540,000 simulation data points) to prevent ineffective statistical inference due to a big data set (Lin et al. 2013).

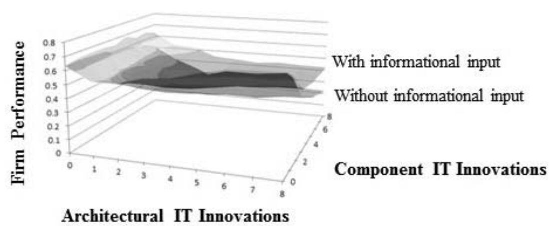

Figure 7. Impact of IT-Enabled Informational Input (Intelligence) on Firm Performance

tion (see Figure 7). In this graph, the performance surface associated with firms possessing intelligence is generally above the performance surface of firms without the input. This suggests the competitive advantage offered by IT-enabled intelligence regarding the nature of interconnection links. OLS regression shows a positive and statistically significant effect of IT-enabled intelligence on firm performance ($\beta = 0.08$, $p < 0.001$; see Appendix C), consistent with P4. Pant and Sheng (2015) provide an example of IT-enabled information regarding the nature of interconnection links. They developed online metrics based on the content, in-links, and out-links of firm websites to predict competitor relationships. These IT-enabled competitor metrics can help firms to gain competitive advantage by understanding their competitive landscape.

Extending Propositions via *Post Hoc* Analysis

A quantitative view of our propositions helped us to realize a few more opportunities to improve the precision of our theory development. More precise propositions can better serve as theoretical references for unifying granular theories regarding IT's role in hyperturbulence and competitive advantage. We therefore made another iteration of theorization.

First, in testing P1 and P2, we noticed that architectural IT innovation produced more pronounced and enduring non-linear time paths than component IT innovation (refer back to Figures 3 and 5). In our literature-based theorization, we argued that architectural IT innovations lead to hyperturbulence by enabling firms to recombine means in greater scope, scale, and speed. In our agent-based simulation, digit value changes in a firm's string indicate this firm's recombination of means. With simulation data, we calculated the number of digit value changes per clock tick per firm in the various experimental conditions (see Table 7).

This result indicates that component IT innovation's impact is mainly local and therefore can be quickly assimilated by the few firms that are directly affected by it. In contrast, architectural IT innovation's impact is far-reaching in a collective of firms. This far-reaching impact manifests as persistent changes in firm attributes and performance ranking. The differentiated effects of component versus architectural IT innovations help to explain why hyperturbulence became more prominent after 1995 when the internet was widely adopted in business (McAfee and Brynjolfsson 2008; Wiggins and Ruefli 2002).

Therefore, we elaborate on P1 and P2 as follows:

***P1 extension**: Component IT innovations act as an external force that **locally and temporally** disrupts incumbent firms' combination of productive means;*

***P2 extension**: Architectural IT innovations act as an internal force that **systematically and persistently** disrupts incumbent firms' combination of productive means.*

Table 7. Number of Digit Value Changes per Firm per Clock Tick

Number of Component IT innovations								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.25	0.26
Pervasiveness of architectural IT innovations								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0.20	1.41	1.78	2.15	2.39	2.67	2.97	3.25	3.57

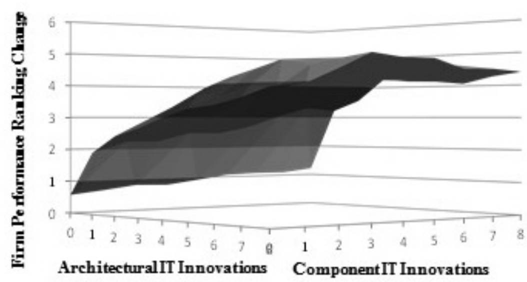

Figure 8. Joint Effect of Component and Architectural IT Innovations

The contradictory simulation finding in reference to P3 motivates us to rethink the joint effect of component and architectural IT innovations on firm performance ranking changes. A 3D graph for this joint effect (see Figure 8) suggests the existence of a nonlinear effect at high pervasiveness of architectural IT innovation. OLS regression shows that the quadratic term of the number of component IT innovations has a negative and significant coefficient (β = -0.05, $p < 0.001$), indicating an inverted U-shaped relationship between the number of component IT innovations and hyperturbulence. In addition, the interaction of the quadratic term and the pervasiveness of architectural IT innovations has a marginally significant, negative coefficient (β = -0.01, p = 0.055). This suggests that the inverted U-shaped relationship between component IT innovation and hyperturbulence tends to be intensified by the pervasiveness of architectural IT innovation. In order to further verify this insight, we tested the curvilinear effect of component IT innovation on hyperturbulence using data from the experiment for P1, where the pervasiveness of architectural IT innovation was held at zero. The quadratic term of component IT innovation is not significant (β = 0.003, p = 0.62), confirming the role of architectural IT innovation in moderating the relationship between component IT innovation and hyperturbulence from linear to inverted U-shape (see Appendix C).

This finding suggests that the role of architectural IT innovation is not limited to scaling up the impact of component IT innovation. After revisiting the strategy literature (Albert et al. 2015; McAfee and Brynjolfsson 2008; McKelvey 1999), we realized that architectural IT innovations also facilitate firms to coevolve with new productive means. Architectural IT innovations allow firms to build extensive interconnections with one another. As a result, firms can quickly share information about the arrival of new component IT innovations and coordinate their responses to these new means. This facilitating role of architectural IT innovations can become particularly salient at moderate to high degrees of component IT innovations, as coevolving with component IT innovations becomes especially critical in these situations. For example, when near-field communication (a component IT innovation) was introduced to smartphone platforms, firms quickly sensed its arrival via interfirm interconnections in the platforms and developed new apps (e.g., payment and file sharing apps) based on this innovation. Therefore, we elaborate on P3 as follows:

P3 extension: *Architectural IT innovation's scaling and facilitating effects are a pair of positive and negative feedback loops that respectively amplify and dampen the disruptive impact of component IT innovations, producing nonlinear effects on the intensity of hyperturbulence.*

Although information input to a firm's adaptive capability has a positive effect on its performance, a close inspection of Figure 7 suggests that the competitive advantage offered by IT-enabled intelligence is stronger when hyperturbulence is induced by component IT innovation than by architectural IT innovation. OLS regression shows that IT-enabled intelligence has a significant and positive effect on firm performance when only component IT innovation is introduced ($\beta = 0.06$, $p < 0.001$; see Appendix C), but a nonsignificant effect on firm performance when only architectural IT innovation is introduced ($\beta = 0.002$, $p = 0.73$; see Appendix C).

To make sense of the new findings, we revisited the CAS conception of uncertainty. CAS researchers conceptualize the role of information via two types of uncertainties: reducible and irreducible. According to Ashby's Law of Requisite Variety (Ashby 1956), when the variety of stimuli experienced by agents is less than the variety of responses encoded in agent behavioral rules, the phenomenon is comprised primarily of *reducible uncertainty*. Information allows firms to identify the state of a stimulus and execute the appropriate response accordingly (i.e., reduce uncertainty with information). On the other hand, if the variety of stimuli experienced by an agent exceeds the variety of responses encapsulated in this agent's behavioral rules, this phenomenon is dominated by *irreducible uncertainty* (Ashby 1956). Information regarding states of the stimuli is not sufficient to create productive actions because firms may not have an appropriate response for every state of stimuli.

Applying Ashby's Law of Requisite Variety to our study, we argue that hyperturbulence driven by component IT innovations is dominated by reducible uncertainty because the variety of stimuli associated with local and temporary disruption of component IT innovations is unlikely to exceed the variety of responses in terms of firm-centric recombination of means. By increasing the interactions of firms, architectural IT innovations can generate substantially more variety of stimuli than the variety of responses otherwise available. Therefore, hyperturbulence driven by architectural IT innovation is comprised primarily of irreducible uncertainty. The fierce competition among sellers on Alibaba's business-to-consumer online marketplace—Tmall.com—shows the limitation of IT-enabled intelligence in taming hyperturbulence. Even though sellers have access to market-data analytics provided by Alibaba, their data-driven strategic interactions in Tmall.com can offset each other's competitive advantage and intended performance gains. Therefore, we elaborate on P4 as follows:

P4 extension: *Information provided by IT is likely to have distinct impacts on reducible and irreducible uncertainties, and thereby have different effects on firm competitive advantage in hyperturbulent environments that are driven by component IT innovations, versus those driven by architectural IT innovations.*

The P4-extension indicates the limitation of IT-enabled intelligence in taming hyperturbulence driven by architectural IT innovations. A natural follow-up question is, in what other ways can IT contribute to competitive advantage? Inspired to find a way to improve firm performance by Ashby's thesis that, "only variety can destroy variety" (1956, p. 207), we explored the possibility of leveraging the generativity of architectural IT innovation that drives hyperturbulence.

Recall that generativity refers to "a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" (Zittrain 2006, p. 1980). This capacity to produce unprompted change was represented by the combination and recombination of means in our first iteration of ABM. While recombination is an important aspect of generativity, prior research indicates two additional ways for firms to produce unprompted changes: path creation (Boland et al. 2007) and distributed tuning (Eaton et al. 2015). *Path creation* is a firm's mindful deviation from a historically reinforced pattern of action in order to explore new practices (Garud and Karnøe 2001). Accordingly, we implemented a behavioral rule for path creation in the second iteration of ABM, allowing firms to mindfully renew some means and their associated links. In a clock tick, each firm identifies those digits whose performance contribution is one standard deviation below the average of all digit contributions. Then, a firm can reset the value of the low-performing digits and reset all interconnection links associated with the low performing digits. When this path creation rule is in effect and only architectural IT innovation is introduced, the prominence of nonlinear effects of firm's efforts on performance ranking levels off around moderate pervasiveness of architectural IT innovation (see Table 8). Of greater interest, average firm performance is higher than the condition without path creation (0.52 versus 0.37).

Distributed tuning is a democratic approach for a collective of firms to redefine the synergistic or conflicting nature of interconnection links (Eaton et al. 2015). For example, all independent developers who sell their apps in Apple's App Store jointly influenced Apple's initial decision to prevent in-app subscription and customer data control (Eaton et al. 2015). To implement distributed tuning, we allowed firms in our model to reevaluate 10% of their interconnection links in each clock tick (reevaluating a higher percentage of links produced similar results). Coordination among firms is represented by the restriction that the 10% of links to be reevaluated are associated with digits occupying the same positions in each firm's string of digits (e.g., all links to be reevaluated are associated with the first and second digits in the strings). Each firm has a 50% probability to reset their interconnection

Table 8. Impact of Architectural IT Innovation with Path Creation

	Pervasiveness of Architectural IT Innovation								
	0	1	2	3	4	5	6	7	8
Average firm performance ranking changes per clock tick	1.66	3.32	2.84	3.33	3.01	3.24	3.38	3.30	3.17

Table 9. Impact of Architectural IT Innovation with Distributed Tuning

	Pervasiveness of architectural IT Innovation								
	0	1	2	3	4	5	6	7	8
Average firm performance ranking changes per clock tick	1.50	3.19	3.19	3.68	2.94	3.53	3.28	3.33	3.31

links to the majority setting. Similar to the path creation rule, the distributed tuning rule prevents the prominence of nonlinear dynamics from monotonically increasing (see Table 9). Average firm performance is higher in the distributed tuning condition than with only architectural IT innovation (0.52 versus 0.37).

In both path creation and distributed tuning conditions, firms can reset the synergistic or conflicting nature of interconnection links. Such links are the venue for strategic interactions to take place. Therefore, active resetting of interconnection links by firms allows them to jointly shape their links toward greater productivity. Because architectural IT innovation acts as a generative organizing logic to increase interconnections, it also helps firms to reshape their interconnection links. Consequently, firms can improve their overall performance and prevent performance ranking changes from continuously escalating. We propose that,

P5: *Firms can exploit IT generativity to produce unprompted changes of interconnection links, and thereby relieve the performance challenge of hyperturbulence that is driven by architectural IT innovation.*

The contrast between Google and Yahoo is a good example of P5. Google developed the Android operating system which allows Google to define or influence its interconnection links with independent app developers and hardware makers. Yahoo on the other hand invested in discrete products and services (e.g., Yahoo Mail and Tumblr). Today, Google's parent company Alphabet is one of the largest public companies while Yahoo struggles to find real growth.

Discussion

Unifying the Promise and Challenge of IT in IS Strategy Literature

Prior research has shown both the promise and challenge of IT in business strategy. The multilevel perspective developed in this study shows that the challenge (i.e., IT-driven hyperturbulence) is a logical consequence of the bottom-up effect of IT's promise (i.e., the creative use of IT). Further, the promise of IT (i.e., IT-enabled business solutions) is redefined by the top-down effect of the IT-driven challenge. Within this multilevel perspective, we see the CAS-based conception of IT innovation as a unification point for promoting a cumulative tradition in IS strategy research.

IS researchers have long recognized the importance of an explicit conception of the IT construct in developing IS-specific theories (Orlikowski and Iacono 2001). This study contributes a new conception of IT based on CAS theory. By reducing the IT construct to component IT innovation and architectural IT innovation, we connect IT's role to distinct factors (firm attributes versus interactions) in a multilevel IS phenomenon. Our propositions indicate that when the loci of IT's direct impact are individual firm attributes (i.e., component IT innovation replacing existing means in a firm), the bottom-up nonlinear effect of firm strategic actions on hyperturbulence is less pronounced and persistent (P1 and P1-extension), and therefore IT-enabled intelligence is more likely to facilitate competitive advantage (P4 and P4-extension). On the other hand, when the loci of IT's direct impact are interactions of firms (i.e., architectural IT innovation increasing the interconnectivity of firms), the bottom-up nonlinear effect becomes more prominent and persistent (P2, P2-extension, P3, and P3-extension). Furthermore, generativity of IT is a potential solution to the performance challenge in hyperturbulence because generativity allows firms to reshape their strategic interaction patterns (P5).

The propositions of this study can unify seemingly contradictory observations of IT's role in sustainable competitive advantage. In particular, research that proposes a positive role for IT in gaining sustainable competitive advantage can speak to one of three things: component IT innovation's long-term impact on firm performance; the positive effect of IT-enabled intelligence to tame reducible uncertainty caused by component IT innovation; and the generativity of IT (e.g., path creation and distributed tuning) as a firm's source of internal variety that can destroy the external variety caused by architectural IT innovation. The streams of work that portray IT as a central catalyst in inducing hyperturbulence in effect capture the short-term nonlinear effects that are instigated by component IT innovation or ongoing nonlinear effects of architectural IT innovation. In addition, the difficulty in tackling irreducible uncertainty caused by architectural IT innovation can prompt research findings of a negative impact of IT on competitive advantage. Since component IT innovations and architectural IT innovations tend to coexist in today's firms, their respective effects can commingle and manifest as seemingly contradictory observations.

Unifying Novel and Traditional IS Strategy Research

Our CAS-based conception of IT is also a unification point between traditional and novel IS strategy research. Although the manifestation of IT systems is changing from standalone enterprise systems to open platforms, both old and new IT systems are integral in the cross-level causal paths between firms and their competitive environments. IS strategy theories developed in traditional contexts are mainly concerned with component IT innovations (the resource-based view of IT) and IT-enabled firm capabilities (agility, competitive intelligence, flexibility, digital options, and absorptive capacity). This traditional work provides important foundations for theorizing firm attributes and behavioral rules in digital ecosystems. Research on IT-business alignment, particularly the recent coevolutionary view, provides justification for bringing strategic interactions between firms to the center of IS research models. Together, traditional firm-centric theories and new interaction-centered research can produce timely insights into new IS strategy questions such as why firms increasingly use platform strategies or mergers and acquisitions to tackle hyperturbulence.

In addition to its theoretical direction, this study demonstrates the value of ABM as a quantitative approach for theory unification. The iterative dance between the literature-based theory development approach and ABM can help researchers to generate precise theoretical insights that would facilitate the comparison and collation of granular theories. Given IS researchers' familiarity with computing technology, there is a natural fit for IS researchers to employ ABM to explore and unify IT's nonlinear impacts in other complex IS phenomena.

Limitations

While the CAS lens focuses our theorization on IT-based strategic interactions between firms as the root of hyperturbulence, it ignores other possible drivers of hyperturbulence, such as lowered barriers to global markets, demand fluctuations, and business model innovation. Meanwhile, our conception of architectural IT innovation emphasizes the amount of interconnections between means. It does not capture the full spectrum of architectural decisions (e.g., whether to adopt host-based or peer-to-peer architecture). Future research could explore how factors outside the boundary of our theory development can modify the insights gained from this study. Our ABM implements behavioral rules that are necessarily fixed (agents cannot modify their behavioral rules) because we need to control the confounding effects of adaptive behavior variations. Future ABM could explore other parameter settings to engage firms in strategic interactions.

Conclusion

As emerging technologies such as the Internet of Things and artificial intelligence further enhance firm interactions and the generativity of strategies, hyperturbulence is likely to be a long-term challenge to business success. IS strategy research can equip practitioners with timely knowledge to tackle this. Recent commentaries (Bharadwaj et al. 2013; El Sawy et al. 2010) have expanded our research horizon beyond the boundaries of firms. The multilevel perspective of IS strategy offered here provides a bridge for researchers to integrate traditional theory on firm-centric IS strategy into a new generation of strategy insights, so that practitioners can harness IT advances as a fundamental driver of business success.

Acknowledgments

We are indebted to the senior editor, associate editor, and reviewers at *MIS Quarterly* for their guidance, encouragement, and support during the review process. This work benefitted from presentations at Temple University, HEC Montréal, the University of Texas at Austin, and China University of Geosciences. We thank Iris Vessey, Robert Zmud, and Izak Benbasat for reading and commenting on earlier versions of this paper. Hüseyin Tanriverdi would like to acknowledge and thank Timothy W. Ruefli for numerous inspiring discussions about the potential roles of IT in hyper-competition at the inception stages of this research.

References

Agarwal, R., and Tiwana, A. 2015. "Editorial-Evolvable Systems: Through the Looking Glass of IS," *Information Systems Research* (26:3), pp. 473-479.

Albert, D., Kreutzer, M., and Lechner, C. 2015. "Resolving the Paradox of Interdependency and Strategic Renewal in Activity Systems," *Academy of Management Review* (40:2), pp. 210-234.

Allen, P. 2001. "What Is Complexity Science? Knowledge of the Limits to Knowledge," *Emergence, A Journal of Complexity Issues in Organizations and Management* (3:1), 2001, pp. 24-42.

Allen, P. M., Varga, L., Strathern, M., Anderson, C. R., Baldwin, J., and Ridgway, K. 2009. "Complexity, Evolution and Organizational Science," Working Paper, School of Management, Cranfield University.

Almirall, E., and Casadesus-Masanell, R. 2010. "Open Versus Closed Innovation: A Model of Discovery and Emergence," *Academy of Management Review* (35:1), pp. 27-47.

Anderson, P. 1999. "Complexity Theory and Organization Science," *Organization Science* (10:3), pp. 216-232.

Arthur, W. B. 1994. "Inductive Reasoning and Bundled Rationality," *The American Economic Review* (84:2), pp. 406-411.

Arthur, W. B. 2009. *The Nature of Technology: What It Is and How It Evolves*, New York: Simon and Schuster.

Arthur, W. B. 2014. "Complexity Economics: A Different Framework for Economic Thought," Chapter 1 in *Complexity and the Economy*, Oxford, UK: Oxford University Press.

Ashby, W. R. 1956. *An Introduction to Cybernetics*, New York: John Wiley & Sons, Inc.

Bacharach, S. B. 1989. "Organizational Theories: Some Criteria for Evaluation," *Academy of Management Review* (14:4), pp. 496-515.

Baldwin, C. Y., and Clark, K. B. 2000. *Design Rules: The Power of Modularity*, Cambridge, MA: MIT Press.

Baregheh, A., Rowley, J., and Sambrook, S. 2009. "Towards a Multidisciplinary Definition of Innovation," *Management Decision* (47:8), pp. 1323-1339.

Benbasat, I., and Nault, B. R. 1990. "An Evaluation of Empirical Research in Managerial Support Systems," *Decision Support Systems* (6:3), pp. 203-226.

Benbya, H., and McKelvey, B. 2006. "Using Coevolutionary and Complexity Theories to Improve IS Alignment: A Multi-Level Approach," *Journal of Information Technology* (21:4), pp. 284-298.

Bharadwaj, A. S. 2000. "A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation," *MIS Quarterly* (24:1), pp. 169-196.

Bharadwaj, A., El Sawy, O. A., Pavlou, P. A., and Venkatraman, N. V. 2013. "Digital Business Strategy: Toward a Next Generation of Insights," *MIS Quarterly* (37:2), pp. 471-482.

Boisot, M., and McKelvey, B. 2010. "Integrating Modernist and Postmodernist Perspectives on Organizations: A Complexity Science Bridge," *Academy of Management Review* (35:3), pp. 415-433.

Boland Jr., R. J., Lyytinen, K., and Yoo, Y. 2007. "Wakes of Innovation in Project Networks: The Case of Digital 3-D Representations in Architecture, Engineering, and Construction," *Organization Science* (18:4), pp. 631-647.

Brynjolfsson, E., and Saunders, A. 2010. *Wired for Innovation: How Information Technology is Reshaping the Economy*, Cambridge, MA: MIT Press.

Cavusoglu, H., Raghunathan, S., and Cavusoglu, H. 2009. "Configuration of and Interaction between Information Security Technologies: The Case of Firewalls and Intrusion Detection Systems," *Information Systems Research* (20:2), pp. 198-217.

Chan, Y. E., Huff, S. L., Barclay, D. W., and Copeland, D. G. 1997. "Business Strategic Orientation, Information Systems Strategic Orientation, and Strategic Alignment," *Information Systems Research* (8:2), pp. 125-150.

Chan, Y. E., Sabherwal, R., and Thatcher, J. B. 2006. "Antecedents and Outcomes of Strategic IS Alignment: An Empirical Investigation," *IEEE Transactions on Engineering Management* (53:1), pp. 27-47.

Chen, D. Q., Mocker, M., Preston, D. S., and Teubner, A. 2010. "Information Systems Strategy: Reconceptualization, Measurement, and Implications," *MIS Quarterly* (34:2), pp. 233-259.

Cohen, W. M., and Levinthal, D. A. 1990. "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly* (35:1), pp. 128-152.

Conway, R. W., Johnson, B. M., and Maxwell, W. L. 1959. "Some Problems of Digital Systems Simulation," *Management Science* (6:1), pp. 92-110.

Davis, J. P., Eisenhardt, K. M., and Bingham, C. B. 2007. "Developing Theory Through Simulation Methods," *Academy of Management Review* (32:2), pp. 480-499.

Eaton, B., Elaluf-Calderwood, S., Sorensen, C., and Yoo, Y. 2015. "Distributed Tuning of Boundary Resources: The Case of Apple's iOS Service System," *MIS Quarterly* (39:1), pp. 217-243.

El Sawy, O. A., Malhotra, A., Park, Y., and Pavlou, P. A. 2010. "Seeking the Configurations of Digital Ecodynamics: It Takes Three to Tango," *Information Systems Research* (21:4), pp. 835-848.

El Sawy, O. A., and Pavlou, P. A. 2008. "IT-Enabled Business Capabilities for Turbulent Environments," *MIS Quarterly Executive* (7:3), pp. 139-150.

Ethiraj, S. K., and Levinthal, D. 2004. "Modularity and Innovation in Complex Systems," *Management Science* (50:2), pp. 159-173.

Financial Times. *Innovative Lawyers Report*, 2015.

Fine, C. H. 1998. *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, New York: Basic Books.

Garud, R., and Karnøe, P. 2001. "Path Creation as a Process of Mindful Deviation," in *Path Dependence and Creation*, R. Garud and P. Karnøe (eds.), Hillsdale, NJ: Lawrence Erlbaum Associates.

Gell-Mann, M. 1994. *The Quark and the Jaguar: Adventures in the Simple and the Complex*, New York: W. H. Freeman.

Gell-Mann, M. 2002. "What Is Complexity?," in *Complexity and Industrial Clusters: Dynamics and Models in Theory and Prac-*

tice, A. Quadrio Curzio and M. Fortis (eds), Heidelberg, Germany: Physica-Verlag, pp. 13-24.

Goes, P. B. 2014. "Editor's Comments: Big Data and IS Research," *MIS Quarterly* (38:3), pp. iii-viii.

Grewal, R., and Tansuhaj, P. 2001. "Building Organizational Capabilities for Managing Economic Crisis: The Role of Market Orientation and Strategic Flexibility," *Journal of Marketing* (65:2), pp. 67-80.

Henderson, R. M., and Clark, K. B. 1990. "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," *Administrative Science Quarterly* (35:1), pp. 9-30.

Holland, J. H. 1995. *Hidden Order: How Adaptation Builds Complexity*, New York: Basic Books.

Holland, J. H., Holyoak, K. J., Nisbett, R. E., and Thagard, P. R. 1986. *Induction*, Cambridge, MA: MIT Press.

Im, G., and Rai, A. 2008. "Knowledge Sharing Ambidexterity in Long-Term Interorganizational Relationships," *Management Science* (54:7), pp. 1281-1296.

Keen P, and Williams R. 2013. "Value Architectures for Digital Business: Beyond the Business Model," *MIS Quarterly* (37:2), pp. 643-647.

Kirschner, M., and Gerhart, J. 1998. "Evolvability," *Proceedings of the National Academy of Sciences* (95:15), pp. 8420-8427.

Levinthal, D. A. 1997. "Adaptation on Rugged Landscapes," *Management Science* (43:7), pp. 934-950.

Lin, M., Lucas Jr., H. C., and Shmueli, G. 2013. "Research Commentary—Too Big to Fail: Large Samples and the p-Value Problem," *Information Systems Research* (24:4), pp. 906-917.

McAfee, A., and Brynjolfsson, E. 2008. "Investing in the IT that Makes a Competitive Difference," *Harvard Business Review* (86:7/8), pp. 98-107.

McFarlan, W. F., McKenny, J. L., and Pyburn, P. 1983. "The Information Archipelago: Plotting a Course," *Harvard Business Review* (61:1), pp. 145-156.

McKelvey, B. 1999. "Avoiding Complexity Catastrophe in Coevolutionary Pockets: Strategies for Rugged Landscapes," *Organization Science* (10:3), pp. 294-321.

McKelvey, B. 2001. "Energising Order-Creating Networks of Distributed Intelligence: Improving the Corporate Brain," *International Journal of Innovation Management* (5:02), pp. 181-212.

Mendelson, H., and Pillai, R. R. 1998. "Clockspeed and Informational Response: Evidence from the Information Technology Industry," *Information Systems Research* (9:4), pp. 415-433.

Miller, J. H., and Page, S. E. 2007. *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*, Princeton, NJ: Princeton University Press.

Milgrom, P., and Roberts, J. 1995. "Complementarities and Fit Strategy, Structure, and Organizational Change in Manufacturing," *Journal of Accounting and Economics* (19:2/3), pp. 179-208.

Motulsky, H. J., and Christopoulos, A. 2003. *Fitting Models to Biological Data Using Linear and Nonlinear Regression: A Practical Guide to Curve Fitting*, San Diego, CA: GraphPad Software Inc.

Nan, N. 2011. "Capturing Bottom-Up Information Technology Use Processes: A Complex Adaptive Systems Model," *MIS Quarterly* (35:2), pp. 505-532.

Nevo, S., and Wade, M. R. 2010. "The Formation and Value of IT-Enabled Resources: Antecedents and Consequences of Synergistic Relationships," *MIS Quarterly* (34:1), pp. 163-183.

Nicolis, G., and Prigogine, I. 1989. *Exploring Complexity: An Introduction*, New York: St. Martin's Press.

Oh, W., and Pinsonneault, A. 2007. "On the Assessment of the Strategic Value of Information Technologies: Conceptual and Analytical Approaches," *MIS Quarterly* (31:2), pp. 239-265.

Orlikowski, W. J., and Iacono, C. S. 2001. "Research Commentary— Desperately Seeking the 'IT' in IT Research: A Call to Theorizing the IT Artifact," *Information Systems Research* (12:2), pp. 121-134.

Overby, E., Bharadwaj, A., and Sambamurthy, V. 2006. "Enterprise Agility and the Enabling Role of Information Technology," *European Journal of Information Systems* (15:2), pp. 120-131.

Pant, G., and Sheng, O. R. 2015. "Web Footprints of Firms: Using Online Isomorphism for Competitor Identification," *Information Systems Research* (26:1), pp. 188-209.

Pavlou, P. A., and El Sawy, O. A. 2006. "From IT Leveraging Competence to Competitive Advantage in Turbulent Environments: The Case of New Product Development," *Information Systems Research* (17:3), pp. 198-227.

Porter, M., and Siggelkow, N. 2008. "Contextuality Within Activity Systems and Sustainability of Competitive Advantage," *The Academy of Management Perspectives* (22:2), pp. 34-56.

Rivkin, J. W., and Siggelkow, N. 2007. "Patterned Interactions in Complex Systems: Implications for Exploration," *Management Science* (53:7), pp. 1068-1085.

Rogers, M. E. 2003. *Diffusion of Innovation* (5th ed.), New York: Free Press.

Sabherwal, R., Hirschheim, R., and Goles, T. 2001. "The Dynamics of Alignment: Insights from a Punctuated Equilibrium Model," *Organization Science* (12:2), pp. 179-197.

Sambamurthy, V., Bharadwaj, A., and Grover, V. 2003. "Shaping Agility Through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms," *MIS Quarterly* (27:2), pp. 237-263.

Schumpeter, J. 1942. *Capitalism, Socialism and Democracy*, New York: Harper & Brothers.

Simon, H. A. 1996. *The Science of Design: Creating the Artificial*, Cambridge, MA: MIT Press.

Tai, L., and Phelps, R. 2000. "CEO and CIO Perceptions of Information Systems Strategy: Evidence from Hong Kong," *European Journal of Information Systems* (9:3), pp. 163-172.

Tanriverdi, H., Rai, A., and Venkatraman, N. 2010. "Reframing the Dominant Quests of Information Systems Strategy Research for Complex Adaptive Business Systems," *Information Systems Research* (21:4), pp. 822-834.

Tiwana, A. 2008. "Does Technological Modularity Substitute for Control? A Study of Alliance Performance in Software Outsourcing," *Strategic Management Journal* (29:7), pp. 769-780.

Tiwana, A., Konsynski, B., and Bush, A. A. 2010. "Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics," *Information Systems Research* (21:4), pp. 675-687.

van Oosterhout, M., Waarts, E., and van Hillegersberg, J. 2006. "Change Factors Requiring Agility and Implications for IT," *European Journal of Information Systems* (15:2), pp. 132-145.

Vessey, I., and Ward, K. 2013. "The Dynamics of Sustainable IS Alignment: The Case for IS Adaptivity," *Journal of the Association for Information Systems* (14:6), pp. 283-311.

Wade, M., and Hulland, J. 2004. "*Review:* The Resource-Based View and Information Systems Research: Review, Extension, and Suggestions for Future Research," *MIS Quarterly* (28:1), pp. 107-142.

Wiggins, R. R., and Ruefli, T. W. 2002. "Sustained Competitive Advantage: Temporal Dynamics and the Incidence and Persistence of Superior Economic Performance," *Organization Science* (13:1), pp. 81-105.

Wilensky, U. 1999. "Netlogo, Center for Connected Learning and Computer-Based Modeling," Northwestern University, Evanston, IL.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724-735.

Zheng, Z., Fader, P., and Padmanabhan, B. 2012. "From Business Intelligence to Competitive Intelligence: Inferring Competitive Measures Using Augmented Site-Centric Data," *Information Systems Research* (23:3-part-1), pp. 698-720.

Zittrain, J. L. 2006. "The Generative Internet," *Harvard Law Review* (119:7), pp. 1974-2040.

About the Authors

Ning Nan is an assistant professor of Management Information Systems in the Sauder School of Business at the University of British Columbia. Her research applies the complex adaptive systems paradigm to examinations of the uses and impact of information and communication technology in business systems. She combines agent-based simulation and traditional research methods in her work. Her current research and teaching focuses on digital business strategy. Ning Nan has published in *MIS Quarterly, Journal of Management Information Systems, Journal of the Association for Information Systems,* and *IEEE Transactions on Software Engineering*, among others. She received her Ph.D. in Business Information Technology from University of Michigan's Ross School of Business and her M.A. in Mass Communication from the University of Minnesota.

Hüseyin Tanriverdi is an associate professor of information, risk, and operations management at the Red McCombs School of Business at the University of Texas at Austin. His research and teaching examine how organizations innovate, profitably grow, and achieve and renew competitive advantages in hypercompetitive industries. He studies digital business strategies, IT, and knowledge management capabilities that enable a firm to scale up efficiencies and learning while minimizing risks across businesses and regions of the firm. He also studies IT-enabled analytics capabilities that enable a firm to read market dynamics and make winning decisions in real time. Hüseyin teaches courses on strategic IT management, IT governance for enterprise risk management and regulatory compliance, and management of emerging information technologies. His research has been published in information systems journals such as *Information Systems Research, MIS Quarterly, Journal of the Association for Information Systems,* and *European Journal of Information Systems*, and management journals such as *Academy of Management Journal* and *Strategic Management Journal*. His publications received Best Published Paper Awards from the Organizational Communications and Information Systems Division of the Academy of Management and the Telemedicine Journal.

MIS Quarterly

THEORY & REVIEW

UNIFYING THE ROLE OF IT IN HYPERTURBULENCE AND COMPETITIVE ADVANTAGE VIA A MULTILEVEL PERSPECTIVE OF IS STRATEGY

Ning Nan
Management Information Systems Division, Sauder School of Business, The University of British Columbia,
2053 Main Mall, Vancouver BC V6T 1Z2 CANADA {ning.nan@sauder.ubc.ca}

Hüseyin Tanriverdi
Department of Information, Risk, and Operations Management, Red McCombs School of Business,
The University of Texas at Austin, Austin, TX 78712 U.S.A. {huseyin.tanriverdi@mccombs.utexas.edu}

Appendix A

Overview of IS Strategy Literature Streams

Literature Stream	Sample References	Level of Analysis	Main Arguments	How Is it Synthesized into Our Theorization?
IT and industry competitiveness	Fine 1998; Mendelson and Pillai 1998; McAfee and Brynjolfsson 2008	Collective (industry)	Turbulences in a competitive environment can be endogenously generated from IT-based firm strategic actions.	It provides the foundation for the collective-level conception in our multilevel perspective.
IT-business alignment	Benbya and McKelvey 2006; Tanriverdi et al. 2010; Vessey and Ward 2013	Collective and firm	A co-evolutionary theoretical lens is appropriate for capturing the dynamic nonlinear relationships between turbulent environments and business strategy, as well as IT's role in supporting business strategy.	It provides the foundation for a bi-directional (coevolutionary) causal relationship between hyperturbulence and firm strategic actions, and the changing role of IT to enable competitive advantage.
Resource-based view of IT	Nevo and Wade 2010; Wade and Hulland 2004	Firm	IT is manifested by specific firm assets and enterprise information systems.	It provides the foundation for our conception of component IT innovation.
Digital innovation	Tiwana et al. 2010; Yoo et al. 2010	Firm (product)	Digital innovation allows business products and processes to continuously create and recreate themselves by combining modularized productive means via standardized interfaces.	It provides the foundation for our conception of architecture IT innovation.
Dynamic capabilities	El Sawy et al. 2010	Firm	Turbulent environments require dynamic and improvisational capabilities.	It provides the foundation for our conception of firm adaptive capabilities.

Literature Stream	Sample References	Level of Analysis	Main Arguments	How Is it Synthesized into Our Theorization?
Enterprise Agility	Sambamurthy et al. 2003; Overby et al. 2006; van Oosterhout et al. 2006	Firm	Agility is an important subset of dynamic capabilities. It's the ability to sense and respond to changes in the environment.	It provides the foundation for our conception of the opportunity for IT to contribute to firm adaptive capabilities and ultimately competitive advantage.
Digital options	Sambamurthy et al. 2003	Firm	Digital options are building blocks of dynamic capabilities. They coevolve with agility.	It provides the foundation for our conception of firm adaptive capabilities and ABM representation of productive means.
Competitive intelligence	Pant and Sheng 2015; Zheng et al. 2012	Firm	Competitive intelligence is integral to the sensing component of agility. It can help firms to more accurately identify the changes in the competitive landscape	It provides the foundation for our conception of the opportunity for IT to contribute to firm adaptive capabilities and ultimately competitive advantage.
Absorptive capacity	Cohen and Levinthal 1990	Firm	Absorptive capacity is integral to dynamic capabilities. It is the continuous acquisition, search, management of knowledge.	It provides the foundation for our conception of the ongoing and recurrent applications of firm adaptive capabilities.
Strategy search as hill climbing (NK model)	Levinthal 1997; McKelvey 1999	Collective and firm	A firm's effort to coevolve with competitive environment can be visualized as hill climbing in a rugged landscape.	It provides the foundation for our conception and ABM representation of firm adaptive capability and strategic interaction.

Appendix B

Agent-Based Model Validation and Sensitivity Analysis

We took three actions to ensure validity of our agent-based model design. First, we chose conservative parameter values so that without experimental treatments the baseline parameter setting alone is unlikely to produce the expected simulation results. For example, previous agent-based strategy modeling research (e.g., Ethiraj and Levinthal 2004; Ethiraj et al. 2008; Levinthal 1997; Rivkin and Siggelkow 2007) showed that the number of interconnection links among productive means is positively related to the difficulty for firms to achieve and maintain superior performance. By restricting the initial value of interconnection links to small numbers (1 interfirm link and 2 intra-firm links) we can attribute simulation results to the theoretical propositions codified in the experimental treatments rather than the baseline parameter values.

Second, the simulation results regarding our P1 and P2 are qualitatively consistent with the well-known "creative destruction" argument (Schumpeter 1942) and IT's impact on industry competitiveness (McAfee and Brynjolfsson 2008) respectively. Furthermore, the probabilities for a firm to remain in a performance stratum in our simulation are quantitatively comparable (see Table B1 below) to those in the empirical study by Wiggins and Ruefli (2002). Consistent qualitative and quantitative results provide grounds for belief that the agent-based model can serve as a theorization tool for further development and testing of our propositions.

Finally, we performed sensitivity tests of the simulation results across a range of values for each parameter in the model. Results are summarized in the Table B2. These results indicate that qualitative insights from our model are robust against changes in parameter values.

Table B1. Probabilities for a Firm to Transit Between Performance Strata from One Time Period to the Next

To / From	Top 15% Stratum	Middle 70% Stratum	Bottom 15% Stratum
Top 15% stratum	0.764 (0.784)	0.181 (0.195)	0.003 (0.021)
Middle 70% stratum	0.042 (0.038)	0.890 (0.919)	0.036 (0.042)
Bottom 15% stratum	0.015 (0.030)	0.208 (0.208)	0.847 (0.762)

Note: Numbers outside parentheses are simulation results while those in parentheses are from Table 7 in Wiggins and Ruefli (2002).

Table B2. Summary of Sensitivity Tests

Parameters	Values Tested	Results
Number of digits in a firm's string	• 20 • 60	Varied number of digits has no systematic effect on firm performance ranking change. Firm performance increases slightly with the number of nodes.
Number of intra-firm links and interfirm links originated from each digit	• 4 intra-firm and 1 interfirm links • 1 intra-firm and 4 interfirm links	The average firm performance ranking change increases with higher number of interfirm links. Firm performance increases slightly as the total number of links increases.
Number of firms	• 10 • 40	The average firm performance change increases with the number of firms. Varied number of firms has no systematic effect on firm performance.
Number of digits in each bundle of component IT innovations	• 10 • 40	The effect of component IT innovations on firm performance ranking change becomes slightly more pronounced with increased number of digits. Firm performance decreases with increased number of digits.
Number of links from each digit in a bundle of component IT innovation to existing digits in incumbent firms	• 2 • 5	Varied number of links from component IT innovations to incumbent firms has no systematic effect on firm performance ranking change. Firm performance increases with the increased number of links.
Digit values in a bundle of component IT innovation	• Randomly set at 0 or 1 with equal probability	The average firm performance ranking change is consistent the result from the initial value of all 1s (average ranking change from 0 to 8 innovations: 0.58, 0.68, 0.76, 0.90, 1.00, 1.14, 1.20, 1.37, 1.46).
Module size	• 2 • 10	The average firm performance ranking change reduces slightly as module size increases. Firm performance decrease slightly as module size increases.
Number of clock ticks in a simulation session	• 50 • 200	Effect of component IT innovations on firm performance ranking change diminishes with increased number of clock ticks. Architectural IT innovation's effect on firm performance ranking change does not diminish with increased clock ticks. Number of clock ticks has no systematic effect on firm performance.
Number of simulation sessions in each experimental condition	• 10 • 50 • 250	Number of simulation sessions has no systematic impact on firm performance ranking change or firm performance.

Appendix C

Post Hoc Analysis Results

		P3†	P3 Extension†	P3 Extension	P4	P4 Extension	P4 Extension
Number of component IT innovations	β	0.13	0.13	0.07	-0.03	-0.008	
	p	< 0.001	< 0.001	0.12	< 0.001	< 0.001	
Pervasiveness of architectural IT innovations	β	0.36	0.42		-0.01		0.02
	p	< 0.001	< 0.001		< 0.001		< 0.001
Number of component IT innovations * pervasiveness of architectural IT innovations	β	-0.02	-0.02				
	p	0.046	0.034				
(Number of component IT innovations)^2	β		-0.05	0.003			
	p		< 0.001	0.62			
(Number of component IT innovations)^2 * pervasiveness of architectural IT innovations	β		-0.01				
	p		0.055				
IT-enabled informational input	β				0.08	0.06	0.002
	p				< 0.001	< 0.001	0.73
Constant	β	3.61	3.96	0.56	0.58	0.62	0.56
	p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
N		3025	3025	2707	3025	2707	2702
F		63.57	42.80	27.67	245.29	77.74	213.71
R^2		0.06	0.06	0.02	0.20	0.05	0.14

†Independent variables in these models are centered around mean to prevent the multicollinearity concern.
Dependent variable: the average firm performance ranking change in the collective of firms.

Appendix D

Pseudo-Code of the Agent-Based Model

```
Let the model user set the number of component IT innovations
\\ This is an experiment treatment for proposition testing

Let the model user set the pervasiveness of architectural IT innovations
\\ This is an experiment treatment for proposition testing

Let the model user set firm path creation to true or false
\\ This is an experiment treatment for the post hoc analysis of IT generativity

Let the model user set distributed tuning to true or false
\\ This is an experiment treatment for the post hoc analysis of IT generativity

Setup firms {
\\ This procedure creates firms and defines their attributes.
    Create 20 firms with each firm possessing 40 productive means (i.e., a string of 40 digits)
    Set the value of each digit in a firm's string as either 0 or 1 with equal probability
    Set IT-enabled information input of each firm as true or false with equal probability
}

Setup interconnection links {
\\ This procedure implements the pervasiveness of architectural IT innovation

    IF pervasiveness of architectural IT innovation > 0 [
    Set the number of repeats = pervasiveness of architectural IT innovation
    Repeat the number of repeats [
    Assign each firm's leftmost 5 digits that have not been assigned to a module to a new module
    ]

    ]
    Set K=2 + (pervasiveness of architectural IT innovation * 2)
    Ask each digit in a firm's string to create K outgoing links to digits in the same module
    IF there is no other digit left in the same module for links, set the outgoing links to digits outside the module
    Set each link as synergistic or conflicting with equal probability

    Set C= 1 + pervasiveness of architectural IT innovation
    Ask each digit in a firm's string to create C outgoing links to digits in other firms' corresponding modules (a corresponding model
    occupies the same digit positions as the focal digit's module)
    Set each link as synergistic or conflicting with equal probability
}

Setup fitness payoff schedule {
\\ This payoff schedule is unknown to firms.

    Ask each digit {
        For each of my outgoing link {
        If the link is synergistic [
        Set fitness (0, 0) = 0 \\ the first number in the parentheses is the focal digit's value,
        \\ the second number in the parentheses is the alter digit's value
        Set fitness (0,1) = a random number from [0,1] distribution
        Set fitness (1,0) = a random number from [0,1] distribution
        Set fitness (1,1) = fitness (0,1) + fitness (1,0) + a random number from [0,1] distribution
        ]
```

```
        If the link is conflicting [
        Set fitness (0,0) = 0
        Set fitness (0,1) = a random number from [0,1] distribution
        Set fitness (1,0) = a random number from [0,1] distribution
        Set fitness (1,1) = a random number from [-2,0] distribution
        ]
        }
    }
}

Run one tick of the model clock {

    IF number of component IT innovations > 0 [Introduce-component-IT-innovation]
    IF number of component IT innovations > 0 and pervasiveness of architectural IT innovation > 0 and it is the 10th clock tick [Introduce-
    component-IT-innovation]
    Ask firms to [Compete-and-adapt] \\ call the Compete-and-adapt procedure
    IF firm path creation is TRUE [Path-creation]
    IF distributed tuning is TRUE [Distributed-tuning]

    Record-result \\ call the Record-result procedure at the end of each simulation run
    Tick \\ increase the internal clock ticks by one
}

Repeat [Run one tick of the model clock] 100 times \\ This produces recurrent firm strategic
\\ actions and the time paths of their nonlinear effects

Compete-and-adapt {
\\ This procedure implements a firm's behavioral rules: internal search, external imitation, and
\\ responding to innovations.
    Randomize the order of executing the three behavioral rules below [
    // below is the internal search rule
    Ask each firm {
        Choose a pair of digits in its string of digits
        IF this firm has IT-enabled informational input
        [RESET the values of the selected pair of digits according to the synergistic/conflicting nature of the interconnection link between
        them]
        ELSE
        [RESET the values of the selected pair of digits randomly]
        If firm performance after resetting the pair of digits > firm performance before
        [Keep the new values]
        Else [revert to the previous values]
        \\ end of the internal search rule.

        \\ below is the external imitation rule
        IF pervasiveness of architectural IT innovation > 0 [
            ASK each firm [
                Choose one of my modules as the to-be-replaced module
                Select the set of other firms whose fitness is greater than mine
                Select the exemplar modules that are in the selected firms, occupy the same digit positions as the to-be-replaced module,
                and have higher fitness than the to-to-replaced module
                IF this firm has IT-enabled informational input
                [Select the one exemplar module that has the best match in terms of distribution and nature of interconnection links]
                ELSE
                [Select one module randomly from all exemplar modules]
        ]
        ]
        \\ end of the external imitation rule
```

```
        \\ below is the responding to component IT innovation rule
        IF number of component IT innovation > 0 [
        Ask each firm [
        IF this firm has IT-enabled informational input
        [RESET the values of the digits affected by a component IT innovation according to the synergistic/conflicting nature of the
        interconnection links between my digits and the component innovation's digits]
        ELSE
        [RESET the values of the digits affected by a component IT innovation randomly]
        ]
        ]
        \\ end of the responding to component IT innovation rule
        ]
        ]
    }
}

Path-creation {
    Ask each firm [
        Find low-performing digits whose fitness contributions are one standard deviation below the average fitness contributions of all digits
        in all firms
        Reset each low-performing digit value as either 0 or 1 with equal probability
        Reset each interconnection link of low-performing digits as synergistic or conflicting with equal probability
]
}

Distributed-tuning {
    Ask randomly selected 10% of all interconnection links [
        Find my equivalent links (i.e., links whose two node digits occupy the same digit positions as mine)
        Find the majority link nature of my equivalent links
        Reset my link nature to the majority link nature with 50% probability
]
}

Calculate-fitness {
    Set each digit's fitness contribution = MEAN (all this digit's outgoing links' actualized fitness values)
    ]
    Set each firm's fitness = MEAN (all this firm's digits' fitness values)
}

Introduce-component-IT-innovation {
    Create the model user specified number of component IT innovations [
    Create 5 digits in each component IT innovation [
    Set digit value to 1
    Create an outgoing link to a randomly selected digit in one of incumbent firms [
    Set the nature of the outgoing link to conflicting
    ]
    ]
    ]
}

Record-result {
\\ This procedure will specify all the data values we want to collect from the simulations.
    Record each firm's performance ranking
    Record each firm's fitness
    Record number of digit value changes in each firm
    Record current experimental treatment
    Record current clock tick
}
```

References

Benbya, H., and McKelvey, B. 2006. "Using Coevolutionary and Complexity Theories to Improve IS Alignment: A Multi-Level Approach," *Journal of Information Technology* (21:4), pp. 284-298.

Cohen, W. M., and Levinthal, D. A. 1990. "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly* (35:1), pp. 128-152.

El Sawy, O. A., Malhotra, A., Park, Y., and Pavlou, P. A. 2010. "Seeking the Configurations of Digital Ecodynamics: It Takes Three to Tango," *Information Systems Research* (21:4), pp. 835-848.

Ethiraj, S. K., and Levinthal, D. 2004. "Modularity and Innovation in Complex Systems," *Management Science* (50:2), pp. 159-173.

Ethiraj, S. K., Levinthal, D., and Roy, R. R. 2008. "The Dual Role of Modularity: Innovation and Imitation," *Management Science* (54:5), pp. 939-955.

Fine, C. H. 1998. *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, New York: Basic Books.

Levinthal, D. A. 1997. "Adaptation on Rugged Landscapes," *Management Science* (43:7), pp. 934-950.

McAfee, A., and Brynjolfsson, E. 2008. "Investing in the IT that Makes a Competitive Difference," *Harvard Business Review* (86:7/8), pp. 98-107.

McKelvey, B. 1999. "Avoiding Complexity Catastrophe in Coevolutionary Pockets: Strategies for Rugged Landscapes," *Organization Science* (10:3), pp. 294-321.

Mendelson, H., and Pillai, R. R. 1998. "Clockspeed and Informational Response: Evidence from the Information Technology Industry," *Information Systems Research* (9:4), pp. 415-433.

Nevo, S., and Wade, M. R. 2010. "The Formation and Value of IT-Enabled Resources: Antecedents and Consequences of Synergistic Relationships," *MIS Quarterly* (34:1), pp. 163-183.

Overby, E., Bharadwaj, A., and Sambamurthy, V. 2006. "Enterprise Agility and the Enabling Role of Information Technology," *European Journal of Information Systems* (15:2), pp. 120-131.

Pant, G., and Sheng, O. R. 2015. "Web Footprints of Firms: Using Online Isomorphism for Competitor Identification," *Information Systems Research* (26:1), pp. 188-209.

Rivkin, J. W., and Siggelkow, N. 2007. "Patterned Interactions in Complex Systems: Implications for Exploration," *Management Science* (53:7), pp. 1068-1085.

Sambamurthy, V., Bharadwaj, A., and Grover, V. 2003. "Shaping Agility Through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms," *MIS Quarterly* (27:2), pp. 237-263.

Schumpeter, J. 1942. *Capitalism, Socialism and Democracy*, New York: Harper & Brothers.

Tanriverdi, H., Rai, A., and Venkatraman, N. 2010. "Reframing the Dominant Quests of Information Systems Strategy Research for Complex Adaptive Business Systems," *Information Systems Research* (21:4), pp. 822-834.

Tiwana, A., Konsynski, B., and Bush, A. A. 2010. "Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics," *Information Systems Research* (21:4), pp. 675-687.

van Oosterhout, M., Waarts, E., and van Hillegersberg, J. 2006. "Change Factors Requiring Agility and Implications for IT," *European Journal of Information Systems* (15:2), pp. 132-145.

Vessey, I., and Ward, K. 2013. "The Dynamics of Sustainable IS Alignment: The Case for IS Adaptivity," *Journal of the Association for Information Systems* (14:6), pp. 283-311.

Wade, M., and Hulland, J. 2004. "*Review:* The Resource-Based View and Information Systems Research: Review, Extension, and Suggestions for Future Research," *MIS Quarterly* (28:1), pp. 107-142.

Wiggins, R. R., and Ruefli, T. W. 2002. "Sustained Competitive Advantage: Temporal Dynamics and the Incidence and Persistence of Superior Economic Performance," *Organization Science* (13:1), pp. 81-105.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724-735.

Zheng, Z., Fader, P., and Padmanabhan, B. 2012. "From Business Intelligence to Competitive Intelligence: Inferring Competitive Measures Using Augmented Site-Centric Data," *Information Systems Research* (23:3-part-1), pp. 698-720.