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An Evolutionary Theory of Innovation and Strategic Platform Openness for Web 2.0 Businesses

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Keywords: Business Strategy, Co-Creation, Evolutionary Theory, Innovation Diffusion, Intellectual Property Rights, Open Source, Web 2.0

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Introduction

Web 2.0 refers to both a software technology and a business paradigm shift that has occurred in the recent years with the adoption of more open technology platforms and the design of more open business models by companies across industries (O'Reilly, 2005). While the first generation of Web businesses (Web 1.0) were largely focused on delivering firm-developed, closed products and services top-down through a centrally managed server to customers, Web 2.0 businesses are designed to invite bottom-up user participation, including, information sharing and collaborative content reuse.

For the purpose of this paper, we thus define Web 2.0 businesses as organizations which offer service platforms built with Web 2.0 technology that implement features to support collaborative and participatory interactions with customers and third party developers. Our definition of Web 2.0 businesses consists of online businesses whose Web 2.0 service platforms are at the core of their business model (Web 2.0 business model).

Typical business examples include online community review and rating (Amazon, Netflix), social bookmarking (Del.icio.us, Furl), online social networking (MySpace, Facebook), blogging (Blogspot), wikis (Wikipedia, HowTo), peer-to-peer file and content sharing (Napster, YouTube, Flickr, Slashdot), mashup (Google Maps), music remix (ccMixter), interactive recommendation systems

(Pandora), mobile applications on smartphones (Shazam on Apple's iPhone and RIM's Blackberry), massively multiplayer online games (Half-Life, World of Warcraft) and virtual worlds (Second Life). Our definition of Web 2.0 businesses also extends to businesses, such as Barnes and Nobles and Apple, which implement Web 2.0 platforms to support one or several particular customer services (Web 2.0 enabled businesses). While Web 2.0 platforms and features are implemented as software applications, we are not concerned with issues of software development but rather view Web 2.0 platforms and their features as domain-specific capabilities that are made available to users.

Like other knowledge-based services, the sustained competitive advantage of Web 2.0 businesses lies in their innovative capability and their aptitude to meet users' needs through continuous improvement of the design of their service offerings (Quinn et al., 1997). A superior ability to satisfy users may allow some Web 2.0 businesses to gather a large enough user-base to establish service norms in specific niches of the Web 2.0 industry. At the time of the writing of this article, most business models attempting to monetize Web 2.0 platforms were still inconclusive (Clemons, 2009). Establishing service benchmarks that create economic value through direct and indirect network effects (Shapiro and Varian, 1999) may therefore be vital for the success of Web 2.0 businesses (Bresnahan and Greenstein, 1999).

Defining openness as the degree of opportunities and invitations to users and third-party developers to participate in value-creating activities, we observe an increased openness that characterizes Web 2.0 platforms (Lessig 2004). This in turn raises interesting issues from both the theoretical and practical perspectives. The sources of new platform and feature innovations can be internal to firms, usually from teams or individuals working in formal R&D units, acquired by firms in the market, or co-developed with users and developer communities. These innovations may be incremental improvements, or solutions that are radically different.

Traditional economic theory suggests a firm-based approach and tightly controlled rights over intellectual property as the economically most efficient way to organize new product or service development. At the same time, users are increasingly expecting participatory environments that allow them to express their creativity. Then again, there is also some new theory emerging in the literature that presents *social production* models based on nonmarket collaboration and user-generated content production (Jenkins, 2006), predicting a deviation from conventional closed innovation and design approaches towards the adoption of more open innovation models (e.g. Benkler, 2004; von Hippel, 2005; Lessig, 2008; Cusomano, 2010; Shirky, 2010).

Even though there have been recent moves to enforce more platform openness (c.f. the recent fair use exemptions to the Digital Millenium Copyright Act (DMCA) that pronounce jailbreaking of smartphones, namely Apple's iPhone device, and the installation of third party applications as a legal practice[1]), we do not engage in this paper in the debate regarding cyber law and optimal copyright regulation in a changing technological environment[2]. We observe, however, that Web 2.0 businesses are increasingly considering more platform openness out of their own volition rather than because of regulatory change, and the decision of whether to hold their copyrights to the extent that the law affords them, as a powerful strategic instrument rather than a legal imperative. We also recognize that platform openness is not binary and there is not one optimal platform openness level for all Web 2.0 businesses. Each firm sets its openness level in

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1 Statement of the Librarian of Congress Relating to Section 1201 Rulemakings (July 2010). http://www.copyright.gov/1201/2010/Librarian-of-Congress-1201-Statement.html

2 See for example Goldsmith and Wu (2006) and Farrel and Shapiro (2004)

accordance with its own internal conditions and external environment. We therefore do not consider platform openness as an environmental parameter that is fixed by law, but rather regard it as a strategic variable that is bound by the law.

The aim of this paper is therefore to develop new process theory that helps us better understand openness and innovation in the Web 2.0 business environment and also to provide practitioners with some guidelines to determine effective innovation strategies when designing tools and services for Web 2.0 businesses. The evolutionary theory for innovation and platform openness that we present will enable us, in particular, to answer the following research question:

What is the right level of platform openness for Web 2.0 businesses?

To answer this question, we first distinguish three main platform innovation paradigms:

a. A traditional *proprietary firm-based* centralized approach that allows the firm full control over the quality and processes of innovation but demands substantial corporate investments (e.g., Cusomano, 2002).

b. A *social production* or user-generated model that requires less initial capital investment but largely depends on self-organization and the talent of self-selected contributors. Organizations adopting such approaches have little control over consumer creativity and its directions. (e.g. Benkler, 2007)

c. A combination of elements from both approaches, *hybrid co-creation* models. A careful balancing of corporate and user community interests is critical for such hybrid approaches (e.g., von Hippel, 2005).

Adopting the methodological perspective of *engaged scholarship* (van de Ven, 2007), we anchor our research in a pressing practical business problem (namely determining the right level of openness for Web 2.0 service platforms) and then develop an abstract theoretical model that helps us in obtaining an answer to our problem in an idealized research environment.

Our evolutionary innovation theory is then translated into a formal stochastic process model expressed as a finite state Markov chain, which is followed by a numerical simulation analysis that examines the interactions between the organizational strategic and environmental constructs. Simulations are in fact well suited for theory development when the framework under study is non-linear, has a feedback mechanism and empirical data is limited (Davis et al., 2007).

Theoretical Perspectives and Background

We do not focus on the technology or design of Web 2.0 businesses per se, but instead look at innovation in the wider context of organizational capabilities and how they relate to competitive advantage (Zahra and George, 2002). We hence study the technology-dependent strategic initiatives (Piccoli and Ives, 2005) of Web 2.0 businesses that aim for the improvement of organizational performance, creation of a standard or appropriation of economic value.

We adopt the methodology framework suggested by Davis, Eisenhardt and Bingham (2007), which includes both deductive and inductive reasoning, that suggests the use of simulation methods to develop new theory. Basic (simple) theories that are not yet mature and stable are first validated, then computational experimentation that explores different theoretically relevant parameter configurations refines and extends them. The current simple theories of innovation, mainly the traditional proprietary, social production and hybrid co-creation models, are one-dimensional, lack thorough analytic grounding and construct conceptualization, and do not acknowledge non-linear interactions between innovation openness and other environmental parameters. Moreover, underlying these theories is the assumption that there is one optimal innovation process design. However, since organizations are endowed with different social and technical resources, it is reasonable to expect more than one form of innovation process to be viable at the industry level. The assumption of the existence of one optimal innovation process may therefore have unnecessarily limited the attempts to conceive a diverse set of innovation business model designs.

Our proposed evolutionary theory on the other hand looks at the innovation process from a configurational (Meyer et al.,1993) lens. It integrates the broad concepts of the proprietary, social production and hybrid co-creation models into a rich, multivariate holistic framework. We therefore do not analyze platform openness in isolation, but rather consider it as an integral part of the whole innovation process.

Our theory also takes into account the non-linear relationships between the different constructs, which may be related under one configuration, but unrelated under another. Finally, our evolutionary theory of innovation is unique in that it embraces the important notion of 'equifinality'. Equifinality as a concept has its roots in von Bertalanffy's General Systems Theory (1968), which is ideally suited for analyzing complex Information Technology phenomena (Porra et al., 2005). Equifinality underlines the fact that in open arrangements, such as social or biological ones, there is no need for a direct cause-and-effect relationship between the initial conditions and end states of the system. Indeed, diverse trajectories, starting with different configurations of initial conditions, may lead to the same end results. There is no optimal configuration of constructs, and there is not one configuration that is superior to another. Each configuration has unique strengths and weaknesses with important implications for an innovation's propagation and survival.

We next review relevant literature from two research streams, namely Innovation Theory and Evolutionary Theory. These two streams provide the theoretical foundation for our own evolutionary theory of innovation and strategic platform openness for Web 2.0 businesses.

Theories of Closed, Open and Hybrid Innovation

Innovation refers to the outcome as well as to the practice of converting knowledge and ideas into novel entities that are valued by individuals and communities. Innovation outcomes may be broadly classified into two major types: product and process innovation. Innovations may also be classified according to their intensity, or the extent of novelty introduced. They may be incremental (evolutionary) or radical (revolutionary) (Sircar et al., 2001).

Several simple models that organize the innovation process have been developed theoretically in the literature and implemented in business practice depending on the presence of technological affordances and socio-political conditions.

Openness of innovation, that is, the degree to which users and third-party developers have access to product designs and possibilities to participate in the innovation process, is the main differentiator of innovation strategies. Closed innovation models are firm-based while open innovation models are situated in the public domain. More specifically, one can describe three distinct theoretical innovation models that are relevant to designing Web 2.0 services and applications.

Traditional Proprietary Innovation Paradigm

The classic private investor model assumes strong property rights and concentrates decision-making power in a central authority (management by fiat). The innovation and design processes are firm functions that are organized as managerial hierarchies with clearly defined control and command structures. This model is most effective in terms of efficient resource allocation when the venture requires capital-intensive investments, the firm has a clear understanding of markets and demand, and investors need strong economic incentives to take on risks that are associated with new innovations (Demsetz, 1967). In the Web 2.0 context, the private investor model is characterized by a market-based production of closed source software applications that are typically built according to clearly structured requirements specifications and blueprints that describe in detail their looks, function and quality. Professional software engineers, organized as hierarchical teams whose members are assigned very specific roles and responsibilities, are the principle developers of the proprietary designs. They are employed by the firm and produce software as work for hire. The firm retains the exclusive copyrights over the resulting software and customers typically have access to a copy of the executable code but not to the source code. Users hence do not directly participate in the design of the platform or applications or in innovating new features and extensions. Their role is limited to providing product feedback through market research and customer service channels.

Social Production Innovation Paradigm

The social production model for innovation is based on a commons of ideas for nonmarket collaboration and exchange. This peer-based, collective approach can be applied most effectively for creating information, knowledge, and cultural content (Benkler, 2007). Intrinsic motivation based on non-monetary rewards and self-selection is the key driver for users to participate and contribute to the project (Lerner and Tirole, 2002). In the Web 2.0 environment, the social production model is constituted of loosely coordinated users and developers who collectively work on designing, implementing, and testing new services or applications. Typically, there is still some organizational network center that manages the development process to some degree, but most of the actual development work is decentralized and can occur anywhere in the online user community. Using Internet-based communication platforms, the project leadership initiates a new venture, with defined goals and requirements, and solicits help from the community. A coordination mechanism is necessary to decide which of the changes and additions that the volunteer network suggests are to be incorporated into the product. Quality control is implemented through a peer-review process. Participation in the project is completely voluntary and there is no direct financial compensation for contributed work. Community members can join and leave at anytime, and contribute as little or as much as they want. In order to facilitate such an open development process, the source code, which defines the state of the project at any time, is publicly shared and the community takes ownership of the evolving product.

Hybrid Co-Creation Innovation Paradigm

The newly emerging hybrid private-collective innovation model (von Hippel and von Krogh, 2003; Huston and Sakkab, 2006) that combines and balances elements from both proprietary and commons based approaches. Innovation is seen as a function that is democratized and partially outsourced to the user community while final adoption and product development decisions are still coordinated within the organization (Malone, 2004). We identify two types of such hybrid co-creation models: (a) Hybrids that favor proprietary ownership by appropriating most of the value that is generated by the user network, and (b) Hybrids that favor collective ownership by sharing most of the added value with the user community. The success of the private-collective innovation model, especially in the Web 2.0 context, depends on the effectiveness of incentive mechanisms and the participation of lead users as well as the arrangements for value sharing and ownership of the innovations and creations. Users are in fact becoming increasingly weary of Web 2.0 businesses that endorse hybrid co-creation with the sole intention of capitalizing on user-created content without sharing the value with the community (Lessig, 2007; Terranova, 2000).

It is important to note here that Web 2.0 services are of course, on one level, just software, and the lessons and challenges of propriety and open source software (Raymond, 1999) directly apply to them. However, whether Web 2.0 software code is proprietary or open source does not, in principle, determine the boundaries of the creative possibilities it extends to the designers. The real value of innovation for Web 2.0 businesses in fact lies not so much in the software tools themselves, but in how well these tools assist designers in their creative efforts to construct compelling and interactive Web 2.0 services and spaces that will invite user participation (Arakji and Lang, 2007b). It is at this higher level of building Web 2.0 businesses that openness of innovation and design matter the most in terms of both the quality of the services and how users experience and interact with the applications that have been created for them.

Evolutionary Economics and Evolutionary Organizational Theory

The simple innovation theories detailed above characterize innovation as a linear process passing through three discrete stages: invention, innovation and diffusion (Luecke and Katz, 2003). The first stage, invention, occurs with the creative conception of a new product, process or service. The second stage, innovation, refers to the successful commercialization of the invention when introduced to the market. The third stage, diffusion, is the dissemination of the innovation and its adoption by organizations or users. This generalized sequence of events however disregards the important feedbacks that occur between the three stages (Kline and Rosenberg, 1986; Hall, 2005).

In order to take into account the inter-linkages between the three stages, we conceptualize innovation as a continuous process, with a series of inventions / innovations introduced to the product, process or service over time. This evolutionary logic, that is best suited for analyzing the progressive and cumulative nature of innovation, inevitably requires that we take into consideration the wider social, economic and institutional context in which the innovation process takes place (Edquist, 2005).

The evolutionary perspective was originally developed theoretically for the biological and life sciences, but has since been adapted to a number of other disciplines (Novak, 2006), including economics and organizational science. It takes a process view as a crucial methodological choice for understanding why a system is in the state it currently is in. The dynamics of the process may be described qualitatively or quantitatively.

Evolutionary thinking in economics has its roots in the works of Schumpeter (1934) who commented on the mechanism of progressive economic change, and of Alchian (1950) who asserted that understanding the implementation of firm decisions in actual practices necessitated the introduction of some form of indeterministic selection mechanism. An extensive theory of evolutionary economics was later introduced by Nelson and Winter (1982) as an alternative, and a complement, to neoclassical economics.

Evolutionary economic theory is useful when analyzing how organizations effectively respond to environmental threats and opportunities. It eschews the neoclassical assumptions of agent rationality, optimal agency contracts and incentive systems and emphasizes bounded rationality, organizational routines and practical employment of knowledge in problem solving settings (Cyert and March, 1963). Organizations therefore change and adapt as they add to their organizational knowledge capital and implement innovative solutions to confront new challenges arising in the market.

Ontologically, evolutionary economic theory entails a multi-level analysis of processes. *Ontogenetic* investigation at the lower level of analysis pertains to the change processes occurring within an individual organization. The aggregation of interactions at this level is dynamically linked to and simultaneously informs, through a process of co-evolution, the unfolding of structural phenomena at the higher market-wide or industry level of analysis (Dopfer, 2005). *Phylogenetic* investigation at the industry level investigates the distribution of organizational traits within an industry and is driven by selection mechanisms that determine which organizational traits are favored (Metcalfe, 1994).

Evolutionary organizational theory on the other hand essentially considers organizations as platforms for routines and competencies (Murmann et al., 2003). Routines codify organizational procedures and include technical routines for producing artifacts, decision-making rules, behavioral rules, and institutional rules. When routines are implemented effectively, they establish competencies or problem-solving organizational capabilities. As expressions of routines, competencies are practical features, and hence it is the competencies, not the routines, that influence organizational performance.

An Evolutionary Theory of Innovation in Web 2.0 Businesses

In this section, we develop theoretically, based on the Davis, Eisenhardt and Bingham (2007) methodology and the arguments from the literature presented in the previous section, an evolutionary theory of innovation and strategic platform openness. We refine the three simple proprietary, social production and hybrid co-creation innovation paradigms by incorporating them into an evolutionary theory of innovation that presents them not as alternatives, but as part of a continuum on the innovation openness scale. We also expand the three basic paradigms by relating their strategic openness level to other (internal and external) environmental constructs.

We propose an evolutionary theory of innovation that is particularly suited to Web 2.0 platforms. In fact, even though innovation in the Web 2.0 context is primarily an organizational concern, it occurs in a user and institutional environment (DiMaggio and Powell, 1983), the influence of which, when taken into account, enriches the research and analysis efforts (Orlikowski and Barley, 2001). Furthermore, innovation itself does not simply refer to the appearance of a uniform product or service at a precise point in time, but rather is a generalized term for a path-dependent process where the product or service is continuously refined after its initial appearance in the environment (Kline and Rosenberg 1986). Finally, two unique properties of Web 2.0 platforms, transmutability and openness (Jenkins, 2006), were essential for our choice of an evolutionary perspective. Transmutability (Choi et al., 1997; Hughes and Lang, 2006) refers to the property of software that allows code and digital content to be seamlessly copied, transferred, reused and recombined. Openness (Lessig, 2004), on the other hand, determines technologically, legally, and contractually the level of access to the features and content made available on the platforms.

Given the basic concepts of evolutionary economics and evolutionary organizational theory, we distinguish five essential ontological concepts, adapted from Dosi and Marengo (2007), that describe innovation processes: *Variation* in routines is the fundamental factor in organizational and market evolution. It drives the gradual modification, in due course, of organizational competencies. Variation in organizational routines and competencies is triggered by mutation and directed by selection. *Mutation* is the catalyst initiating variation and represents discontinuity or invention that introduces novel routines. It may be random or the result of deliberate organizational adaptation to environmental changes. *Adoption* describes implementation of novel routines by an organization and the passing of the routines and associated competencies to its offspring, and possibly its competitors. *Selection* determines the momentum and direction of growth of emerging varieties of organizational competencies and guides their diffusion. The selection mechanism generates differential growth patterns for the various competencies as they interact with the environment and hence determines which organizational traits eventually succeed and diffuse. Finally, *retention* looks at the stability patterns of the diffusion of novel competencies in the industry. As an aggregate phenomenon, industry structure is an emergent property of the evolutionary process and the diffusion of a competency may be stable, leading to its fixation in the industry, or unstable leading to its elimination.

We adopt the view, presented in (Murmann et. al., 2003), that Web 2.0 businesses are, at an abstract level of analysis, repositories of organizational routines and competencies. Conceptually, we distinguish between managerial routines and technology routines. While both types of routines are knowledge-based, evolve in response to environmental conditions and offer organizational competencies, managerial routines are difficult to codify and are hence less likely to be passed to other organizations (Granstrand, 1998). They are also not subject to intellectual property protection. In terms of innovation in Web 2.0 services and applications, the technology routines to consider are software-based ones. Once the software code is implemented, these routines determine the competencies or traits of Web 2.0 services in terms of appearance, interactivity, system performance and other features that affect system efficiency and user experience.

Routines and their associated competencies that are widely adopted across Web 2.0 businesses become best practices or de facto industry standards. Collectively they describe the state of the industry and its continuing evolution. Software code transmission may occur vertically as a Web 2.0 business includes the novel routine in a new version of its service or application, or horizontally as other businesses in the industry adopt the routine. Imitating and replicating another organization's innovation requires, of course, that the adopter has access to it, either by reverse engineering or through open source or other contractual arrangements. A process of (natural) selection determines which routines are adopted and implemented and how they propagate through the industry. The selection mechanism thus ties the low-level organizational phenomenon to the high-level industry phenomenon. In that sense, a Web 2.0 business is merely a carrier and does not matter as much as the routines and their distribution. As an illustrative example, one may recall Napster Inc., which failed as a profit-maximizing organization in the music industry, but at the same time offered peer-to-peer file-sharing (a software-based organizational routine for distributing digital content) a fertile platform for development and proliferation. Even though the year 2001 marked the downfall of Napster, the file-sharing routine and its associated competency have survived and are arguably stronger today (in 2010) than they ever were before.

The co-evolution of an innovative Web 2.0 routine and the makeup of the Web 2.0 industry necessitates that we take into account the infrastructure necessary for innovation in the Internet realm. We hence conceptualize the Web 2.0 industry as an ecosystem (cf. Figure 1) that comprises four key elements: *Organizations*, *users* and *institutions* that play essential roles in the development and diffusion process of the *software-based technology* component of Web 2.0 businesses:

INSERT FIGURE 1 ABOUT HERE

Software-based technology is the patentable knowledge that provides interactive access to users and sustains a Web 2.0 business' market power. As possible solutions for market challenges and opportunities, the software components are combined and re-combined in the innovation process, with the technologically and economically feasible solutions selected by managers for initial deployment and by users for adoption and diffusion.

Organizations refer to the distinct Web 2.0 businesses that design Web 2.0 services, tools and applications, develop business models, offer their products and compete in the market. The ability of a Web 2.0 business to adapt to its environment hinges upon whether it is organic or mechanistic (Burns and Stalker, 1994), i.e. whether it is ready to implement frequent changes that may affect core organizational culture, structure and practices. Mechanistic organizations adapt slowly to their environment and thrive under stable conditions. They are rigid and subject to substantial internal inertial forces (Hannan and Freeman, 1984) that make them unable to achieve radical changes to their structure or strategies. This is the case for example of music publishers who have generally failed to transform in response to the software routines enabling the peer-to-peer file-sharing competency. Companies that operate in the technology and telecommunication sectors are however more organic in nature. Their internal arrangements are flexible and accommodate the frequent organizational changes that sustain the rapid innovation rate that is necessary for their survival (Brown and Eisenhardt, 1997). It is worth noting here that even though Web 2.0 businesses that support collective ownership of innovation may not necessarily be interested in economic competition, they still engage in ecological competition (Nickerson and Muehlen, 2006) over resources, legitimacy and long-term survival (Hannan and Freeman, 1977).

Users are the customers and third party developers using the services, tools and applications offered by the Web 2.0 businesses. In social production or hybrid forms of digital social space organizations, they may also take part in the innovation process by providing elements of the software-based technology (for example by writing application code). Furthermore, user culture, embedded in values and norms, shapes the interests of the consumer base and affects consumer selection and adoption of novel Web 2.0 services and applications.

Institutions, both private and public, may facilitate or restrain the innovation process in Web 2.0 services and applications. They provide the scientific and research infrastructure, financial support, and the regulatory and legal environment in which Web 2.0 businesses operate.

Stochastic Process Model of Innovation in Web 2.0 Businesses

We next formalize our evolutionary theory of innovation as a stochastic process model that we employ (in accordance with Davis et al., 2007) in order to test its basic properties and derive new insights. Following Dopfer (2005) we group the five ontological concepts of *variation*, *mutation*, *adoption*, *selection* and *retention* into a three-phase evolutionary process that characterizes the innovation process (in our context of Web 2.0 businesses). It is important to note here that unlike traditional models of innovation, the process we are describing here is non-linear and the three phases hence unfold concurrently.

Phase (A) – *Origination*: Invention of a new software-based routine and its first implementation by a Web 2.0 business.

Phase (B) – *Adoption*: Transmission of the novel routine to the derivatives (new versions and spinoffs) of the originating Web 2.0 business, as well as to competitor Web 2.0 businesses and their derivatives. The transfer process determines the diffusion of the routine in the industry and is governed by a probabilistic selection mechanism.

Phase (C) – *Retention*: Extent of diffusion of the routine and its associated competency in the Web 2.0 industry. There are three possible long-term outcomes of the diffusion of a novel routine: (i) the routine is little used and quickly disappears from the population, (ii) the routine partially penetrates the population, and (iii) the routine is widely adopted and becomes an industry standard. We refer to this third possible outcome as fixation of the routine

We configure the stochastic process model as a finite state Markov chain whose parameters (summarized in Table 1) correspond to the three phases described above.

INSERT TABLE 1 ABOUT HERE

(A) Origination Phase:

The evolution of a Web 2.0 novel routine begins with its invention and implementation as a competency by a Web 2.0 business. For example, a social networking website may add a geo-location service (software-based routine) that allows the detection of users' actual geographical location. It is important to note here that our simulation model uses the routine, and not its associated competency, as the unit of analysis. However, and as detailed below, it is the extent of transformation in the associated competency that determines whether the routine is incrementally or radically modified over time.

The Web 2.0 industry has a population size of N. N is hence the number of competing Web 2.0 businesses that provide Web 2.0 services, tools and applications. At the start of the evolutionary process, $n = 1$, where n is the total number of Web 2.0 businesses carrying and implementing the novel routine.

(B) Adoption Phase:

The novel routine diffuses in the Web 2.0 industry along two trajectories, one vertical and the other horizontal (Figure 2). At every point in time, the population is divided into two segments, *n* businesses that carry the novel routine, and *(N-n)* businesses that do not.

Vertical diffusion of the routine is tree-like in shape, where the novel routine is passed down from Web 2.0 business to its derivatives, such as subsequent service versions and spin-offs. If Web 2.0 businesses that do not carry the novel routine produce derivatives at the standardized rate of 1 derivative per generation, then Web 2.0 businesses that do carry the novel routine generate derivatives at the rate (1+s), where *s* is the selective advantage (or disadvantage) of the competency associated with the novel routine, expressed in relative growth rate terms. The parameter *s* may be positive, negative or equal to zero. The competency associated with a routine that has $s > 0$ confers comparative advantage to the business and the routine is hence more likely to get picked up for adoption and replication. A competency that has $s = 0$ is neutral and does not affect the selection or adoption of the associated routine. Finally, a value of $s < 0$ implies a comparative disadvantage when, for example, a novel routine introduces new user security or privacy concerns, is not compatible with a range of Web 2.0 platforms, or slows down system performance. Such routines are less likely to be incorporated in future designs.

Vertical transmission of the novel software-based routine is made possible by transmutation (Choi et al., 1997; Clemons et al., 2007); a property of digital code that allows it to be seamlessly copied, transferred and reused, as well as recombined, added to, cut or deleted. We assume that the core routine is retained in any vertical transmission when its code is refined over time through transmutation but the competency associated with it does not fundamentally change. This simplifying assumption is reasonable since it is the competency that confers selective advantage or disadvantage, and not the routine itself. Vertical transmission of the routine is therefore a form of incremental innovation.

The novel routine, while being passed vertically, may undergo a mutation, or drastic transmutation that creates radical innovation and significant competency transformation. In mutation cases, the novel routine and its associated competency are considered to no longer exist in the derivative. This change occurs at the mutation rate *m*. Radical innovations in the novel routine under study constitute the birth of other novel routines, with different competencies, and diffusion trajectories. The parameter *m* is equal to or greater than zero, $m \geq 0$, and is positively correlated with the intensity of a Web 2.0 business' innovative efforts.

The novel software-based routine may also be transferred horizontally to other Web 2.0 businesses that do not possess the associated competency. This occurs at the horizontal reuse rate, *h*, or the rate at which the novel routine is shared between the various Web 2.0 businesses through imitation or some form of market exchange. The horizontal reuse rate varies between 0 and 1. At one end of the spectrum, a value of $h = 0$ means that the novel routine is not shared in the market. This situation corresponds to the traditional proprietary model of innovation, where a Web 2.0 business is able to obstruct the use of the routine by other businesses through, for example, exercising intellectual property rights, prohibitive cost structure, or secrecy. At the other end, a value of $h = 1$ means the routine is open for adoption across the industry through, for example, licensing, contractual or collaborative agreements, or social production arrangements.

Finally, a value of *0 < h < 1* indicates that a hybrid model of innovation is in place. Even though a value of *h > 0* involves not only economic and technological, but also legal issues, in this study we are only concerned with the strategic setting of the value of h, and do not partake in the debate on the most advantageous forms of licensing or contractual arrangements (cf. Lin and Kulatilaka, 2006).

INSERT FIGURE 2 ABOUT HERE

(C) Retention Phase:

Given the extent of diffusion, both vertically and horizontally, of the novel routine in the Web 2.0 industry, the routine may become an industry standard by getting fixed in the population. With fixation, the number of organizations carrying the novel routine reaches the population size, or $n = N$. Fixation does not imply perpetual universal presence of the routine in the industry. It is temporary, with the routine rising to prominence, possibly becoming a buzzword in the industry (Ramiller and Swanson 2003) then disappearing over time. Despite possible organizational or institutional strategies to promote or discourage the fixation of a chosen novel routine, there are stochastic environmental factors beyond their control. The evolution of the novel routine is therefore subject to chance and may randomly drift in any possible direction. We hence calculate a probability of fixation, $P(n = N)$, which is dependent on the parameters N, s, m and h.

Model Parameters

The parameters N, s, m and h are determined by the ecosystem of the Web 2.0 industry, namely by the organizations, users and institutions influencing the development and diffusion of novel software-based routines. While taking into account all factors that may affect the parameters, we focus on the deliberate control of the platform openness level as it relates to the value of the other parameters. In fact, strategies that influence the probability of fixation through adjustment of the *h* parameter constitute part of the organizational adaptation mechanism to environmental opportunities or threats.

The number *N* of businesses operating in the Web 2.0 industry is exogenously determined by entry to or exit from the market, and by mergers with competitors. The number *N* may also be influenced by the legal bodies that set anti-trust laws and industry regulations.

The selective advantage parameter, *s*, is mainly determined by the environment's, especially the users', reaction to the competency associated with the novel routine. It may be considered as a proxy for the service or application's quality. Web 2.0 businesses may improve the value of *s* to some extent by introducing changes to the routine in new generations of the service; changes that may make the associated competency more attractive to users.

The mutation parameter, *m*, is related to the overall innovation rate in the Web 2.0 industry. It is determined by the general market rate of technological change, institutional support, as well as by the micro-dynamics (Lam, 2005) underlying the innovative capabilities of Web 2.0 businesses. These capabilities are formed at the individual, firm and network levels (Rothaermel and Hess, 2007). On the individual level, the productivity of human capital engaged in innovative efforts positively affects the innovation outcomes in terms of quantity and quality. At the firm level, investments in R&D endeavors significantly contribute to the value of *m*. At the network level, forming alliances with institutional actors (such as research institutions), private consultants and networks of users engaged in conducting research or experiments relevant to the Web 2.0 environment may have positive impact on the organizations' innovation rate.

Strategic Setting of Web 2.0 Platform Openness

A positive horizontal reuse rate, *h*, is initially determined by the legal system that sets the duration and extent of intellectual property protection. While the traditional resource-based view of the firm holds that the ability to protect organizational knowledge is key for creating and sustaining competitive advantage (e.g. Teece et al., 1994), modern economic growth theory suggests that organizational knowledge, especially if it is related to information technology, is hard to protect and likely to create knowledge spillover (Romer, 1986; Weitzman, 1998) and spread to other organizations. In other words, there are no guarantees that a Web 2.0 business can retain control over a competency by restricting access to the underlying routine. Competing organizations or third-party developers may very well develop different routines that impart the same (or a similar enough) competency. For example, even though Twitter was the first social network to implement live feeds for user updates, Facebook was quick to follow suit by developing a routine, specific to its platform, that carries a similar function.

Furthermore, organizational culture, structural form and strategy have a tremendous effect on the arrangement of innovative activities (Teece, 1998; Arakji and Lang, 2007b). An organizational culture that is profit driven is likely to lean towards full control over the new software's copyrights, while an organizational culture that is heavily influenced by the "hacker" ethos, or "design culture" (Monteiro, 1998) is more likely to favor collective ownership of the innovation. Also, the lower the capital and time requirements for the development of a Web 2.0 service or application, the less need for private investors demanding to capture the majority of the value created, and hence the higher the propensity for embracing more open innovation models. Furthermore, applications whose design can be easily broken down into independent tasks that are later reintegrated again allow the users to self-identify and select the tasks they are able and willing to work on. Since contributors in open models are driven by intrinsic motivation such as self-efficacy, self-esteem, status, and altruism, open or hybrid innovation may even motivate greater effort and better results if the best people for the task self- identify and self-select to do the job.

Voluntary horizontal transfer of routines is also contingent upon the availability of rewards that encourage the sharing of routines (Murray and O'Mahony, 2007). If profits from monopoly over a novel routine are lower than those achieved by having a smaller share of a growing market (Nickerson and Muehlen, 2006) for the associated competency, Web 2.0 businesses may elect to run in packs (Van de Ven, 2005) with their competitors. Recent cases in the technology and telecommunications sectors indicate that the benefits of co-opetition (Brandenburger and Nalebuff, 1996) outweigh its risks, and that cooperation with competitors and third party developers is especially valuable if the novel competency is unfamiliar and in need of legitimacy and critical mass. However, a closed innovation and development process is preferred when there are substantial security risks or business confidentiality concerns, such as when services and applications are designed for inter-firm communication or business planning. This is for example the case of the proprietary Blackberry smart phone service which is primarily used by executives to access potentially sensitive corporate e-mails.

Even though horizontal transfer of a routine is largely dependent on the willingness of the Web 2.0 business that originated it to share it, the value of parameter *h* is also influenced by the potential recipients. Some Web 2.0 businesses may mindlessly adopt the offered novel routine, through sheer imitation and bandwagon effect, especially if the associated competency is a high profile one (Abrahamson, 1991). Others may be more mindful (Swanson and Ramiller, 2004) and adopt the offered routine only if the associated competency is deemed useful. There may even be a lag in adoption (Rogers, 1995) or an assimilation gap (Fichman and Kemerer, 1999), which may vary depending on the resource requirements (such as network support, availability of complements, etc…) needed for implementing the routine. An absence of or a lag in adoption of an offered routine decreases the value of parameter *h*.

In the following section, we translate this evolutionary framework into a stochastic process model and conduct a computer simulation that demonstrates the interactions between the Web 2.0 platform openness level and other environmental constructs. The results of the simulation are later drawn upon to formulate specific organizational strategic recommendations.

The Model Specification

Based on models developed in evolutionary economics (e.g. Nelson and Winter, 1982; Dopfer, 2005) and evolutionary biology (esp. Moran 1958; Berg and Kurland, 2002; Novozhilov et al., 2005), we formulate a stochastic process of continuous and overlapping generations of software-based routine evolution in the Web 2.0 industry. We assume that the population size *N* is constant and make a distinction between the number of providers that carry and implement the novel routine *n*, and the number of those that do not *(N-n)*. The model consists of a Markovian process with a finite state space *{0,1,…,N}* for the parameter *n*. Transitions between the different states follow a birth-and-death process:

The birth rate, b_n, is the rate of transition from state *n* to *(n+1)*, when an additional Web 2.0 business acquires the novel routine. This occurs if a carrier of the routine generates a derivative that retains the routine's integrity, or if the routine is transferred laterally and adopted by another organization[3].

The death rate, d_n, on the other hand, is the rate of transition from state *n* to *(n-1)* when a novel routine is lost through mutation or dropped altogether from the derivatives or new generation of a Web 2.0 service or application that previously carried it. When a death takes place, a digital social space carrying the routine is randomly chosen and removed from the population.

We hence formulate the birth-and-death process as follows:

$$b_n = [(1+s)(1-m)n + hn]\frac{N-n}{N+1}$$

$$d_n = [N-n+m(1+s)n]\frac{n}{N+1}$$

We further assume that the birth-and-death process has absorbing boundaries, with $b_0 = 0$ and $d_N = 0$. In other words, if state *0* is reached, or the number of Web 2.0 businesses carrying the novel routine becomes $n = 0$, the propagation of the novel routine is stopped and the routine is abandoned and disappears from the population. If state *N* is reached, $n = N$, the novel routine is fixed in the

[3] A business that does not carry the routine is randomly chosen from the pool *(N-n)* and removed from the population. This technical procedure (Novozhilov, 2006) is necessary to keep the population size constant when a birth occurs.

entire population and temporarily becomes a de facto industry standard. The probability for a routine innovated by one Web 2.0 business to become an industry-wide adopted standard is:

$$P_{Fixation} = \frac{1}{1 + \sum_{i=1}^{N-1} \prod_{n=1}^{i} \frac{d_n}{b_n}}$$

We use an approximation (derived in the appendix) to numerically evaluate the probability of fixation:

$$P_{Fixation} \approx \frac{1}{1 + N \int_{1/N}^{1-1/N} e^{-xN(s+h)} (1-x)^{-mN} \, dx}$$

This approximation holds well for the parameter margins as specified above. We next explore, through a computer simulation, the relationship between the variable *h* and the other environmental parameters.

Simulation Results

In this section, we derive (inductively) new insights from our numerical simulations and discuss their theoretical implications in terms of theory refinements and extensions of existing theory on platform innovation. In order to draw specific inferences regarding Web 2.0 platform openness levels, we analyze the effect of variation in the parameters *N*, *s*, *m* and *h* on the likelihood of a novel routine spreading to encompass the entire Web 2.0 industry.

We use the approximation above to numerically evaluate the probability of fixation for the ranges of values of the parameters as specified in section 3.1. The analysis yields a number of interesting scenarios whose outcomes may provide valuable recommendations for Web 2.0 providers interested in promoting fixation of chosen novel routines.

Traditional Proprietary Innovation Model

We first analyze the proprietary innovation model where the Web 2.0 platform is closed and cannot be accessed by competitors, users or third-party developers. The horizontal reuse parameter is set to $h = 0$. Exploring how (exogenous) variation of population size through industry growth or mergers affects the diffusion of novel routines, we assume for illustrative purposes that N ranges from 5 to about 1000, based on crude industry estimates that vary greatly depending on the exact definition of what constitutes a Web 2.0 business. We exclude all evolutionary forces, except for random drift, and set $s = 0$ and m = 0 as well. As expected from the approximation equation, where N appears in the denominator, the probability of fixation decreases as population size increases. In the absence of evolutionary forces that favor fixation, the vertical transfer of the routine is only dependent on random occurrences, such as its bundling with other routines that may or may not hold selective advantage and probability of fixation is less than 1% (Figure 3a). Fixation of a novel routine that is only subject to random events becomes practically impossible as population size increases.

INSERT FIGURE 3 ABOUT HERE

We then introduce selective advantage, while still excluding the evolutionary force of mutation. We vary the selection advantage rate over the plausible range $-2 < s < +2$, covering the range from highly significant selective disadvantage $(s = -2)$, neutral selection $(s = 0)$, to significant selective advantage $(s = 2)$. When present, positive selective advantage has considerable effect on the probability of fixation (Figure 4a), with highly significant values almost guaranteeing fixation ($P > 0.9$ for $s = 2$).

The introduction of mutation into the analysis naturally reinforces the negative effect of population size on the probability of fixation. The simulation reveals that mutation is a powerful evolutionary force and in the absence of selection and horizontal reuse, it leads the probability of fixation to zero for values as small as $m = 0.1$ for $N \approx 50$. For population sizes N > 150, an m ≈ 0.05 is sufficient to prevent the fixation of a novel routine.

Since the evolutionary force of mutation counteracts that of selection, we investigate their relative strength on the probability of fixation in the absence of horizontal reuse. Since the population size is overshadowed by both mutation and selection forces, I keep it fixed at the representative population size of N = 500. Choosing a different value for N within its plausible range has no noticeable effect on the results of the analysis. Interestingly, the model predicts that even when selective advantage of an innovation is high, an increase in m has the power to considerably slow down diffusion and can abruptly stop fixation (Figure 4c). For a selective advantage of $s = 2$ for example, a value of $m = 0.4$ is sufficient to completely halt fixation by bringing its probability down to 0.

INSERT FIGURE 4 ABOUT HERE

Social Production Innovation Model

Positive values of selective advantage and horizontal reuse constitute evolutionary forces that encourage fixation of the novel routine. Even with zero selective advantage, open innovation with *h = 1* automatically places the probability of fixation at above 70%. Perfect horizontal reuse also nullifies the negative effect of increasing industry size on the probability of fixation for the plausible range $5 < N < 5000$ (Figure 3b).

In the presence of a low mutation rate m, perfect horizontal reuse even compensates for selective disadvantage ($s < 0$) (Figure 4d).

Hybrid Co-Creation Innovation Model

Positive values of selective advantage and horizontal reuse constitute evolutionary forces that encourage fixation of the novel routine. Horizontal reuse further reinforces the effect of selective advantage, or compensates for selective disadvantage when the novel routine constitutes a liability rather than a competence to the web product or service provided. In fact, for values of mutation $m < 0.6$, the probability of fixation is entirely determined by the combined forces of selective advantage and horizontal reuse (Figure 4e). However, when the mutation rate bypasses the value of 0.6, mutation abruptly and completely overpowers even high values of selective advantage and horizontal reuse, rendering the fixation of a novel routine nearly impossible.

In effect, there are a number of parameter value configurations that promote fixation of a novel routine. For instance, Figure 4f indicates the parameter space where the probability of fixation is greater than 70%. A Web 2.0 organization that is targeting a certain value of the probability of fixation may therefore set the value of *h* in accordance with the values of *m* and *s* that are present in its internal and external environment.

Discussion

The simulation analysis presented above is intended to corroborate, refine and extend the three basic traditional proprietary, social production and hybrid co-creation innovation models, as well as increase the validity of our evolutionary theory of innovation and strategic Web 2.0 platform openness. The results are also helpful in assisting firms operating in the Web 2.0 industry in setting their innovation strategies. The results of the model are especially valuable for firms that are attempting to establish a standard for one of their novel routines, with the intent of gaining legitimacy in the market or benefiting from direct and indirect network effects.

The results suggest that a positive horizontal reuse rate plays a key role in innovation diffusion and fixation in the Web 2.0 industry. It is especially important to allow access to the Web 2.0 platform if the organization has a culture of continuous radical innovation that discourages the fixation of a certain novel routine. It is also necessary to allow access to a routine whose competency (due to quality or other concerns) is at a selective disadvantage to increase its chances of penetrating the industry.

The analysis further suggests that strategies that aim at decreasing competition in the market (through for example setting high entry costs or acquiring competing businesses) instead of opening the Web 2.0 platform will not succeed in increasing the probability of fixation of a novel routine. This is the case for routines whose competencies enjoy selective advantage, and even more so for those that suffer from a selective disadvantage.

The model results also emphasize the considerable negative effect that the innovation rate has on the probability of establishing a standard in the market. A high rate of radical innovation (i.e. a mutation rate of more than 60%) is likely to stop the diffusion of a novel routine, even in open and social innovation settings and when the competency associated with the routine has a high selective advantage. The common wisdom that organizations operating in the technology services sector need to constantly produce radical innovations in order to sustain their competitive advantage does not hold for the Web 2.0 industry. Radical innovation may be effective for a new entrant to the market in the short run, but it may prove destructive in the long run (March, 1991).

It may be in the interest of Web 2.0 businesses to reduce their innovative efforts once they produce a novel routine that is essential for their service and whose competency has selective advantage. Focusing on improving such a routine to increase its selective advantage and allowing (even limited) access to its source code will greatly assist its diffusion in the market. This is a form of *competence enhancing* innovation as opposed to continuous radical innovation that constitutes *competence destroying* innovation (Tushman and Andersson, 1986). Scaling down on radical innovation efforts and focusing on partial platform openness and product diversification using the same routine is already a norm in multiplayer video games (Tschang, 2007), and recently becoming more prevalent in the smartphone and social network businesses (e.g. third-party iPhone and Facebook applications). These organizations refine their routines, release installments and updates to their existing product portfolio over the years, without offering any radically new content, yet allowing and encouraging user-led innovations, the value of which they can partially appropriate through effective contractual agreements (Arakji and Lang, 2007a).

Limitations

Clearly, there are a number of limitations present in our stochastic model that we used for theoretical analysis. Aside from general limitations that arise from using abstract models, we would like to point out some more specific considerations. First, population size is kept constant in the model. Thus, impact of industry growth on innovation diffusion is not endogenous to the model and can only be analyzed through varying size exogenously. Moreover, even though network effects are implicitly considered in the analysis, we do not explicitly take them into account in the model. The number N of Web 2.0 businesses that carry a certain routine does not determine the success of the innovation, that is, it does not confer any selective advantage. It is also highly likely that platform openness and a substantial level of horizontal reuse will have a positive effect on the overall rate of innovation in the industry (Landes and Posner, 1989). There are however no empirical studies to date that quantify the relationship between the parameters h and m. The model also does not take into account the topology and density of networks of users and organizations, which has an impact on diffusion of innovation and establishment of standards (Weitzel et al., 2006). Finally, while the model fully demonstrates how lower level variables affect higher level ones, it does not constitute a full multi-level perspective on innovation in digital social spaces. It does not take into account how higher level phenomena shape the nature of innovation on a lower level (Gupta et al., 2007).

Conclusion and Directions for New Research

We have examined in this study technology adoption and diffusion of innovation from an evolutionary perspective that leads to an analysis that adds to our theoretical understanding of platform innovation and that is very different from the traditional adoption and diffusion literature in information systems. Our evolutionary theory of innovation and platform openness refines and extends the currently prevailing simple innovation paradigms and allows the theoretical analysis of innovation as a truly dynamic multi-level phenomenon that affects organizational as well as industry change. We have presented a formal model that serves as a basis for simulating specific theoretical parameter settings. Analytical analysis of the Markovian process model enabled the examination of how organizational innovation strategies affect industry trends.

The results of our simulation analysis suggest that platform openness plays a key role in innovation diffusion and fixation in the Web 2.0 industry, especially in an environment where the innovation is at a selective disadvantage or if the environment fosters an unrelenting radical innovation rate. The analysis further suggests that strategies that aim at decreasing competition in the market instead of opening the Web 2.0 platform will not succeed in increasing innovation diffusion.

Both traditional producer-driven and emergent user-driven approaches for designing and building Web 2.0 services and applications are coexisting in the market at present. Our theoretical evolutionary model of innovation rules out the need to examine which innovation strategy is optimal or more efficient from an economics perspective. Both approaches are viable and the best strategy, will in most cases, depend on environmental factors and will likely take the form of co-creation that includes elements of both the firm-based innovation and social production models. Effective risk management and value sharing contractual agreements for the collaboration between organizations and users remain crucial for sustainable co-creation in the Web 2.0 industry.

Since our analysis, in the absence of empirical data, could not make specific predictions with any level of accuracy, it will be an important direction for future research to complement the theoretical analysis with empirical work. Our evolutionary theory of innovation that incorporates environmental configurations is likely to add precision and power, as well as increase the variance explained, of any ensuing empirical analysis.

Finally, there are a number of issues regarding innovation strategies that are not covered in the present research and that constitute interesting questions for future studies. It is for example important to ask which innovation model, proprietary, social production or hybrid, yields the highest innovation quality as well as consumer surplus. Analyzing the welfare effects associated with the innovation models would inform the current debate on the copyright laws that govern the Internet.

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Table 1: Model Parameters

Parameter	Parameter Name	Parameter Description
N	Web 2.0 population size	Industry size; number of Web 2.0 businesses offerings
n	Number of Web 2.0 businesses carrying the novel routine	Distinguishes between adopters and non-adopters of the innovation
s	Selective advantage/disadvantage	Measure of innovation success
m	Mutation rate	Rate of alteration of the novel routine
h	Horizontal reuse rate	Imitation or adoption by other Web 2.0 businesses
P	Probability of fixation	Diffusion at the industry level

Figure 1 – The Ecosystem of the Web 2.0 Industry

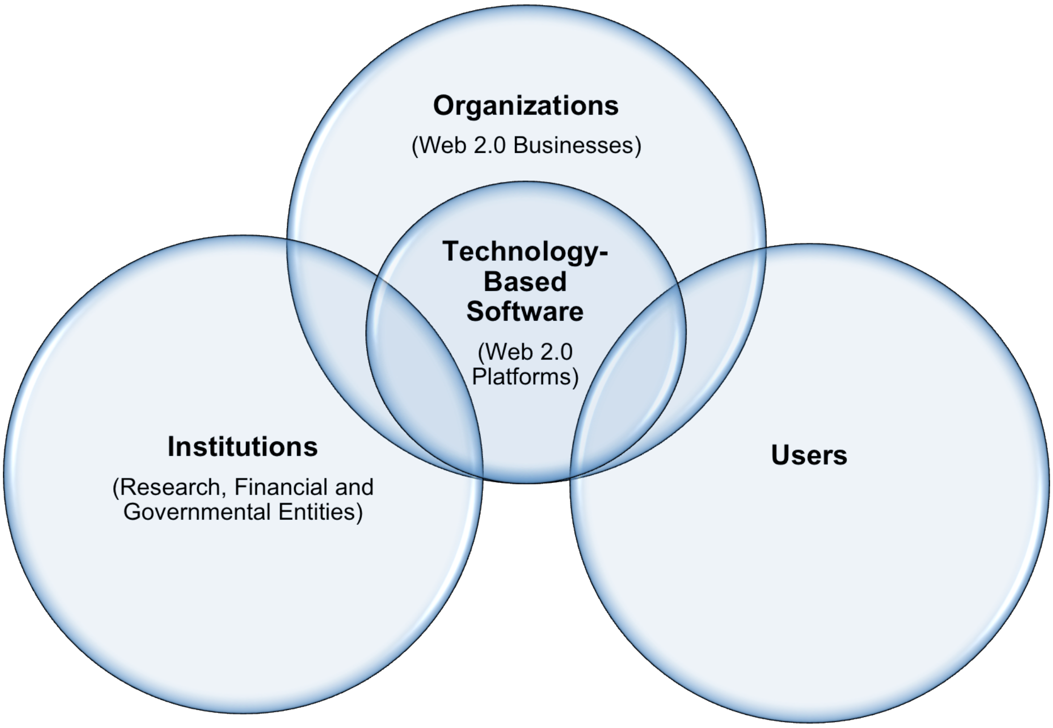


Figure 2 - Origination of a Novel Routine and Its Vertical and Horizontal Diffusion Across Generations of Web 2.0 Businesses

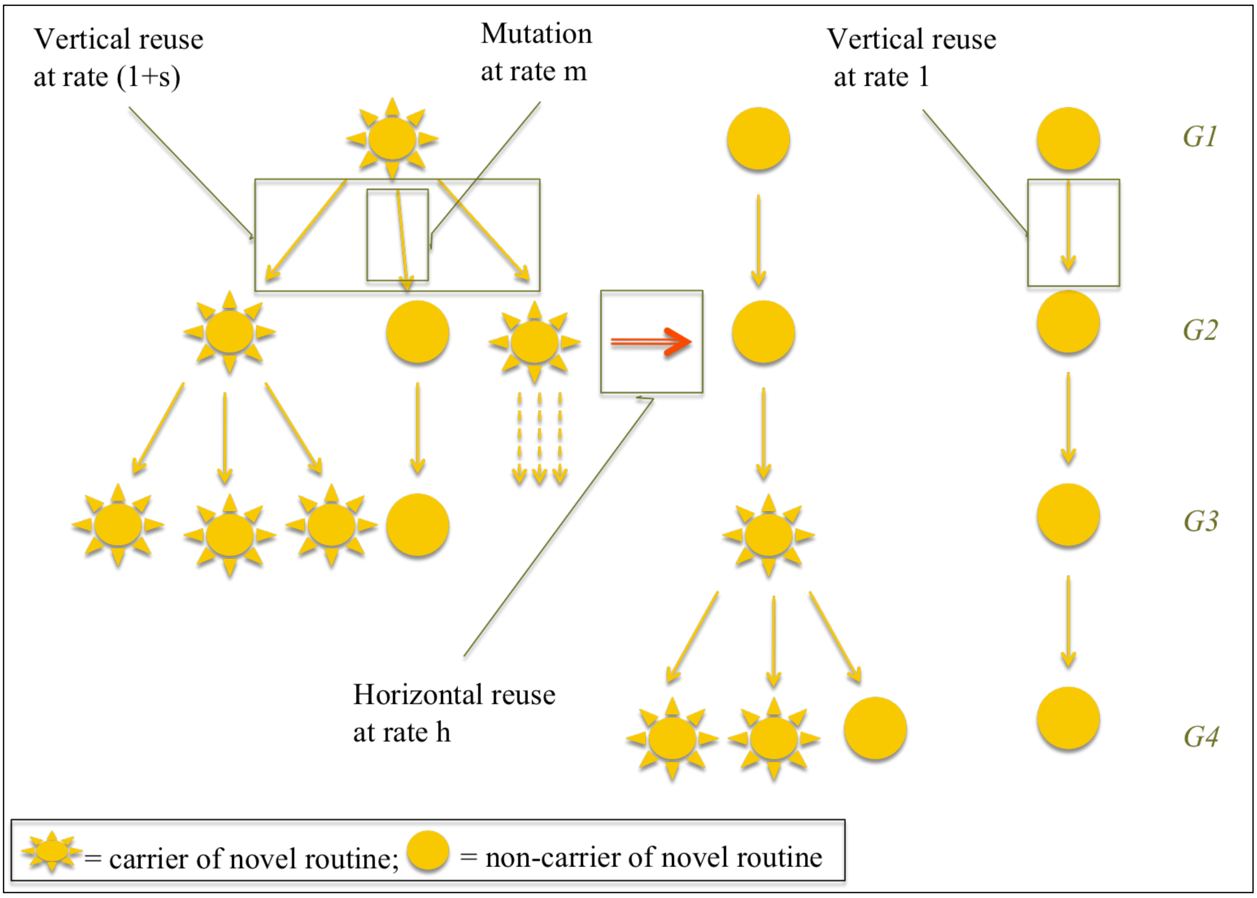


Figure 3 - Effect of Population Size *N* on the Probability of Fixation *P*

(a) Absence of Any Evolutionary Forces, Except Random Drift
(b) Absence of Mutation and Selection, but with Perfect Horizontal Reuse

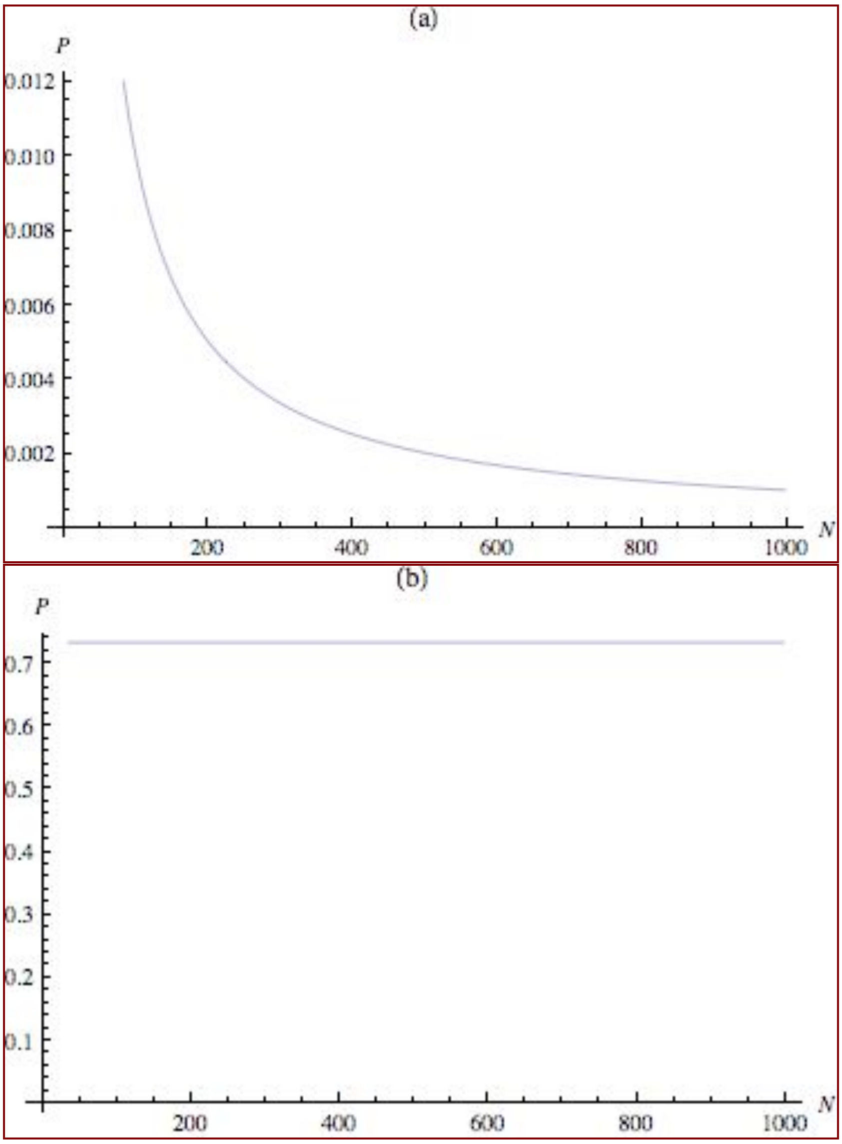
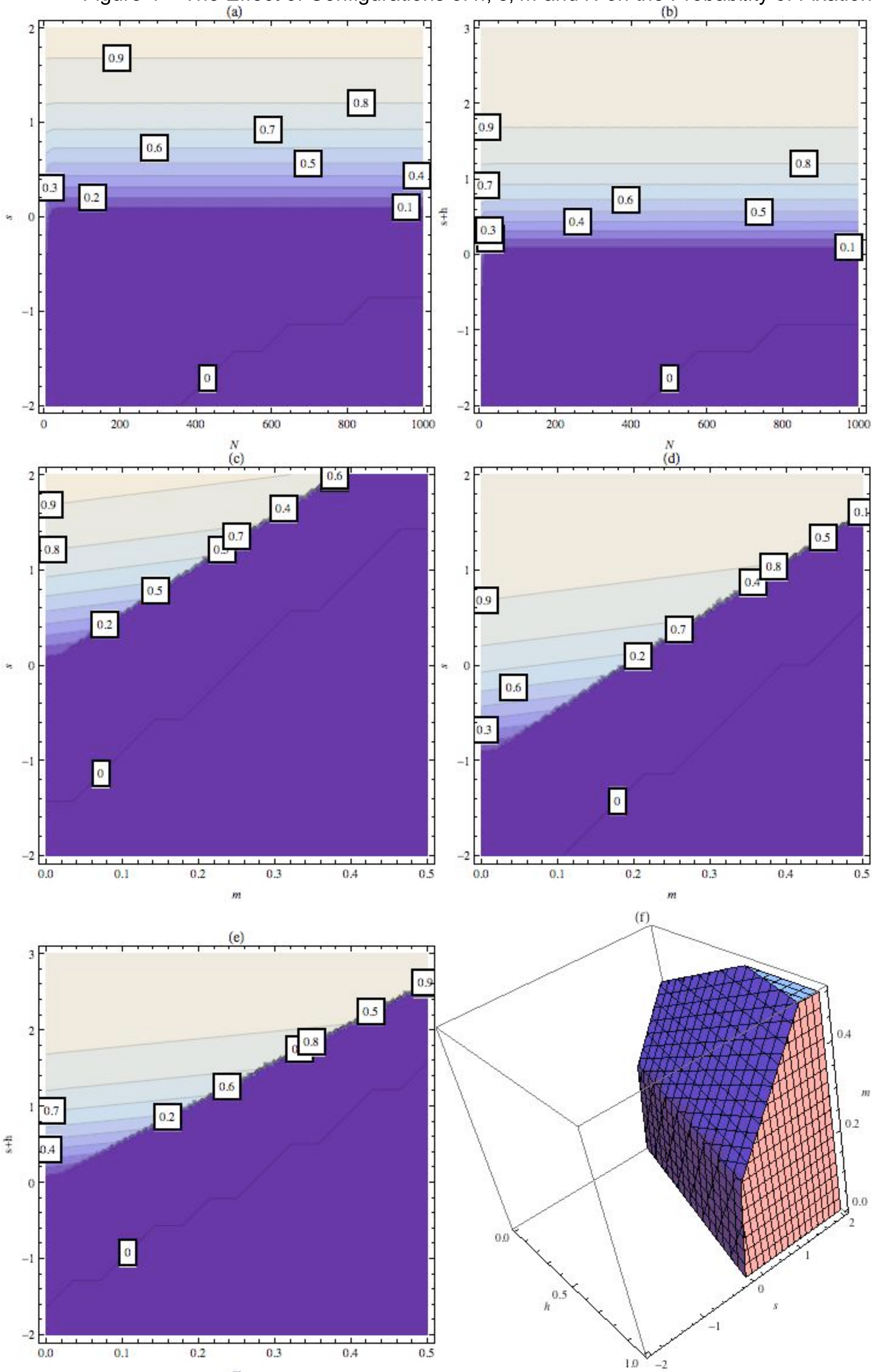


Figure 4 – The Effect of Configurations of *h*, *s*, *m* and *N* on the Probability of Fixation



(a) *h =0*, *m=0* (b) *m=0* (c) *h=0*, *N=500* (d) *h=1, N=500* (e) *N=500* (f) *N=500*, *P>0.7*

APPENDIX

Approximation of probability of fixation (cf. Ewans, 1979; Goel and Richter-Dyn, 1974):

$$\frac{d_n}{b_n} = \frac{[N-n+m(1+s)n]\frac{n}{N+1}}{[(1+s)(1-m)n+hn]\frac{N-n}{N+1}}$$
$$= \frac{n[N-n+mn+msn]}{[N-n][n-mn+sn-smn+hn]}$$
$$\approx \frac{1+\frac{mN}{N-n}}{1+s+h}$$
$$\approx 1+\frac{mN}{N-n}-s-h$$

Where we use the facts that fixation implies that n is very close to N and that for typical cases ms << 1 and m << 1. We also use the approximation $\frac{(1+a)}{(1-b)} \approx 1+a+b$ for small values of a and b.

To derive the approximation to the probability of fixation, we first simplify the product $\prod_{n=1}^{i}\frac{d_n}{b_n}$ by assuming that 1/N → x and using the approximation $\ln(1+a) \approx a$ for small values of a.

$$\ln(\prod_{n=1}^{i}\frac{d_n}{b_n}) = \sum_{n=1}^{i}\ln(1+\frac{mN}{N-n}-s-h)$$
$$\approx \sum_{n=1}^{i}(\frac{mn}{N-n}-s-h)$$
$$\approx -(s+h)\sum_{n=1}^{i}[\frac{mN}{1-\frac{n}{N}}]\frac{1}{N}$$
$$\approx -(s+h)\int_{1/N}^{1-1/N}\frac{mN}{1-x}dx$$
$$\approx -(s+h)\ln(1-x)^{-mN}$$

$$\prod_{n=1}^{i}\frac{d_n}{b_n} \approx e^{-(s+h)}(1-x)^{-mN}$$

Substituting for $\prod_{n=1}^{i}\frac{d_n}{b_n}$, we obtain an approximation to the probability of fixation:

$$P_{Fixation} = \frac{1}{1+\sum_{i=1}^{N-1}\prod_{n=1}^{i}\frac{d_n}{b_n}}$$
$$\approx \frac{1}{1+\sum_{i=1}^{N-1}e^{-(s+h)}(1-x)^{-mN}}$$
$$\approx \frac{1}{1+\sum_{i=1}^{N-1}e^{-\frac{N}{N}(s+h)}(1-x)^{-mN}\frac{N}{N}}$$
$$\approx \frac{1}{1+N\int_{1/N}^{1-1/N}e^{-xN(s+h)}(1-x)^{-mN}dx}$$

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