An Evolutionary Economics Approach to Ecosystem Dynamics

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***Abstract*—Biology and evolution lie at the heart of the ecosystem metaphor that is recurrently applied in the digital era. Although the evolution and analogy with evolutionary biology is acknowledged within the research domains of business ecosystems and digital ecosystems, several key definitions and self-organizing properties of ecosystems have not been fully explored. In addition, the diffusion process of radical innovations altering the structure of an ecosystem remains elusive. This paper addresses this deficiency through a cross-fertilization of multiple research domains, by introducing evolutionary economics concepts based on insights from biology. The research synthesis presented serves for the introduction of a novel perspective on ecosystem analysis. Practitioners will gain insight in how to apply concepts from evolutionary economics when determining their position in an ecosystem. Trade-offs can then be considered and balanced to positively impact firm performance as well as the ecosystem in which the firm operates.**

I. Introduction

Business ecosystems have gained interest from researchers and practitioners since their introduction by Moore in 1993 [1]. Inspired by biology, the concept of business ecosystems provides a metaphor to comprehend the intertwined nature of industries. In the software industry, for example, software producing organizations depend on platforms, libraries and delivery channels provided by third parties to thrive. In later work, Moore defined a business ecosystem as "*an economic community supported by a foundation of interacting organizations and individuals*" [2]. To make business ecosystems more applicable to high-technology industries, software ecosystems focus on studying intertwined software companies [3], while digital ecosystems put interacting services that facilitate collaboration among entities central in their approach [4].

Similar to their biological counterparts, do business ecosystems evolve over time under pressure of competition and innovation [1]. A prime example is the software industry, that is often regarded as the epitome of high-technology industries and can be characterized as *'hyper competitive'* [5]. Other characteristics that shape the software industry are persistent innovation occurring in a rapid manner [6] and fast-paced technological change [7], [8]. These characteristics contribute to the complexity of reasoning about and understanding the dynamics of the software industry. An ecosystem approach then functions as a framework to see the interconnected and multi-granular reality of a set of entities, to order and comprehend their complexity.

While evolution and the analogy with evolutionary biology is acknowledged within the research domain of digital ecosystems, several key definitions such as inheritance, natural selection and mutation have not been fully explored [4]. Nor have their translated counterparts in evolutionary economics, respectively being routines, competition and innovation, been directly applied to analyze digital ecosystems. The introduction of evolutionary economics based on insights from biology [9], [10], [11], [12] to the domain of ecosystem literature, will provide researchers and practitioners insights in how to apply an economics perspective to study the self-organizing properties of ecosystems. We will therefore introduce and assess the applicability of core evolutionary economics concepts such as bounded rationality, irreversibility, lock-ins, unpredictability and sub-optimal outcomes.

Based on the evolutionary economics concepts introduced, we also present an exemplary diffusion process including illustrative examples for the introduction, expansion and maturity phase of a new product, technology or service that alters the structure of an ecosystem. By means of the illustrative diffusion process provided, actors in an ecosystem can recognize how their ecosystem develops over time and how technological choices and chance events shape the future structure of an ecosystem. Trade-offs can then be considered and balanced to positively impact firm performance as well as the ecosystem(s) in which firms operate.

The remainder of this paper continues with a theoretical background in Section II. The theoretical background contains a brief history and overview of evolutionary biology and evolutionary economics, and discusses their applicability when studying ecosystems. In Section III, we elaborate upon how innovation occurs within a digital ecosystem and provide definitions for the main terminology utilized. A first step towards describing a radical innovation diffusion process from an evolutionary economics perspective including illustrative examples is presented in Section IV. A discussion of the validity and limitations of this research including a summary of the content in this paper is addressed in Section V.

II. Theoretical Background

Biology and evolution lie at the heart of the ecosystem metaphor that is recurrently applied in the digital era [4], [1]. As this paper draws upon this analogy from an economics perspective, the remainder of this section elaborates upon core concepts in evolutionary biology, their analogy to evolutionary economics and their applicability to ecosystems.

A. Core Definitions in Evolutionary Biology

The basic principle of evolutionary theory is that individuals belonging to a specific species *vary* from their peers, and that these differences are *inherited* [13]. This variation in a population is inextricably linked with natural *selection*, making the chance to survive different for every individual in a given population. Individuals born with physical traits that give them even a slight advantage in their struggle for food, space and security, have a greater chance to survive (selection) and reproduce compared to their less favored peers. Central to evolutionary biology and evolutionary theory are therefore the concepts of *variation*, *selection* and *inheritance* [10], [13], [14], which are defined as follows:

- **Variation:** diversity among a species as a result of genetic mutations.
- **Selection:** survival or death of individuals based on superior or inferior physical traits.
- **Inheritance:** genetic material passed on to offspring from parents by means of reproduction.

In evolutionary theory, inheritance of successful traits is pivotal to the survival rate of species. If successful traits would not be inherited by offspring, traits that went through the natural selection process without hindrance would be lost at the death of the individual, and as such not be passed on to new generations [9], [13]. In biology, inheritance is ensured by passing on genes from parents to their offspring. The combination of inheritance and selection implies that carriers of traits that augment the chance of reproduction get more offspring that possess the same traits. The share of the population possessing those traits will therefore increase, whereas the share of less favored peers will decrease. This way, change can occur on even the highest level of a population.

Another important part of evolutionary theory, is *mutation* [13]. In case the natural selection process would go its own way without a mechanism that constantly adds new variation to a population, the selection process would be finite and little or no variation would remain [10], [14]. Even minor genetic disadvantages would eventually lead to extinction, and as a result only one perfect species would remain.

B. Core Definitions in Evolutionary Economics

The rise of evolutionary economics in the late 1970s came as a reaction to systematic criticism on neoclassical economics [9]. Opponents of the neoclassical approach argued that its equilibrium models with assumptions of among others perfect competition, perfect rationality and a-historicity were a mere caricature of the real world. Contrary to viewing an economic system as a static and predictable environment, evolutionary economics does the opposite [9]. It regards an economic system as a self-organizing, complex heterogeneous ecosystem with a focus on change. Accordingly, evolutionary economics translates the principles of evolutionary biology to equivalent processes of economic change as shown in Table I [9].

Whereas biological entities pass on genetic material to their offspring that is inherited over generations, firms pass on *routines* to new employees by means of teaching and imitation. Routines herein refer to proven formal and informal procedures organizations rely on during decision-making, and as such are the primary means by which organizations accomplish their day-to-day activities [9]. Companies rely on their routines as they operate in an environment where fundamental uncertainty, complexity and change are the norm [15]. Due to the proven nature of routines concerning decision-making, firms demonstrate routinized (i.e. risk-avoiding) behavior [16] and sporadically review these routines [17].

TABLE I. TRANSLATION OF EVOLUTIONARY BIOLOGICAL CONCEPTS TO EVOLUTIONARY ECONOMIC EQUIVALENTS

Evolutionary biology	Evolutionary economics
Inheritance	Routines
Selection	Competition
Variation (mutation)	Innovation

Evolutionary economists argue that the creation of organizational routines can be translated to specific competences unique to every organization, that to a certain extent determine the success of an organization in the long run [18]. Biological organisms go through a process of natural selection as a consequence of the scarce availability of natural resources. Such selection processes also occur in ecosystems, where firms with successful routines (competences) acquire greater market shares or stock valuations compared to less competent firms. The outcome of *competition* between organizations is therefore based on the same selection principle: organizations with superior routines and competences thrive and survive, whereas their less competitive peers lose market share and eventually disappear from the ecosystem [9].

Similar to random genetic mutation in evolutionary biology leading to new variation in a population, is *innovation* a new source of variation for organizations. Companies proceed with innovation when their existing routines are threatened by competitors. This is particularly prevalent in hyper competitive industries such as the software industry [5], where the technology of today may be the legacy of tomorrow. Innovation is therefore required to prevent organizations from becoming inert, inflexible, or go bankrupt [17].

C. Evolutionary Economics and Ecosystems

One of the primary characteristics of evolutionary economics, is the assumption that actors have both different and imperfect capabilities to process and interpret information acquired by their senses, and that all information is not ubiquitously available [9], [19]. Although actors are assumed to strive for profit maximization even when all information is available to them, the cost and effort of making complex deductions to calculate the most optimal choice does not outweigh the benefits. Agents are thus *bounded in their rationality* [20], [21] and will therefore resort to organizational routines (i.e. risk-avoiding behavior).

The bounded rationality of firms has consequences for the self-organizing nature of an ecosystem [4]. First, since firms often display conservative and risk-avoiding behavior by relying on routines built up over time in an uncertain world [17], firms tend to be blind for other profitable opportunities on unfamiliar terrains. This results in a path-dependent decision-making process, in which existing competences restrict firms in their behavioral freedom and result in limited adaptability to changes occurring in their ecosystem. Successful software firms are therefore often tied to their existing customers and business models, making it increasingly difficult for firms to change their products or platforms coupled with structural consequences for the ecosystem [22]. An example is the eviction of Nokia from its market-leading position in the mobile phone market. Nokia saw its market share, stock valuation and financial performance suffer, and faced job losses as Apple's iPhone and Google's Android software came to disrupt and dominate the mobile phone ecosystem [23]. It is therefore essential for firms to maintain a wide range of contacts within an ecosystem. Firms must ensure that they do not only establish relationships with contacts that are cognitively proximate when looking for complementary knowledge (reinforcing the tunnel vision leading to lock-ins), but also establish relationships with contacts that are cognitively distant to establish new organizational routines [24].

Second, next to firms being locked-in because of their fixation on established routines, can *historical events* lead to inferior and sub optimal outcomes for both a firm and other actors in an ecosystem. Historical events are often self-reinforcing and irreversible [19], as it is impossible to reverse time and to make events undo themselves. Due to bounded rationality, firms are largely unable to predict the impact strategic and technical decisions will have in the long run. For instance, organizations creating their own 'platform' are faced with a range of choices concerning its extension architecture such as APIs (application programming interfaces) that are considered to be the most stable part [25]. Once the decision for a particular platform architecture is made, the decision can hardly be reversed. This is where co-evolution and network effects play a major role in two-sided markets such as the mobile ecosystem or video games ecosystem [26]. For example, the more third-party developers (platform complementors) engage in niche creation, the more users are attracted due to extended functionalities offered, and vice versa. These network effects tend to reinforce the platform in a cumulative manner, making it increasingly difficult for the platform to be dislodged by competitors. In addition, it becomes near impossible for the architecture to be subject to change after it turns out another alternative decision would have been superior.

Third, *economies of scale* and other practices that form ecosystem *entry barriers* can severely hamper the development of an ecosystem. Examples of such barriers are closed standards or mandatory certification occurring within an ecosystem [3]. New entrants with innovative ideas are often unable to grow due to preventive measures taken by incumbent influential organizations within the ecosystem that desire to retain their powerful position [27].

III. Innovation in Ecosystems

Most breakthrough innovations do not succeed in isolation without complementary innovations to attract users [28]. Studying technological development is central to evolutionary economics [29], in which technologies are considered as entities that compete for users. When taking the discussed concepts of evolutionary biology and economics into account, the process of technological evolution can be seen as a chain of experiments with new technology (variation), of which some will successfully diffuse in an ecosystem whereas others disappear (selection). This process is termed technological substitution, where incumbent technologies get replaced by new technologies [30]. During this process, shifts in market shares and stock valuations are likely to occur, thereby being a part of the structural evolution of the ecosystem. In this section, we will discuss the main causes and their consequences of innovation (mutation) in ecosystems.

A. Defining Innovation

Software firms spend large portions of their revenues on research and development (R&D). One of the primary goals of R&D, is the creation of new intellectual property that can be either tangible (hardware) or intangible (software). Not all R&D projects, however, lead to the realization of new successful technologies. Firms are confronted with bounded rationality when estimating innovation attractiveness, being "*the sum of the novelty of the innovation and the expected future generality of market demand*" [31]. In addition, firms are faced with uncertainties whether or not the innovation can be turned into ownership by means of patents and copyright protection [31]. Firms with effective and flexible routines (competences) with regard to innovation will outperform other firms in their ecosystem with ineffective and inflexible routines [17]. Innovation is therefore the primary source of variation in an ecosystem. The result of differing competences among firms also functions as a selection mechanism, where some firms will eventually be evicted from the ecosystem whereas other firms will sustain or thrive.

In innovation literature, a distinction is made between product and process innovations [32], [33]. Within the domain of information technology, we define these two types of innovations as:

- **Product innovation:** Successful development and introduction of a new hardware or software product, technology or service.
- **Process innovation:** Successful application of a new and more efficient production process.

Product innovations involve the successful development and introduction of a new hardware or software product, technology or service. Examples of product innovations are successive product models of the Samsung Galaxy lineup, newer versions of operating system software such as Windows 8, the creation of new open or closed proprietary technology standards, or the creation of a new consultancy service. Process innovations, however, involve the application of new production processes. An example is the implementation of modern software development methods such as Agile or Lean, with the aim of streamlining the software development process to cut development and maintenance costs. In sum: firms compete on product quality through product innovations and compete on minimizing costs through process innovations.

Another prominent distinction made in innovation literature is between radical innovations that establish a new dominant design, and incremental innovations that refine a dominant design [34], [33]. We define these two types of innovations and the term 'dominant design' as:

- **Radical innovation:** The establishment of a new dominant design that is embodied in a new software product, technology or service.

- **Incremental innovation:** The refinement and extension of an established dominant design in a software product, technology or service.
- **Dominant design:** De facto technology standard in an ecosystem.

Examples of radical innovations are the introduction of Software-as-a-Service, cloud architectures and their associated delivery models. Another example is the introduction of Apple's iPhone in 2007, that caused a complete restructuring of the mobile phone ecosystem, including major shifts in both horizontal and vertical markets (e.g. mobile network operators, mobile phone manufacturers and mobile application developers) [35]. Radical innovations also come with a new set of core design concepts and principles (i.e. a dominant design) upon which complementary products, technologies or services can be built [34].

Examples of incremental innovations are the creation of newer versions of operating system software including novel or improved features such as Apple iOS 7 or Google Android 4.2 Jelly Bean. Niche creators also contribute with incremental innovations with the aim of making a profit while at the same time refining, diversifying and extending a dominant platform (e.g. Windows 8) by means of complementary products, technologies or services [36]. The cumulative character of incremental innovations cause the ecosystem to be refined, extended, sustained and grow over time, leading to a '*technological trajectory*' [37]. When the underlying knowledge and routines required by firms in order to complement (i.e. incremental innovations) to the dominant design remain unchanged, we speak of a '*technological paradigm*' [37]. As soon as the dominant design is dislodged and replaced due to the successful introduction of a radical innovation, the technological paradigm ends and is succeeded by a novel paradigm along with its own required knowledge and routines. It should be noted that whereas incremental innovations are generally the consequence of firms having improved their current competences (routines), radical innovations often demand the creation of novel insights, knowledge and routines beyond the existing competences present within organizations [38].

IV. Diffusion and Structural Change

When a radical innovation is introduced, the new dominant software product, technology or service will diffuse among users through 'adoption' in an ecosystem. Although the nature of a radical innovation may vary, the diffusion process tends to follow a similar pattern and has already been studied in-depth (e.g. [39], [40]). This pattern can be regarded as being an S-shaped (sigmoid) curve, also termed the adoption curve [41], and is illustrated in Fig. 1. As shown in Fig. 1, three different phases of the diffusion process can be distinguished, being (1) introduction, (2) expansion and (3) maturity. In this section, we will address each phase and commonly occurring economic mechanisms at play shaping the formation of the ecosystem, including their causes and their consequences.

A. Introduction Phase

The first phase in a diffusion process is called the *introduction phase*. The introduction of a radical innovation often occurs when the dominant design of a software product, technology or service from an incumbent leading firm in an ecosystem has matured and perfected through incremental innovations [17]. At specific moments, '*windows of opportunity*' open to the benefit of new and agile firms with flexible routines [9], [17]. During such occurrences, a radical innovation will first have to 'prove' itself among rivaling radical innovations. Early adopters (regardless of their nature) and (venture capital) investors are of key importance to generate an initial user base and to fuel manufacturing and marketing processes [41]. The availability of such resources is crucial during early moments of fierce competition and may give specific variants a head-start over less favored peers, regardless of the quality of the competing innovations that remains largely unknown by investors and users due to bounded rationality [20].

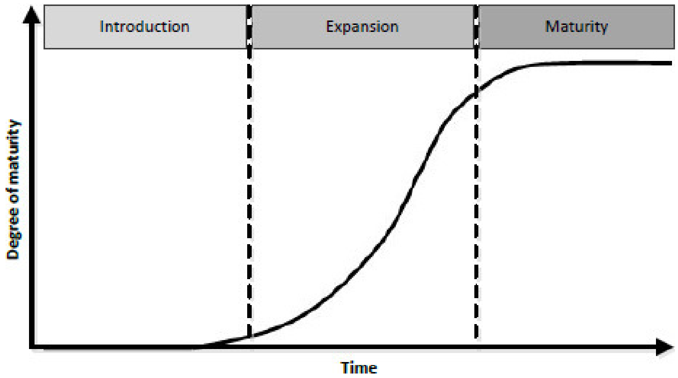

Fig. 1. S-shaped diffusion process of a radical innovation

During the introduction phase, radical innovators battle for the dominance and establishment of their design. The establishment is often the consequence of self-organizing economic mechanisms such as *increasing returns*, *technological lock-ins* and *switching costs* [42]. For instance, an increasing amount of customers that commit themselves to a product, technology or service during the introduction phase will serve as bait for niche creators [36]. The greater the amount of users, the greater the amount of attracted third-party firms will be [26]. This increase in the amount of third-party firms extending the product, technology or service upon which they build in turn attracts more users, while at the same time refining the design and solidifying the position of the radical innovator (also termed increasing returns to adoption). With regard to the latter, particularly the technological lock-in mechanism is prevalent. When a lock-in occurs, users become dependent on the software product, technology or service delivered by the radical innovator. Users are then unable to use the software products, technologies or services provided by competitors without facing *switching costs* (i.e. forced duplication of investments) [43]. Examples of switching costs in the software industry are nontransferable app store purchases between Apple's iOS, Google's Android and Nokia's Symbian, or interoperability and incompatibility issues between Microsoft Windows and Apple Mac OS [44]. In addition, coupled with the retention of users due to lock-ins, do successful radical innovators enjoy economic benefits: the greater the amount of users, the lower the production costs tend to be due to economies of scale and other network-effects boosting the adoption rate of their introduced innovation [26].

An increasing and sufficient user base (i.e. critical mass) coupled with the refinement and extension of a design leads to the establishment of the new dominant design in an ecosystem [34]. This is a turning point and decisive moment in the diffusion process, where only one or a couple of variants make their way into the *expansion phase*. This occurs at the cost of other variants that will eventually either have to adopt the dominant design established by the winning radical innovator (with the consequence of lagging behind), or get evicted from the ecosystem triggering structural change.

B. Expansion Phase

As soon as an ecosystem transitions into the *expansion phase* along with a selected group of radical innovators, competition remains fierce and subject to self-organizing economic mechanisms [41]. When one or multiple dominant designs have been established, however, firms will increasingly compete through process innovations [32], [45]. Since the dominant design has become the de facto technology standard in the ecosystem along with its set of core design concepts and principles [34], will process innovations allow firms to attain production efficiency and cost reduction. Firms also continue to compete through product innovation, however, and introduce newer versions of their products, technologies or services to achieve differentiation, quality improvements and niche exploitation [46]. Niche creators remain influential players in the ecosystem by means of refining and extending the dominant design(s) through incremental innovations.

During the expansion phase, the consequences of the established dominant design will become clear. Although in the meanwhile incremental innovations have refined and complemented the dominant design, it may turn out that the established dominant design is *sub-optimal* compared to earlier designs introduced by rivaling firms [47]. Because of bounded rationality and chance events, the established dominant design need not necessarily be superior to all its former rivaling designs. Despite the sub-optimal outcome of the initial selection process that was not known beforehand, are dominating firms often reluctant to review their established dominant designs due to the unwillingness to cannibalize their own prior investments and assets [48]. In addition, niche creators already reinforced the position of the new dominant design in a cumulative manner by means of co-evolution through refinement and extensions [36]. This advance is an example of *path dependence*, where an ecosystem gets locked in one or a couple of succeeding variants and thereby ignoring other options due to a focus on short and medium term growth [42]. Historical events that occurred during the introduction phase thus have a lasting and directing influence on the development of the ecosystem, making historical sub-optimal choices and outcomes practically *irreversible*. Even almost negligible and *unpredictable* differences in for instance the amount of early adopters can be of major influence during the selection process during the introduction phase [42].

C. Maturity Phase

As the dominant design of a product, technology or service matures, the rate of process and product innovations will slowly come to a halt [32], [42]. During the *maturity phase* of the ecosystem, the technical potential to further improve a dominant design decreases, while the market demand saturates and the innovation diffusion process stops [41]. Only a small amount of firms with perfected routines survive the selection process and emerge as the eventual ecosystem dominators (oligopolists), leading to an *oligopolistic ecosystem structure* [49]. During the maturity phase, it is likely windows of opportunity in the ecosystem will open again for radical innovators aiming to establish a new dominant design. Although incumbent oligopolists may introduce radical innovations themselves, they tend to experience great difficulties due to the requirement of new knowledge and routines since existing routines do not suffice [17], [38]. When a new battle among competing firms for the establishment of a new dominant design commences, the ecosystem will enter a stage of self-renewal [1]. The diffusion processes of radical innovations in an ecosystem are likely to be repeated following the S-shaped curve as illustrated in Fig. 1 where incumbent firms will be challenged, and new entrants vie for dominance – again altering the ecosystem structure.

V. Discussion and Conclusion

This paper introduced basic concepts from evolutionary biology and economics for the purpose of analyzing and comprehending the structural development and self-organizing properties of an ecosystem. We cross-fertilized existing scientific work on business, software and digital ecosystems with literature on innovation, evolutionary economics and biology to examine the applicability of these theories. In particular, attention was directed at the biological concepts of (1) variation (i.e. innovation) being mutation and diversity among species in an ecosystem, (2) natural selection (i.e. competition) of species based on their competences, and (3) inheritance (i.e. routines) of these competences by offspring. Attention was also directed at the evolutionary economics counterparts of the biological concepts provided, including their applicability to analyze ecosystems that hitherto remained deficient.

To illustrate the applicability of these concepts to ecosystems, the diffusion processes associated with a radical innovation (e.g. the establishment of a new de facto standard) were discussed. This process can be divided in three phases, being (1) introduction in which different firms battle for their design to become dominant, (2) expansion in which one dominant design experiences increased adoption and incremental improvements, and (3) maturity at which innovation slowly comes to a halt, causing windows of opportunities to open for firms introducing new radical innovations. The discussion of the latter process showed that incumbent dominant firms experience difficulties in renewing their own ecosystem with radical innovations, and tend to be challenged by newcomers. This difficulty stems from firms being reliant on routines (proven solutions and competences) to compensate for fundamental uncertainty due to being rationally bounded. This causes firms to be limited in their innovative capabilities, and may result in technological decisions that may turn out to be sub-optimal afterwards. However, economic mechanisms such as lock-ins, switching costs and chance events occurred in the past tend to reinforce sub-optimal dominant designs of which the consequences become irreversible as the adoption rate of a technology increases. This paper provides a step towards the further examination and application of concepts from evolutionary biology and economics in ecosystem literature. In order to verify the phases and accuracy and applicability of the economic mechanisms described, quantitative and qualitative future research is required to individually address each element of the diffusion process of a radical innovation within an information-technology oriented ecosystem.

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