The rate of change in evolutionary systems and evolutionary economic modeling

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Abstract

Evolutionary economics seeks to model socio-economic reality as an evolutionary system. This powerful approach entails the implication of the continuous loss of information through the evolutionary process. The implication corresponds to evolutionary biology, though systems in evolutionary economics are different from those in evolutionary biology. The issue of the loss of information has not been extensively studied in economics. Many open questions remain: Which knowledge is lost under what circumstances? Can loss of information be harmful the socio-economic system as a whole in the presence of runaway dynamics caused by, e.g., network externalities? How can the developmentof knowledge in economic systems be studied? The present article addresses these questions exploratively.

Introduction

In the most recent decades – starting with Paul Dale Bush's contribution in 1987 [Bush, 1987] – several models [Villena and Villena, 2004, Elsner, 2012, Heinrich and Schwardt, 2013] have been developed to formalize the Veblenian [Veblen, 1898] approach to evolutionary economics. While this literature tradition has entered a fruitful exchange with Schumpeterian evolutionary theories and other traditions, the theoretical properties of evolutionary systems in economics are not yet well-understood.

Evolutionary systems are characterized by a process of change and generation of variety, and by environmental forces guiding this process. In evolutionary biology, this is represented by mutation and variation on the one hand and by selection on the other. Successful evolutionary entities need to be well-adapted in both dimensions. Excessive or insufficient variety generation are equally disadvantageous as adverse environmental conditions. Biological systems – organisms or ecologies – can be located at different

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points in this continuum. Some allow high mutation rates, others include large arrays of stabilizing factors. But how do evolutionary systems in economics behave in this respect? At what position in the continuum would they be found?

The present contribution explores the details of how loss of information differs between biological and economic evolutionary systems. The case of structural change and network externalities is discussed as an example. In the last section, the use of patent data to quantify information, generation of new information, and loss of information in economic systems is considered.

Loss of information in biological and in economic systems

Economic and biological systems differ substantially. There is no rigid universal system of information storage as with DNA chains - though recent research in evolutionary biology places greater importance on epigenetics and the role of histones around which the DNA helices are arranged. There is also no sequential encoding of information in economic systems, there is no sexual reproduction, conscious interference with the knowledge base is possible, and redundance of information is organized in a very different way. Nonetheless, economics is an evolutionary system that very much obeys the same general principle as genetic ones and is subject to the same issues. As such, it is a dynamic, adaptive optimization device that allows a system to ensure its continued existence in a changing environment. In biological systems, this is the case on many levels from single genes to the individual organisms to the quasispecies to the entire ecology. In economic systems, this may be limited to some levels all of which interface with social, anthropological, psychological, but also ecological systems via a broader interface. This includes individual technologies with related infrastructure, routines in an economic entity, the ecology of economic entities, entire value-added chains, and the global economy as a whole. It does not extend to individuals or individual machines or more microscopic levels, though Richard Dawkins [Dawkins, 1976] argued convincingly for a quasi-genetic evolution of ideas, memes. Maintaining diversity, multiple solutions to the same problem, is important on any level to allow for system resilience in the face of environmental changes or runaway dynamics of the system itself.

Loss of information is therefore a cental concern. Evolutionary systems do and must discard information - a process referred to as selection. Failing to accomplish that will stop the evolutionary process and jeopardize the system's resilience, its capacity to react to environmental changes. A well-functioning diversity generation mechanism generates huge numbers of alternative solutions with the total number growing exponentially with recombination with existing solutions. The cost for the system to maintain all of them accordingly increases exponentially as well. What the system must accomplish is find a balance of which and what number of solutions to maintain and whcih ones to discontinue.

Evidence points to a very high rate of change in economic systems: the absence of structured codification (say, DNA), of sexual reproduction, and of redundant encoding. All these are mechanisms that provide biological systems with stability, a stability

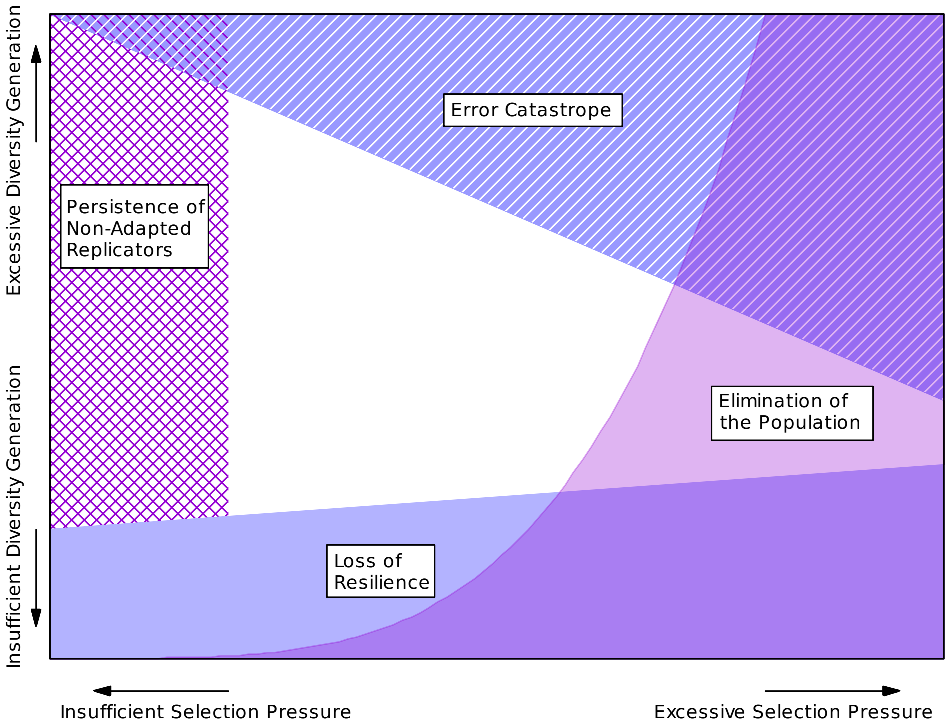

Figure 1: Scheme of potential threats to evolutionary systems.

that may be lacking in economic systems. Furthermore, the possibility of conscious interference allows more structured search for solutions but also a higher rate of change in economic systems.

An evolutionary system can be defined as a population of solutions, encoded and organized in an adaptive system. Whether the solutions are represented as autonomous entities (closer to genetic systems and neo-Schumpeterian evolutionary systems [Nelson and Winter, 1974, Nelson and Winter, 1982, Silverberg et al., 1988, Safarzyńska and van den Bergh, 2010]) or as knowledge at the disposal of some or all subsystems (closer to institutionalis evolutionary economic systems [Elsner, 2012, Gräbner and Kapeller, 2015, Kauffman, 1993, Kirman, 1997, Farmer and Lo, 1999, Farmer, 2002]) or otherwise is not important. What is important is that the system maintains the population of solutions while constantly updating it in response to environmental conditions and its own state.

There are four ways in which an evolutionary system can fail in this respect (see Fig. 1; cf. [Heinrich, 2016, Heinrich, 2017a]):

1. Excessive selection pressure will destroy the population of and the system.
2. Lack of selection pressure will make the evolutionary development undirected and disable effective removal of maladapted solutions.
3. Lack of diversity generation will reduce the system's resilience and ability to

respond effectively to environmental changes, resulting in punishing selection pressure and the likely destruction of the system once such changes occur.

4. Excessive diversity generation will push the system into error catastrophe, a state in which well-adapted solutions are quenched by the sheer quantity of mal-adapted ones. There is always a small chance that the best adapted form - called the master sequence in genetics - is destroyed. In error catastrophe, this chance becomes large and will, given enough time, eventually occur. This is followed by the destruction of the second-best, third best, etc; a mechanism known as *Muller's ratchet*.

While the first three cases of failure of evolutionary systems are rather straightforward, error catastrophe is less intuitive. With replicator dynamics, it can be shown [Eigen et al., 1988] that error catastrophe is made more likely by (1) small size of the system (few individuals in biological systems), (2) high complexity of the information to be preserved (genome length in biological systems), and (3) high rate of change.

Biological systems allow to measure all those quantities nicely and hence characterize the conditions for error catastrophe to occur (this is used in some anti-retroviral medical treatments [Mullins and Jensen, 2006]): The population size can be estimated, the amount of information can be computed from the genome length, and the mutation rate can be measured experimentally. In economic systems, this is much more complicated. Non-codified information cannot easily be quantified, estimating the population size would require counting the number of different solutions, and the rate of diversity generation would have to factor in creativity, inventiveness, and innovation. What is more, selection works differently and does not destroy individuals but leads the system to ”forget” solutions with technological change, with the generational replacement of the workforce, and with the loss of infrastructure.

There are some promising approaches at quantification of this, though. As pointed out by Doyne Farmer and François Lafond [Farmer and Lafond, 2016] and Rupert Way, Lafond, Farmer, Fabrizio Lillo and Valentyn Panchenko [Way et al., 2017], the reduction of the unit cost of production with specific technologies decreases exponentially with different exponents (slopes). This is driven by the gradual improvement of those technologies and could indicate robust statistical properties of the innovative process. This does, however, not cover the emergence of new technologies.

An approach at quantification of the characteristics of the system would be to use patent data. Hjejin Youn, Deborah Strumsky, Luis Bettencourt, and José Lobo [Youn et al., 2015] use US patent data and find that invention can be modeled as a combinatorial process with constant rates of explorative (search for new technologies) and exploitative innovation (refinement of existing technologies).

Structural change

Many aspects of economics are subject to network externalities: technologies, agglomerations, or networks with a large number of participants will provide greater

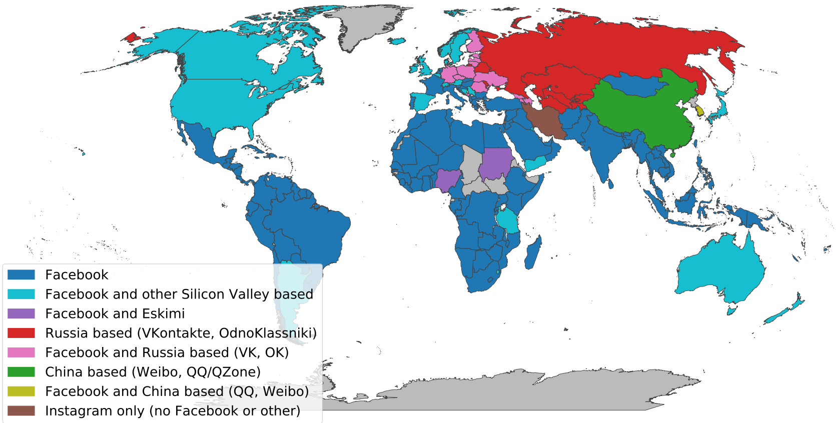

Figure 2: Dominant social media networks (Alexa rank < 10 in December 2017) by country.

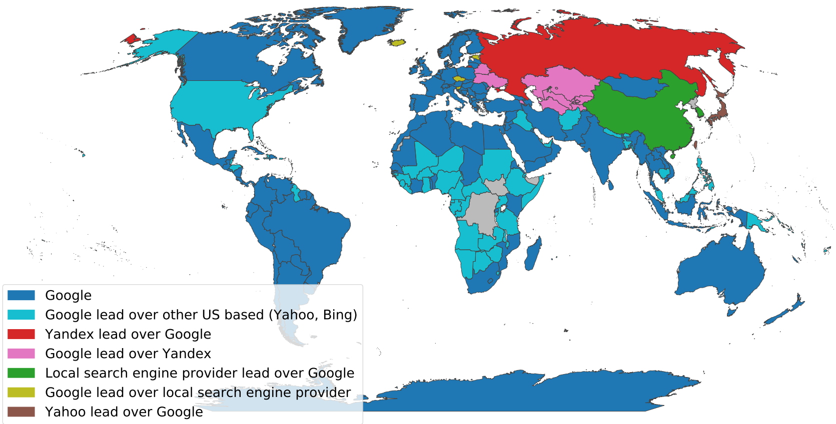

Figure 3: Dominant search engine in 2010 by country (Data from [Kennedy and Hauksson, 2012]).

benefits and therefore more likely to acquire an even larger number of participants or users. This idea is embodied both in Thorstein Veblen's [Veblen, 1898] *cumulative causation* and in Gunnar Myrdal's [Myrdal, 1957, Myrdal, 1974] *circular cumulative causation* (cf. [Berger and Elsner, 2007]) as well as in Alfred Marshall's [Marshall, 1890] *industrial agglomerations*. Historical studies of network externalities and lock-ins were undertaken by Paul David and others [David, 1985, David and Greenstein, 1990]; a mathematical formalization as a generalization of Eggenberger-Pólya urn schemes as developed by Brian Arthur, Yuri Ermoliev, Yuri Kaniovski, and Giovanni Dosi [Arthur et al., 1982, Arthur et al., 1987, Dosi et al., 1994]. Following this, the successful technology will enjoy an absolute dominance over all competitors, resulting monopolies are practically inevitable. Later contributions [Uchida and Shirayama, 2008] revealed that the process depends much on the underlying network structure, that network structures not based on a complete graph (every node connected to every other) can allow systems with several coexisting alternatives, but that a relative dominance of one alternative will generally result from network structures found in reality. Tying technologies of different segments can contribute to the lock-ins [Heinrich, 2014, Heinrich, 2017b]. Lock-ins will emerge quickly and persist for a long time, radical technological and structural change will, for any given technology then be confined to narrow time windows. It is then and there that socially costly mistakes can be made and that loss of information occurs in economic systems before long periods of lock-in will phase out any tacit knowledge still present after the transition.

As a consequence, network externalities on the one hand and periods of technological and structural change on the other are of particular interest in the study of patterns of loss of information in economic systems.

It should be noted that data on the usage of competing technologies points to a trend towards monopolistic industry structures (cf. [Heinrich, 2014, Heinrich and Gräbner, 2017]), but not necessarily monopolies. Social systems seem to have sufficient clustering to allow different alternatives to be dominant in different parts of the network. This may be exemplified by the patterns of social media and search engine usage by country as depicted in Fig. 2 and Fig. 3. While some of the regional differences are explained by the dominant system being blocked in the respective country (the PR China, for instance, blocks both Facebook and Google), others are not and seem to be genuinely emerging from the socio-economic networks.

Network externalities do not only lead to increasing returns and hence to non-equilibrium dynamics, they also entail a number of socio-economic consequences as well as strategic consequences for commercial sponsors of standards, networks, of technologies. The path dependent adoption process means that first-movers generally do have an advantage. This can be countered by building a customer base through free access to the technology or even paying customers. Another strategy is to roll out products as early as possible, even if they are flawed and imperfect. Finally, products commonly coopt pre-existing infrastructure for use with new technologies the infrastructure was not intended for. As an example, consider the development of computer nextworks and later the internet. Early computer networks used telephone lines, which were already in place, relied on tested technologies, were services by established maintenance providers, and very widely

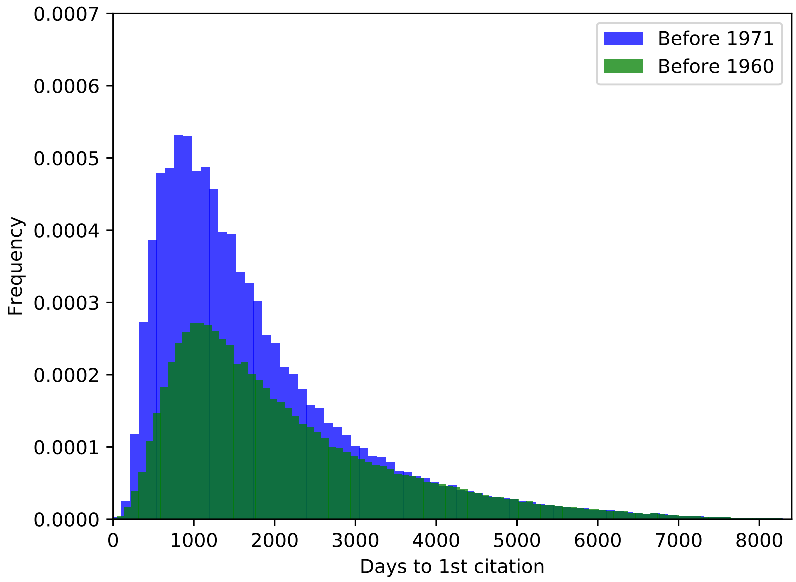

Figure 4: Distribution of times from patemt publication to first patent citation (patents 1947-1970, Amadeus DB).

connected, but not at all intended for use by computer networks. Often this can lead to unfortunate consequences. The development of the internet as a huge, open, and international network relied on technologies intended to provide resilience to an internal military network. The communication protocol infrastructure was prone to breaking in the face of attacks from within. This led to several incidents, including the takeover of InterNIC's (the internet domain name allocation authority's) domain name by Eugene Kashpureff in 1997, cyber-attacks on Estonian government infrastructure in 2006 in the context of the contentious removal of a statue important to the Russian community from the inner city of Tallin [Evron, 2008], and the abundance of email spam that continues to be successfully injected into the email network. For a more extensive list of examples, cf. [Heinrich, 2014]. The recent phenomenon of lobby group sponsored trolling on social media with the intent of influencing the democratic process can be added to the list.

All these mechanisms may lead to dominance of inferior technologies [David, 1985], flawed infrastructure used for unintended purposes, and, if customers are reluctant to adopt technologies without significatn user base, to delayed innovation. The question then becomes what part of alternative technologies is lost to the system and what remains. It should be noted that codified knowledge, such as that layed down in patents, is probably not the crucial part that is prone to being lost; it is the tacit knowledge, the procedural knowledge that is required to make bits of codified knowledge usable and efficient in practice. This includes infrastructure maintenance. While a technology that has been displaced by another standard may itself never be of economic importance again, future innovation can still learn from it; it would be part of the combinatorial process in Youn et al. [Youn et al., 2015].

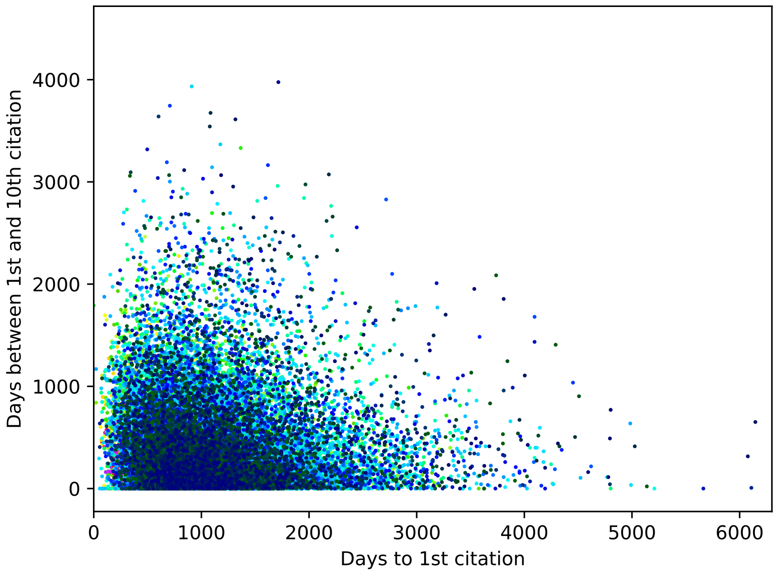

Figure 5: Time to first patent citation vs. time between first and tenth patent citation (patents 1947-1970, Amadeus DB).

Possible evidence

For want of better data, the closest possible data we have to knowledge present in our economic system is patent data. Patent data has been meticulously collected since the late 18th and early 19th centuries. Since ca. 1947, patent citations - references to previous knowledge - are readily available. Patent data is widely used in evolutionary economics and complexity economics since both the data and the necessary computation power have become available to scholars; rapid progress has been made by recent contributions on how patents and innovations are distributed across time and classification categories [Érdi et al., 2013, Lafond and Kim, 2017, Kyebambe et al., 2017, Youn et al., 2015].

Loss of information could potentially be found in the data in the form of patents that are not cited any longer. Technological change in particular fields may be represented in the form of quickly increasing citation numbers in some patents. Fig. 5 provides some moderate evidence for this in terms of a subset of patents quickly accumulating citations after not having been cited a single time for years. The investigation of this is, however, complicated by the fact that the likelihood for a patent to obtain more citations is not uniform in either time or in the number of citations it already has, making a pattern more difficult to extract. It is well-known that citation number distributions are heavy tailed (Fig. 4 cf. [Silverberg and Verspagen, 2007]). It should also be noted that patent citations can only provide a proxy variable the question at hand is the loss of tacit information that is potentially associated with the codified knowledge represented in patent data.

Conclusion

Resilience of economic systems crucially depends on the diversity the system is able to maintain. Changes in the environment may require changes a homogeneous system would be unable to perform. With innovation modeles as a combinatorial process [Youn et al., 2015], diversity may also have a catazyzing effect on future technological development. At the same time, an economic systems is more than any other subject to network externalities and other processes with increasing returns, that have a homogenizing effect.

With this, evolutionary loss of information, expected to happen first and foremostly in times of accellerated technological change in the respective industry, is an important concern. Considerations to study the development of the quantity of available information and any loss of information in economic systems using patent data are moderately promising, as laid out above.

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