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From standard to evolutionary finance: a literature survey

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Abstract
The traditional financial paradigm seeks to understand financial markets by using models in which markets are perfect, which includes agents who are "rational" and update their beliefs correctly based on new information. By comparison, the new institutional economics approach attempts to provide a more realistic picture of economic processes, even in financial markets, by postulating several market imperfections, including the agents' limited rationality. In contrast, behavioral finance completely challenges the rationality assumption and aims to improve the understanding of financial markets by assuming that, due to psychological factors, investors' decisions will contradict the expected utility theory. However, the traditional, new institutional and the behavioral finance models all share one important feature: They are all based on the notion of a representative agent even though this mythological figure is dressed differently. Evolutionary finance suggests a model of portfolio selection and asset price dynamics that is explicitly based on the ideas of investors' heterogeneity, dynamics and changes, learning and a natural selection of strategies. The paper suggests a systematization of this new approach, which is subsequently used to conduct a state-of-the-art literature survey and an evaluation of evolutionary finance research.

Keywords Evolutionary finance · Traditional finance · Behavioral finance · Financial markets

JEL Classification G11 · G14 · D81

1 Introduction

Various (financial) crises in recent decades (such as the dot.com bubble, the subprime and financial crisis, or the subsequent European debt crisis) have revealed that the world economy is severely affected by problems resulting from financial markets

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(Krugman 2009; Shiller 2000a, b). Against this backdrop, standard financial theory, which is based on the efficient market hypothesis and the rational representative agent paradigm (see Fama 1970), has been particularly challenged (see for example, Kirman 2010).

Questioning standard financial theory is not purely crisis-driven. Empirical and experimental work has already challenged the traditional view of efficient markets and the long-sustained belief in market rationality quite successfully, see for example, Campbell (2000) and Hirshleifer (2001). Simon (1955, 1991) had already emphasized the importance of bounded rationality (which became an important assumption in new institutional economics, see Williamson 1975), taking into account agents' limited ability to adapt optimally to complex environments. Later, a new paradigm based on the behavioral models of decision making under risk and uncertainty, was designed to replace the traditional view based on the complete rationality of all market participants (e.g. Kahneman and Tversky 1979; Shiller 1990).

Today, it can be seen that on the one hand, all the previous financial theories were subject to various criticisms. For example, in respect of standard financial theory and perfect rationality, it can be argued that rationality is not always the first reason for human decision making and even the most successful investors have limited knowledge and learning capacities (Shiller 2003; Simon 1991). A criticism of the new institutional economic approach, especially the concept of bounded rationality, came from Langlois (1986, p. 236) who criticized it for not paying sufficient attention to the interactions between agents as part of the environment in which they operate. Further criticism was contributed by Streit et al. (1997) who noted that Simon´s concept neglected human creativity. They argued that cognition is not only a process of pursuing new information about changes in the environment but also a process by which new opportunities for action are created. Even the behavioral finance approach has been a victim of criticism, especially because no closed theory has been found so far, and a collection of individual irregularities exists (Fama 1998; Roßbach 2001). Furthermore, the behavioral effects are often contradictory (see e.g. Ball 2009; Subrahmanyam 2007). On the other hand, however, it should be emphasized that all these financial theories loosened the rationality assumption with regard to the degree of perfection, but not with regarding the stationarity of the level of rationality. Against this background, the paper will analyze the following two research questions:

RQ 1: What are the key characteristics of previous financial theories?
RQ 2: What are the characteristics of evolutionary finance?

While traditional finance borrows from physical ideas such as optimization and equilibrium and behavioral finance borrows from psychology, evolutionary finance borrows from biology (whose relevance to economy was already observed by Hayek 1994b), especially from biological models based on evolutionary dynamics and learning according to the principles of selection, variation and mutation described by Charles Darwin (Hens and Schenk-Hoppé 2005a). Therefore, the third and fourth research questions are:

RQ 3: To what extent can evolutionary finance integrate the previous theories by biological thinking?
RQ 4: Why is a dynamic rationality concept important for integration?

To date, there have been at least three papers giving a comprehensive overview in regard of evolutionary finance: Hens and Schenk-Hoppé (2005a), LeBaron (2000) and Rekik and Boujelbene (2014). Hens and Schenk-Hoppé (2005a, b) summarized the results of nine papers on mathematical models within the field of evolutionary finance. The goal was to contribute a better understanding of the dynamics of financial markets. LeBaron (2000) gave an overview of six papers with early research related to agent-based computational finance, which is used in modeling evolutionary financial markets. Rekik and Boujelbene (2014) carried out an analysis of six existing agent-based models of financial markets and argued that some models were advantageous in relation to the integration of behavioral finance topics.

In addition to these three studies, this in-depth study's contribution includes four elements:

- A systematic state-of-the-art study using English language literature within a time-frame from 1992 to 2017;
- A focus on previous key areas of evolutionary finance research;
- The contribution of future topics of evolutionary finance that can be derived for investors;
- An integration of requirements from academia and investment practice, to guide future research towards possible research gaps.

Although the focus of the study will be primarily of interest to finance researchers, the findings could also be relevant for researchers in other areas of business administration. For example, the following areas: organizational science regarding learning and adaption processes, risk management in respect of the emergence of volatility and general management, due to selection and mutation processes among firms and branches.

The paper is structured as follows: Sect. 2 presents an overview of previous financial theories and an elaboration of their respective key characteristics. Section 3 describes the new paradigm of evolutionary finance, addresses the research methodology and presents the results. Section 4 evaluates the results and analyzes future advances. Conclusions will be presented in Sect. 5.

2 Previous financial theories and their main characteristics

2.1 Traditional financial theory and market efficiency

The postulate that has dominated finance since the 1960's (see Sewell 2012), is the efficient market hypothesis (EMH) elaborated by Fama (1965, 1970). The foundation of this hypothesis, which had a major impact on financial theory as well as investment and financing decisions, is made up of three theoretical arguments (Malkiel 1992; Nik and Maheran 2009; Sewell 2012): The first assumes that investors are rational, and securities are valued rationally. The second is based on the idea that everyone takes careful account of the available information before making investment decisions. The third principle states that the decision maker always pursues self-interest. Fama (1965) indicated that if securities markets were permeated with well-informed

rational investors, investments would be appropriately priced and would reflect the available information (which was already described by Hayek 1945, p. 526, according to whom prices are both collectors and transmitters of information). Therefore, in traditional models, rational investors make efficient use of this information. Thus, the representative investor holds accurate beliefs and is a maximizer of expected utility.

The EMH distinguishes between three levels (Fama 1970): the weak, semi-strong, and strong forms of the hypothesis, referring to different information sets. The weak form of efficiency states that the relevant information is reflected in all current and past prices. This version of the hypothesis implies that technical analysis is not useful. The semi-strong form of efficiency claims that the market is efficient in respect of all publicly available information. So, in addition to past prices, fundamental data such as the firm's product portfolio, balance sheet composition, accounting practices, and quality of management, are included in the current price information. Thus, also in this category, fundamental analysis provides no added value. Finally, the strong form of efficiency is that that stock prices reflects all information relevant to the firm, even including that which is only available to company insiders.

Numerous seminal financial economics models, such as Markowitz's portfolio selection theory (1952), the capital asset pricing model (CAPM) by Sharpe (1964) and Lintner (1965) and the option pricing theory proposed by Black and Scholes (1973) and Merton (1973), are based on the construct of an agent who is rational in the precise sense of the term, which means that he gathers and (perfectly correctly) processes all the available information relevant to a decision, which he also makes perfectly, so that "rationality means that economic agents make the best choices for themselves" Baltussen (2009, p. 2). The efficient market hypothesis is closely linked to the idea of a "random walk", which means that all ensuing price changes display random deviations from previous prices. The logic of the random walk idea is that if the flow of information is unrestricted and information is immediately reflected in stock prices, then tomorrow's price change will only reflect tomorrow's news and will be independent of today's price changes. But news is by definition unpredictable and, thus, the resulting price changes must also be unpredictable and random (Fama 1965, 1970).

The dominance of the efficient market hypothesis, which was quickly called into question (see LeRoy 1976) but was also justified by Fama (1976, 1991), has become far less pronounced since the start of the twenty-first century. Many financial investors, economists and statisticians began to believe that stock prices were at least partly predictable (see for example Statman 1997; Shefrin 2000; Shiller 2000a, b). The opinion that the psychological and behavioral elements of stock-price determination are relevant, and therefore the future stock prices are to some extent predictable, either through past stock price patterns or certain fundamental valuation metrics (e.g. Malkiel 2003; Asness et al. 2013), is becoming more common. Thus, these predictable patterns enable investors to earn excess risk-adjusted returns.

Despite the increasing criticism, the EMH and thus also traditional financial theory, are still accepted today and relevant for explaining stock price movements, as was demonstrated by the award of the Nobel Prize to Fama in 2013 (Fama 2014). Before taking a closer look at the criticism of the concept of rationality and the figure of the *homo oeconomicus*, using the behavioral finance approach, a further criticism

of the traditional theory, namely the assumption that institutional framework conditions are seen as exogenous (e.g. financial intermediaries) and their development is not questioned (see Coase 1998), will be discussed on the basis of new institutional economics.

2.2 New institutional economics

New institutional economics (NIE) can be traced back mainly to Coase's (1937) essay on *The nature of the firm*, although the term NIE was first coined in 1975 by Williamson (1975) and represents an economic perspective that tries to extend traditional economic theory by focusing on the social and legal norms and rules (called institutions) and organizations, which are the basis of economic activity (Schmidt 1981; Hayek 1994a). Unlike traditional economics, a key research subject in NIE is transaction cost arising from asymmetrical information, bounded rationality, and opportunism, which leads to the phenomena of adverse selection and moral hazard of economic agents—and can thus explain how and why institutions emerge, because they are designed to mitigate the aforementioned market features or their consequences (see for example Simon 1955; Akerlof 1970; Jensen and Meckling 1976; Picot 1982; North 1990; Williamson 1996).

The transaction cost approach (recognized with the Nobel Prize for Coase in 1991, and Williamson in 2009) and other important NIE concepts, such as the principal-agent theory (see for example Ross 1973; Jensen and Meckling 1976; Spremann 1988) or the property-rights theory (e.g. Alchian and Demsetz 1972), can be found today in almost all sectors of economics (e.g. marketing, capital markets and financing, corporate management, organization and human resources; see Ebers and Gotsch 1999 or Richter and Furubotn 2010), thus also emphasizing their relevance for the further development of economic questions in the financial sector.

With regard to financial theory, NIE approaches offered explanations for a number of processes and structures in real financial markets, which traditional financial theory was completely or at least partly, unable to explain: The most prominent example is financial intermediaries, which were not included in traditional models (Campbell and Kracaw 1980). In contrast, NIE introduced the seminal idea that the existence of intermediary institutions is explained by transactions costs and in particular, information asymmetry (Benston and Smith 1976; Leland and Pyle 1977).

Like traditional economics, NIE continues to rely on the assumptions of methodological individualism and rational action (Furubotn and Richter 2000), but the assumption of rationality is weaker (see North 1978), as man is seen as an actor who wants and tries to act rationally but is only able to apply bounded rationality (see Simon 1955).

While NIE still adheres to the postulate of rationality (albeit in a restricted form), the behavioral finance approach departs from this assumption, thus moving further away from traditional economic theory.

2.3 Behavioral finance approach

Since the early 1980s, there has been a movement toward incorporating more behavioral science into financial theory (e.g. De Bondt and Thaler 1985, 1987, 1989; Shefrin and Statman 1985; Statman and Caldwell 1987; Camerer 1989; Jegadeesh and Titman 1993; De Bondt 1998; Odean 1998; Fisher and Statman 2000; Bernardo and Welch 2001; Hirshleifer 2001). The supporters of the behavioral finance approach emphasize various key areas in which reality seems to contradict the efficient market hypothesis. As a result, behavioral theory proposes transferring insights from behavioral sciences, such as psychology and sociology, into finance. Behavioral finance is based on the notion of bounded rationality (but to a greater extent than NIE), in which a person utilizes a modified version of rational choice that considers the limitations of knowledge, cognitive biases and emotional factors (Barberis and Thaler 2003). Literature on psychology in general, and behavioral finance in particular, which goes back to, inter alia, Kahneman and Tversky's seminal laboratory experiments (1973, 1974, 1979, 1981, 1984, 2011) and De Bondt and Thaler's pioneering work (1985, 1987 and 1989), proposes that economic behavior is often better explained by simple heuristic rules and framing effects than by rational optimization. According to Roßbach (2001), these so-called behavioral anomalies can be differentiated as follows:

- anomalies in information perception (e.g. selective perception, availability),
- anomalies in information processing (e.g. anchoring, loss aversion),
- anomalies in decision making (e.g. representativeness, overconfidence).

One of behavioral finance approach's key achievements is the possibility of explaining real phenomena on capital markets (e.g. price bubbles or excessive volatility, see e.g. Shiller 1990, 2000a, b) that does not exist in traditional financial theory (Roßbach 2001). In addition, Kahnemann and Tversky's research results in the area of behavioral economics/behavioral finance on the one hand, and those of Thaler and Benartzi (2004, 2008) on the other, should be mentioned, as they ultimately led to the Nobel Prize being awarded in 2002, "for having integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty" (Nobel Committee 2002) and in 2017, for "integrating economics with psychology" (Nobel Committee 2017).

2.4 Main characteristics of the theories

Having presented the previous theories, the main characteristics of each (RQ 1) are illustrated below (Table 1), in preparation for a later integration by evolutionary finance in the following chapter.

The question which arises with regard to the theories presented so far, is to what extent do traditional theory/NIE on the one hand, and behavioral finance on the other hand, represent opposites (the investor either as a strongly or bounded rational or more heuristic, being) or are they two sides of the same coin. In the following, this question will be analyzed and evaluated, using the evolutionary finance approach.

Table 1 Main characteristics of financial economic theories

	Traditional financial theory	New institutional (financial) economics	Behavioral finance
Main methodology	Normative	Rather normative	Descriptive
Role of the individual	The individual is the focus	The focus is on institutions and rules	The focus is on the individual, but also on the impact on the markets
Degree of assumed rationality	Strong rationality	Bounded rationality	Heuristics assume irrationality
Demarcating or symbiotic (synthesis) theory	Demarcating	Rather symbiotic	Demarcating
Important concepts or models	Portfolio selection theory, CAPM, efficient market theory, option pricing theory	Principal-agent theory, transaction cost, property rights	Heuristics and framing, market anomalies
Significant researchers	Fama, Markowitz, Sharpe, Lintner, Black, Scholes (as well as basic ideas from Hayek on the informativeness of prices)	Coase, North, Hayek, Williamson	Kahneman, Tversky, Shiller, Thaler
Helpful disciplines	Mathematics and physics (focus on market equilibrium)	Mathematics and psychology (focus on formal and informal rules)	Psychology and sociology (heuristics focus on greed and fear)
Reasons/trigger for the development of the theory	Transfer of the equilibrium approach/perfect market from neoclassical theory, to the capital market	Recognition of the relevance of opportunistic behavior, limited rationality, information asymmetries and rules between the economic subjects, development of a more realistic image of economy	Increasing volatility in the financial markets since the 1990s, emergence and bursting of the dotcom bubble

3 A new paradigm: evolutionary finance

3.1 Evolutionary economics

The last three decades have seen a strong increase in economic research inspired by evolutionary thinking (see for example Mirowski 1983; Winter 1987; Rosenberg 1994; Witt 1999, 2003, 2004, 2008; Hodgson 2004; Shiozawa 2004; Aldrich et al. 2008). Especially the publication, *An Evolutionary Theory of Economic Change* by Nelson and Winter (1982), has taken on a kind of leadership role. The authors stated significant objections to the fundamental traditional approaches based on profit maximization and market equilibrium (thus, like NIE, it was opposed to mainstream economics), and focused their criticism on the basic question of how firms and industries change over time (Nelson and Winter 1982). Furthermore, they borrowed the concept of natural selection from biology to construct a precise and detailed evolutionary theory of business behavior and were thus able to develop models of competitive firm dynamics under conditions of growth and technological change (Nelson and Winter 2002). A main term within Nelson/Winter's evolutionary approach, is the concept of *routines*, which for its part, presumes (1) the adoption of a rule by an information carrier (e.g. employees in a company, who generate knowledge) and (2) the retention of the rule for recurrent operations (see Nelson and Winter 1982; Herrmann-Pillath 2002; Dopfer 2007). As a result, the special knowledge in companies can, over time, lead to competitive advantages and dynamic displacement processes.

The basis of evolutionary economic thinking can be found much earlier (and in particular, in contributions to Austrian economics), especially in the works of Menger (1871), Veblen (1898), Marshall (1898), Schumpeter (1911), Mises (1940), and Hayek (1945), who, in their works, explained important basic concepts which today are pillars of evolutionary (financial) economics. Menger (1871, 1883) is seen as the founder of the Austrian school, which adopted a heterodox stance on classical economic theory and focused on the idea of evolutionary creation of knowledge, as well as considering the dynamic uncertainty of economic processes. It was Veblen (1898, p. 373) who introduced the term *evolutionary economics* into the discipline, and he did so in recognition of the fundamental fact that the nature of the modern economy could be captured most adequately by referring to its dynamic. In addition, Marshall (1898) emphasized the importance of economics' evolutionary biology, while Schumpeter (1911, 1935, 1942, 1954) placed the rivalrous character of competition processes and the moment of the creatively destructive entrepreneur at the center of his reflections. Mises (1940, 1949), who continued the tradition of Menger's Austrian school, pointed out the need for a decentralized information system, which is crucial to the functioning of the markets and thus renounced central planning. Finally, Hayek (1945, 1973, 1976, 1979) saw, also following the Austrian school, the essence of the modern market economy in the distinctive complexity, accelerated evolution and unequal distribution of knowledge.

To summarize, it can be said that evolutionary economics are fundamentally related to conversion processes, such as structural change (e.g. of an industry), technological change (e.g. due to substitution), institutional change (e.g. new rules) or economic

development generally. Nevertheless, as already pointed out, there are different evolutionary economic approaches or schools of thought (on the fundamental criticism of evolutionary economics, including the various different perspectives, see Schneider 2002), but they all have the search for the basic principles of economic change and in particular, those innovations that will be implemented long term, in common (Schamp 2012). Witt (1987) emphasizes that although the term *evolutionary,* in this context, is interpreted differently by various research directions (e.g. concepts from evolutionary biology, concept of path dependence, self-organization of complex systems or institutional-cultural change), there is a certain degree of unity on the following basic elements: Focus on economic dynamism as a continuing process, path dependency with respect to time (economic development is influenced by the past) and explanation of innovations and their diffusion.

3.2 Evolutionary finance: research methodology and results

While evolutionary economics refers to dynamic, knowledge-based problems and the uncertainty of markets, industries, firms, and actors in general, evolutionary finance deals with the dynamics of financial markets using biological models of evolution (Hens and Schenk-Hoppé 2005a). These models study the interaction of strategies in the financial markets, in which natural selection limits the variety of strategies, while mutation constantly creates new strategies (Evstigneev et al. 2008). According to Lo (2017), Alchian (1950) and subsequently Hirshleifer (1977), can be seen as the original pioneers of evolutionary finance. Alchian was mainly concerned with the question of why some firms were more successful than others and stated that company survival is an evolutionary process of variation and selection (Alchian 1950; for criticism of Alchian, see Penrose 1952). He laid the foundations for Hirshleifer, who saw evolutionary forces at work at all levels of the economy (including financial markets; Hirshleifer 1977). Similarly, in the 1990's, research on computational agent-based modeling at the Santa Fe Institute (called *The Santa Fe Artificial Stock Market*) laid important foundations for a deeper understanding of financial markets' functioning (see for example, Blume and Easley 1992; Palmer et al. 1994; Arthur et al. 1997; Farmer 1998; Farmer and Lo 1999). Financial markets are therefore complex, dynamic systems with different types of investors (agents), in particular, fundamental investors and technical traders (Brock and Hommes 1998; Lux and Marchesi 2000; Föllmer et al. 2005).

In order to evaluate the concept of evolutionary finance more deeply and to answer the remaining research questions, a literature analysis was carried out (see Fisch and Block 2018 for the scientific requirements for a systematic literature review). The literature reviewed and evaluated in the following, covers the period from 1992 to 2017 (the papers by Blume and Easley 1992; Palmer et al. 1994 at the beginning of the 1990s, can be seen as a starting point for evolutionary finance research, see also Dillon 2001). The scheme used represents the views of the literature on evolutionary finance which point out the salient features of the subject, in the hope that they will serve to provide a deeper understanding of the functioning of the financial markets and investing for both academics and practitioners.

Table 2 Design of the state-of-the-art review

Step 1	Keywords	Time frame	Data
99 results	"Evolutionary finance" "Evolutionary dynamics in financial markets" "Heterogeneous agent models in finance" "Agent-based modeling in finance" "Evolutionary asset pricing" "Artificial stock markets"	1992–2017	Google scholar (papers with clear economic scope)
Step 2	**Criteria**	**Time**	**Data**
44 results (cover 95% of all citations)	Most cited papers	End of 2017	Google scholar

The survey's first step was taken using Google scholar and was based on six descriptors (see Table 2), which were considered particularly relevant to the topic of evolutionary finance (see for example, Evstigneev et al. 2008; Hens and Schenk-Hoppé 2005a): *Evolutionary Finance*, *Evolutionary dynamics in financial markets*, *Heterogeneous agent models in finance*, *Agent-based modeling in finance*, *Evolutionary Asset Pricing* and *Artificial stock markets*. As a result, 99 relevant[1] journal articles (including published working papers) were found for the study period.

In a second step, at the end of 2017, Google scholar was used to examine how often the papers were cited, in order to assess their scientific relevance. Then the 44 most-cited papers (representing 95% of all citations) were focused on, in order to answer the research questions in a more targeted way.

The *Journals of Economic Dynamics and Control* (25), *Mathematical Economics* (13) and *Economic Behavior and Organization* (9) contained the majority of the 99 papers (The *Journal of Mathematical Economics* published a special issue on evolutionary finance in 2005, with 10 papers). The scope of these journals reemphasizes the relevance of dynamics and biology (in the form of behavior) to the topic of evolutionary finance. Similarly, mathematics is a useful tool for modeling financial markets. It can also be seen that there has been an increase in the number of articles, especially since the new millennium (89 of 99 papers), which could be due to post crises (dot.com price bubble and financial crisis) modeling of financial markets (see for example, Evstigneev et al. 2016).

[1] Papers from journals without a clear economic scope like e.g. *Physica* or Journal of Artificial Societies and Social Simulation and Nonlinear Analysis: Real Word Applications were out sorted. The full text of each article was also reviewed in order to eliminate those articles that were not really related to evolutionary finance. All 99 papers are included in the bibliography.

Table 3 Lines of development in evolutionary finance research

Developments of evolutionary finance research	
Investor behavior related criteria	1. Ability to learn and adapt
Market and strategy related criteria	2. Stable portfolio rules 3. Selection and survival of strategies 4. Volatility clustering and price dynamics
Model-related criteria	5. Integrated evolutionary financial model thinking

In demarcation to Table 1 and taken from the literature review, the following characteristics of evolutionary finance (RQ 2) can be derived:

- Evolutionary finance is both normative and descriptive (see Hens and Schenk-Hoppé 2005a; Hens and Schenk-Hoppé 2009; for a delineation of traditional finance as normative and behavioral finance as descriptive, see for example, Suryawanshi and Jumle 2016).
- Evolutionary finance focuses on market strategies and not on the investor, who only has a little weight in the market (see Evstigneev et al. 2008, 2013; Hens and Schenk-Hoppé 2005b).
- Evolutionary finance assumes a bandwidth of investors in the market, from rational to irrational, but investors have the ability to learn and adapt to new conditions (see Evstigneev et al. 2016; Föllmer et al. 2005; Hens and Schenk-Hoppé 2005a; Lo 2017).
- Evolutionary finance is a symbiotic (integrating) concept and thus more realistic for explaining market movements (see Hens 2006).
- Evolutionary finance contains important concepts/models, such as computational agent-based modeling, adaptive market hypothesis and evolutionary stable strategy (see Hens and Schenk-Hoppé 2009; Hommes 2009; LeBaron et al. 1999; LeBaron 2006, 2016; Lo 2004).
- Evolutionary finance has been significantly influenced by various researchers, e.g. Arthur, Farmer, Hens, LeBaron, Lo and Palmer (as well as basic ideas from Hayek and Alchian about evolutionary processes).
- Evolutionary finance uses helpful disciplines, such as biology and mathematics (focus on dynamics, complexity, selection, variation and mutation; see Hens and Schenk-Hoppé 2005a).
- Evolutionary finance has been developed to explain the permanent emergence of price bubbles/crises, as well as volatility clustering and post crisis financial modeling (see Evstigneev et al. 2016; LeBaron 2012b).

A detailed analysis of the remaining 44 papers made it possible to distinguish between three areas of research to improve financial modeling and processes, namely, investor behavior related criteria, market and strategy related criteria and model-related criteria. These areas are illustrated in Table 3 and will be discussed in detail in the following subsections.

3.2.1 Ability to learn and adapt

As Table 3 shows, the development of evolutionary finance has firstly to do with the investor and his ability to learn and adapt to new market conditions (see LeBaron 2011, 2012b). According to LeBaron, active learning is indicated by investors' actively switching between strategies. The assumption is that investors learn to switch to more successful strategies due to poor past performance (see e.g. Gaunersdorfer et al. 2008). Thus, learning schemes can (at least normatively) better explain why rationality is a more dynamic concept in the context of evolutionary finance, than in traditional finance. This supports with Hayek's thesis, because investors are learning from the heuristic mistakes of the past (generation of new knowledge) which were based on price information from the market.

The biological term *adaption* is closely related to learning. In Lo's sense (2004, 2017), adaption means that the investor is a biological entity whose features and behaviors are shaped by evolutionary forces (learning from negative feedback). Thus, in an evolutionary finance market, investors with different levels of rationality exist but long-term, they learn from the past, adapt and acquire new knowledge to move dynamically towards more rationality. While the term *learning* is more impacted by the past, adaptation is more forward-looking (a kind of rational preparation for changes in the environment, see Lo 2017).

3.2.2 Stable portfolio rules

The papers by Amir et al. (2005), Evstigneev et al. (2002, 2006, 2008) and Hens and Schenk-Hoppé (2005b), deal with the question of whether there is a stable strategy in an evolutionary, computational, financial market, which survives in the long- term and displaces other strategies. The results show that a stock market is evolutionarily stable, if stocks are evaluated according to expected relative dividends (see for example, Evstigneev et al. 2006). Only this strategy accumulates the entire market wealth in the long term (Evstigneev et al. 2002; Hens et al. 2002). Therefore, these research results show that a normative survival strategy is possible for the investor.

3.2.3 Selection and survival of strategies

The meaning of the selection and survival of strategies is closely related to the topic of stable portfolio rules. Hens et al. (2002) showed, with a simulation of the Swiss stock market, that in competition with rebalancing rules derived from Markowitz's mean–variance optimization, maximum growth theory and behavioral finance, an evolutionary portfolio rule will hold total market wealth and thus survive long term, while the other strategies are out sorted by Darwinian selection. Anufriev and Dindo (2010) and Evstigneev et al. (2002) obtained similar results by using wealth dynamics as a selection rule in a financial market with an arbitrary number of heterogeneous, boundedly-rational investors. Sandroni (2005) states that agents with more accurate beliefs (in the sense of higher market entropy) will accumulate more wealth, dominate the market and survive against other strategies.

3.2.4 Volatility clustering and price dynamics

Evolutionary finance research emphasizes that there is no lasting equilibrium in the market (in contrast to traditional financial theory), but there are always price deviations due to the interaction of strategies or groups of investors (fundamentalists versus chartists/technical trader; see e.g. Chiarella and He 2001; Chiarella et al. 2002; Gaunersdorfer et al. 2008; LeBaron et al. 1999; Lux and Marchesi 2000). These deviations are often accompanied by volatility clustering, which means that large price changes tend to be followed by other large price changes (Hommes 2001; Lux and Marchesi 2000).

Chiarella et al. (2014) used a maximum likelihood approach on S&P 500 data, to explain the emergence and decline of price bubbles as being due to agents switching between different groups of investors (fundamentalists, chartists and noise traders) on the basis of their past performance. Evstigneev et al. (2016) emphasize the need for post crisis modeling because of a lack of knowledge about many aspects of evolutionary financial markets' changing/dynamic natures.

3.2.5 Integrated evolutionary financial model thinking

Finally, different integrated evolutionary financial model thinking approaches are analyzed. In particular, two schools of thought, those of Hens (Hens and Schenk-Hoppé 2005a, b; Hens 2005, 2006) and Lo (2004, 2005, 2017), which create the opportunity to unite different financial theories, should be highlighted. Hens argues that traditional and behavioral finance are two sides of the same coin (Hens 2006) and that this explains why value (used by investors' rationality) and momentum (caused by a high level of investors' irrationality, up until a price bubble) market anomalies are in an evolutionary sense, interdependent in the form of a coexistence (Hens 2005). Furthermore, Hens looks at the level of strategies (Evstigneev et al. 2002; Hens et al. 2002) according to which their performance (similarly to Hayek, a kind of price information of the strategy) dynamically drives the investors' wealth and can explain wealth accumulation as being due to an evolutionarily stable strategy.

On the other hand, Lo, with his adaptive market hypothesis (see Lo 2004, 2005), tries to reconcile the efficient market hypothesis with behavioral economics. He argues that the Fama's theory of efficient markets is not wrong but merely incomplete, due to a dynamic concept (Lo 2017; Siegel 2017). Accordingly, depending on market conditions (e.g. number of market participants or investors' ability to learn), some markets are more efficient while others are not (Siegel 2017). In contrast to Hens (who, as mentioned, instead focuses on strategies), Lo's concept gives more consideration to the individual investor (Gippel 2013; Lo 2017) who is neither always rational nor irrational but a biological entity with behavioral biases and learning abilities (Lo 2017). According to Lo, much of what supporters of the behavioral finance approach cite as counterexamples to economic rationality (e.g. loss aversion, overconfidence, overreaction and other behavioral biases), are consistent with an evolutionary model in which individuals adapt to a changing environment by using simple heuristics (Lo 2004, 2005). Furthermore, Lo sees survival as the ultimate force for competition and innovation (Lo 2017; Siegel 2017), which as can be seen, is similar to Schumpeter.

3.2.6 Summary

The level to which evolutionary finance has been extended provides evidence for the relevance of this new and promising financial approach. The literature review indicates that evolutionary finance has been developed in multiple directions. Table 4 provides a synopsis of the current of research, as well as highlighting opportunities for research to be done in the future.

4 Evaluation and future advances

The literature review of evolutionary finance emphasizes that this approach is able to integrate previous financial theories (RQ 3). Thus, it becomes clear that evolutionary finance proposes a model of portfolio selection and asset price dynamics that is particularly due to rationality and based, in contrast to traditional finance/NIE and behavioral finance, on the idea that there are different types of investors. Accordingly, the investors' strategies may result from rational maximization related to an expected utility function, simple heuristics within the meaning of behavioral finance or principal-agent models which describe incentive problems in institutions (see Hens 2006).

Likewise, evolutionary finance also borrows from biology (whose relevance to economics had already been identified by Marshall, as already mentioned, and even Hayek 1994b), especially from biological models based on evolutionary dynamics according to Charles Darwin's principles of selection, variation and mutation (Hens and Schenk-Hoppé 2005a). According to Lo, the transfer of biological thinking into financial markets makes it possible to assume that investors adapt their behavior due to learning over time.

Thus, evolutionary finance can unite financial theories to a higher explanatory value of financial behavior, without completely abandoning the assumption of rationality. Rationality and consequently efficient markets are therefore to be understood as dynamic concepts independent of the investors' learning abilities and the respective market conditions (RQ 4). Accordingly, some markets are more efficient than others, and thus, in certain market environments, CAPM and portfolio theory are poor approximations.

As described in Table 4, further future advances should be made to improve evolutionary finance topics with regard to academia and investment practice. There are four areas which can be identified:

- further research about investors' learning processes (e.g. the role of unconscious learning and the influence of neuroeconomics)
- more empirical evidence from real market data, to increase the applicability for investors
- the necessity for post-crisis modeling in order to better understand the complexity of markets (e.g. high volatilities and price dynamics)
- further methodological research towards a uniform, evolutionary financial theory

Table 4 The past and future of research on evolutionary finance based on the most-cited papers (1992–2017)

	Relevant sources	Achieved progress	Remaining tasks
Ability to learn and adapt	Brock and Fontnouvelle (2000), Brock and Hommes (1997), Brock et al. (2005, 2009), Chen and Yeh (2001), Chiarella and He (2002), Chiarella and He (2003), Chiarella et al. (2003), Gaunersdorfer (2000), Gaunersdorfer et al. (2008), Hommes (2001), Hommes et al. (2005), LeBaron (2001b, 2012a), LeBaron et al. (1999), Lo (2004), Lux and Schornstein (2005)	Rationality is a dynamic concept due to learning schemes Investors are biological entities who learn from the past and adapt to new market conditions	Further differentiation of the term learning (conscious versus unconscious; positive versus negative market conditions) Learning from a point of view of neuroeconomics (role of the reward system)
Stable portfolio rules	Amir et al. (2005), Evstigneev et al. (2002, 2006, 2008), Hens and Schenk-Hoppé (2005b), Hens et al. (2002)	In an evolutionary, computational, financial market, a stable strategy exists in the long run The evolutionary stable strategy accumulates total market wealth long-term	
Selection and survival of strategies	Amir et al. (2005), Anufriev and Dindo (2010), Blume and Easley (1992), Chiarella et al. (2006, 2007), Evstigneev et al. (2002, 2006, 2008), Hens and Schenk-Hoppé (2005b), Hens et al. (2002), Hommes (2001), Sandroni (2005)	An evolutionary portfolio rule will survive long-term while other strategies are out sorted by a kind of Darwinian selection Investors with more ac-curate beliefs will survive against other strategies and increase total wealth	More empirical orientation, as mainly mathematical computer modeling More practical relevance to expand the knowledge and its applicability for investors
Volatility clustering and price dynamics	Anufriev and Panchenko (2009), Bottazzi et al. (2005), Brock and Hommes (1998), Chiarella et al. (2002, 2003), Chiarella and He (2001, 2002, 2003), Chiarella et al. (2014), Farmer and Joshi (2001), Föllmer et al. (2005), Gaunersdorfer et al. (2008), Horst (2005), LeBaron (2000, 2001a, b, 2012b), LeBaron et al. (1999), Levy et al. (1994), Lux (1997, 1998), Lux and Marchesi (2000), Youssefmir and Huberman (1997)	There is no lasting equilibrium in an evolutionary financial market Different strategies by investor groups (fundamentalists versus chartists) lead to price deviations accompanied by volatility clustering Volatility clustering and price dynamics make post-crisis modeling necessary	Post-crisis modeling including fast market changes, high volatilities and dynamics

Table 4 continued

	Relevant sources	Achieved progress	Remaining tasks
Integrated evolutionary financial model thinking	Chen and Yeh (2001), Hens and Schenk-Hoppé (2005b), Lo (2004)	Traditional and behavioral finance are two sides of the same coin Value and momentum strategies are interdependent Efficient markets are a dynamic concept depending on market conditions Behavioral anomalies are consistent with an evolutionary model of individuals adapting to a changing environment	Further methodological research towards a uniform theory Integration of neuroeconomic knowledge into evolutionary financial modeling

These research gaps should guide upcoming research and will be analyzed in more depth in the following:

4.1 Investors' unconscious learning processes

The term *active learning,* coined by LeBaron (as mentioned in chapter III), describes a conscious process. Accordingly, investors are guided by strategies' past performance. The psychological literature on the processes of perception, judgment and decision-making, confirms the relevance of the unconscious in human behavior (see e.g. Dijksterhuis 2004; Dijksterhuis et al. 2006; Wilson and Schooler 1991). Thus, especially in complex situations, unconscious decision-making can be more advantageous than conscious thinking. Transferring these findings to the area of investment decisions, leads to a future research stream regarding investors' unconscious learning processes.

Likewise, the findings on neuroeconomics (see basically Glimscher et al. 2009; Wilhelms and Reyna 2014) could be helpful for understanding investors' unconscious learning processes better. In particular, the role of the reward-system (as part of the limbic system) for learning processes (Stangl 2016). Lo has already rudimentarily considered the importance of neurobiological findings in his approach (2017).

4.2 Empirical evidence from real market data

In order to increase the applicability of evolutionary finance in practice, a stronger empirical validation is necessary. So far, there has been a predominantly normative development of the evolutionary finance approach through mathematical computer modeling, however, investment managers need functioning strategies for their money.

According to Hens (2006), there is a great application for evolutionary finance in the field of asset management (evolutionary asset allocation). The recommended process is as follows: In the first step, investment managers have to identify the set of investment strategies in the market (active and passive or value and growth, etc.). Then they have to get numbers for the relative importance of those strategies (e.g. from custodians) in order to classify the strategies according to the investor and wealth. Now the investment managers have the strategies and wealth at any point in time and can calculate a so-called wealth-flow function, which means that one particular strategy attracts more wealth than another. A useful object of analysis would be e.g. hedge funds.

4.3 Post-crisis modeling

Evstigneev et al. (2016) believe that post-crisis modeling has become necessary in view of the consequences of the financial crisis. The crisis has thus shown that the previous rational models cannot make good predictions on high volatility, black swans (for this term, see Taleb 2007) and price dynamics. The Gaussian normal distribution

of risks has thus become obsolete, with risks being more likely to be represented by Mandelbrot distributions (see Mandelbrot 1963).

Likewise, it is also indicative of the need to better understand and depict the complexity of financial markets with all their participants and processes. Mandes and Winker (2017) already provide initial approaches for taking account of complexity in agent-based models of financial markets. An important factor in measuring complexity here is the degree of organization, which depends on the possibility of direct interaction between agents.

4.4 Uniform evolutionary financial theory

Evolutionary finance has not been able to replace traditional financial theory, at least until now. Therefore, the methodological foundations of evolutionary finance need to be further developed in respect of a unified theory. Scientific approaches to expand or optimize Hens and Lo's previous schools of thought, can be found e.g. in the areas of behavioral equilibrium, evolutionary asset allocation (as mentioned before) and neuro-finance.

Behavioral equilibrium is an alternative equilibrium paradigm which abandons the hypothesis of full rationality and admits that market participants have a whole range of behavioral patterns, depending on their individual psychology (Evstigneev et al. 2016). Neuro-finance, as a part of neuroeconomics, experimentally analyzes the nature of the cognitive processes involved in acquiring and processing information in financial decision making (Miendlarzewska et al. 2018). By combining neuro-finance with computational financial modeling, useful added value with regard to investors' cognitive patterns (e.g. learning patterns) can be provided.

5 Conclusion

A distinction was made between evolutionary finance and previous financial theories in order to work out and evaluate the special features of this new approach. In addition, a literature search was undertaken to identify the most-cited articles related to evolutionary finance. This resulted as a first step, in the identification of 99 articles published between 1992 and 2017 and the subsequent selection of the 44 most-cited papers from this pool (covering approximately 95% of citations), which were taken for a classification of their evolutionary finance content into five research streams, which provides reasonable insights into the state of the art.

From these filtered research areas, four topics for future research were identified, which could be valuable for further evolutionary finance research. By aligning these with the filtered key topics, the resulting research agenda could be derived (see Table 5).

The evaluation of evolutionary finance suggests that this approach can integrate previous financial theories, such as traditional finance and behavioral finance, into a synthesis. Furthermore, the concept of dynamic rationality due to learning and adaption, is useful for the integration, because it shows that the market can offer changing conditions.

Table 5 Prospective research directions for evolutionary finance' methodological development

Current research areas	Future research areas for evolutionary finance			
	Investors' unconscious learning processes (including neuroeconomics)	Empirical evidence from real market data	Post-crisis modeling (including complexity)	Uniform evolutionary financial theory (including neuro-finance)
Ability to learn and adapt	X		X	
Stable portfolio rules		X		
Selection and survival of strategies		X		
Volatility clustering and price dynamics			X	
Integrated evolutionary financial model thinking	X		X	X

The paper also has some limitations. With regard to the state-of-the-art analysis, it is possible that the six descriptors for the systematic literature review did not identify all the relevant papers. In addition, the implications discussed for future research on evolutionary finance, are not encompassing but instead, selective.

In conclusion, it can be stated that the paper:

- shows investment managers how to get to know evolutionary finance better and opportunities in using this approach
- can help finance researchers develop the understanding of financial markets and identify further upcoming research streams.

References

Akerlof G (1970) The market for lemons: quality uncertainty and market mechanism. Quart J Econ 84(3):488–500

Alchian A (1950) Uncertainty, evolution and economic theory. J Polit Econ 58(3):211–221

Alchian A, Demsetz H (1972) Production, information cost and economic organization. Am Econ Rev 62(5):777–795

Aldrich H, Hodgson G, Hull D, Knudsen T, Mokyr J, Vanberg V (2008) In defense of generalized darwinism (working paper), University of North Carolina

Alós-Ferrer C, Ania A (2005) The asset market game. J Math Econ 41(1–2):67–90

Amir R, Evstigneev I, Hens T, Schenk-Hoppé KR (2005) Market selection and survival of investment strategies. J Math Econ 41(1–2):105–122

Amir R, Evstigneev I, Hens T, Xu L (2011) Evolutionary finance and dynamic games. Math Financ Econ 5(3):161–184

Amir R, Evstigneev I, Schenk-Hoppé KR (2013) Asset market games of survival: a synthesis of evolutionary and dynamic games. Ann Finance 9(2):121–144
Ankarloo D, Palermo G (2004) Anti-Williamson: a Marxian critique of new institutional economics. Camb J Econ 28(3):413–429
Anufriev M, Bottazzi G (2010) Market equilibria under procedural rationality. J Math Econ 46(6):1140–1172
Anufriev M, Bottazzi G (2011) Asset pricing with heterogeneous investment horizons. Stud Nonlinear Dyn Econom 16(4):1–38
Anufriev M, Dindo P (2010) Wealth-driven selection in a financial market with heterogeneous agents. J Econ Behav Organ 73(3):327–358
Anufriev M, Panchenko V (2009) Asset prices, trader´s behavior and market design. J Econ Dyn Control 33(5):1073–1090
Anufriev M, Bottazzi G, Pin P (2012) Excess covariance and dynamic instability in a multi-asset model. J Econ Dyn Control 36(8):1142–1161
Argitis G (2017) Evolutionary finance and central banking. Camb J Econ 41(3):961–976
Arthur W, Holland J, LeBaron B, Palmer R, Tayler P (1997) Asset pricing under endogenous expectations in an artificial stock market (working paper), Santa Fe Institute
Asness C, Moskowitz T, Pedersen LH (2013) Value and momentum everywhere. J Finance 68(3):929–985
Axioglou C, Skouras S (2014) Asset Pricing with Flexible Beliefs. Stud Nonlinear Dyn Econom 19(4):415–443
Bahsoun W, Evstigneev I, Xu L (2011) Almost nash equilibrium strategies in evolutionary models of asset markets. Math Methods Oper Res 73(2):235–250
Ball R (2009) The global financial crisis and the efficient market hypothesis: what have we learned. J Appl Corp Finance 21:8–16
Baltussen G (2009) Behavioral finance: an introduction (working paper). Stern School of Business, New York
Barberis N, Thaler R (2003) A survey of behavioral finance, chapter 18. In: Constantinides GM, Harris M, Stulz RM (eds) Handbook of the economics of finance, vol 1, 1st edn. Elsevier, Amsterdam, pp 1053–1128
Bektur C (2016) The kelly portfolio rule dominates. J Appl Finance Econ 2:1–10
Benartzi S, Thaler R (1995) Myopic loss aversion and the equity premium puzzle. Q J Econ 110(1):73–92
Benston G, Smith C (1976) A transactions cost approach to the theory of financial intermediation. Journal of Finance 31(2):215–231
Berardi M (2011) Fundamentalists vs. chartists: learning and predictor choice dynamics. J Econ Dyn Control 35(5):776–792
Bernardo A, Welch I (2001) On the evolution of overconfidence and entrepreneurs. J Econ Manag Strat 10(3):301–330
Black F, Scholes M (1973) The pricing of options and corporate liabilities. J Polit Econ 81(3):637–654
Blume L, Easley D (1992) Evolution and market behavior. J Econ Theory 58(1):9–40
Blume L, Easley D (2009) The market organism: long-run survival in markets with heterogeneous traders. J Econ Dyn Control 33(5):1023–1035
Bottazzi G, Dindo P (2013a) Evolution and market behavior in economics and finance. J Evol Econ 23(3):507–512
Bottazzi G, Dindo P (2013b) Selection in asset markets: the good, the bad and the unknown. J Evol Econ 23(3):641–661
Bottazzi G, Dindo P (2014) Evolution and Market Behavior with Endogenous Investment Rules. Journal of Economic Behavior and Control 48(2):121–146
Bottazzi G, Dosi G, Rebesco I (2005) Institutional Architectures and Behavioral Ecologies in the Dynamics of Financial Markets. J Math Econ 41(1–2):197–228
Brock WA, Fontnouvelle P (2000) Expectational diversity in monetary economics. J Econ Dyn Control 24(5–7):725–759
Brock WA, Hommes C (1997) A rational route to randomness. Econometrica 65(5):1059–1096
Brock WA, Hommes C (1998) Heterogeneous beliefs and routes to chaos in a simple asset pricing model. J Econ Dyn Control 22(8–9):1235–1274
Brock WA, Hommes C, Wagener O (2005) Evolutionary dynamics in markets with many trader types. J Math Econ 41(1–2):7–42
Brock WA, Hommes C, Wagener O (2009) More hedging instruments may destabilize markets. J Econ Dyn Control 33(11):1912–1928

Buchmann B, Weber S (2007) A continuous time approximation of an evolutionary stock market. Int J Theor Appl Finance 10(7):1229–1253
Cabrales A, Hoshi T (1996) Heterogeneous beliefs, wealth accumulation and asset price dynamics. J Econ Dyn Control 20(6–7):1073–1100
Camerer C (1989) Bubbles and fads in asset prices. J Econ Surv 3(1):3–41
Campbell J (2000) Asset pricing at the millennium. J Finance 55(4):1515–1567
Campbell T, Kracaw W (1980) Information production, market signalling and the theory of financial intermediation. J Finance 35(4):863–882
Chen M (2014) Using a hybrid evolution approach to forecast financial failures for Taiwan-listed companies. Quant Finance 14(6):1047–1058
Chen S, Yeh C (2001) Evolving traders and the business school with genetic programming: a new architecture of the agent-based artificial stock market. J Econ Dyn Control 25(3–4):363–393
Chiarella C, He X (2001) Asset price and wealth dynamics under heterogeneous expectations. Quant Finance 1(5):509–526
Chiarella C, He X (2002) Heterogeneous beliefs, risk and learning in a simple asset pricing model. Comput Econ 19(1):95–132
Chiarella C, He X (2003) Heterogeneous beliefs, risk and learning in a simple asset pricing model with a market maker. Macroecon Dyn 7(4):503–536
Chiarella C, Dieci R, Gardini L (2002) Speculative behavior and complex asset price dynamics: a global analysis. J Econ Behav Organ 49(2):173–197
Chiarella C, Gallegati M, Leombruni R, Palestrini A (2003) Asset price dynamics among heterogeneous interacting agents. Comput Econ 22(2–3):213–223
Chiarella C, Dieci R, Gardini L (2006) Asset price and wealth dynamics in a financial market with heterogeneous agents. J Econ Dyn Control 30(9–10):1755–1786
Chiarella C, Dieci R, He X (2007) Heterogeneous expectations and speculative behavior in a dynamic multi-asset framework. J Econ Behav Organ 62(3):408–427
Chiarella C, He X, Zheng M (2011) An analysis of the effect of noise in a heterogeneous agent financial market model. J Econ Dyn Control 35(1):148–162
Chiarella C, Dieci R, He X (2013a) Time-varying beta. A boundedly rational equilibrium approach. J Evol Econ 23(3):609–639
Chiarella C, Dieci R, He X, Li K (2013b) An evolutionary CAPM under heterogeneous beliefs. Ann Finance 9(2):185–215
Chiarella C, He X, Zwinkels R (2014) Heterogeneous expectations in asset pricing: empirical evidence from the S&P500. J Econ Behav Organ 105(1):1–16
Coase R (1937) The nature of the firm. Economica 4(16):386–405
Coase R (1998) The new institutional economics. Am Econ Rev 88(2):72–74
Coche J (1998) An evolutionary approach to the examination of capital market efficiency. J Evolut Econ 8(4):357–382
Data Colada (2014) http://datacolada.org/15. Accessed 19 Oct 2017
De Bondt W (1998) A portrait of the individual investor. Eur Econ Rev 42(3–5):831–844
De Bondt W, Thaler R (1985) Does the stock market overreact? J Finance 40(3):793–805
De Bondt W, Thaler R (1987) Further evidence on investor overreaction and stock market seasonality. J Finance 42(3):557–581
De Bondt W, Thaler R (1989) Anomalies: a mean-reverting walk down wall street. J Econ Perspect 3(1):189–202
De Giorgi E (2008) Evolutionary portfolio selection with liquidity shocks. J Econ Dyn Control 32(4):1088–1119
Diamond D (1984) Financial intermediation and delegated monitoring. Rev Econ Stud 51(3):393–414
Dijksterhuis A (2004) Think different: the merits of unconscious thoughts in preference development and decision making. J Pers Soc Psychol 87(5):586–598
Dijksterhuis A, Bos M, van Baaren R (2006) On making the right choice: the deliberation without attention effect. Science 311(5763):1005–1007
Dillon D (2001) Review of the Santa Fe Institute: institutional and individual qualities of expert interdisciplinary work (working paper). Harvard Interdisciplinary Studies Project, No. 22
Dopfer K (2007) Grundzüge der Evolutionsökonomie—Analytik, Ontologie und theoretische Schlüsselkonzepte (working paper no. 2007-10). University of St. Gallen Department of Economics

Ebers M, Gotsch W (1999) Organisationstheorien. In: Kieser A (ed) Institutionenökonomische Theorien der Organisation, 3rd edn. Kohlhammer, Stuttgart, pp 199–251
Evstigneev I, Hens T, Schenk-Hoppé KR (2002) Market selection of financial trading strategies: global stability. Math Finance 12(4):329–339
Evstigneev I, Hens T, Schenk-Hoppé KR (2006) Evolutionary stable stock markets. Econ Theor 27(2):449–468
Evstigneev I, Hens T, Schenk-Hoppé KR (2008) Globally evolutionarily stable portfolio rules. J Econ Theory 140(1):197–228
Evstigneev I, Hens T, Schenk-Hoppé KR (2011) Local stability analysis of a stochastic evolutionary financial market model with a risk-free asset. Math Financ Econ 5(3):185–202
Evstigneev I, Schenk-Hoppé KR, Ziemba WT (2013) Introduction: behavioral and evolutionary finance. Ann Finance 9(2):115–119
Evstigneev I, Hens T, Schenk-Hoppé KR (2016) Evolutionary behavioral finance. In: Haven E, Molyneux P, Wilson J, Fedotov S, Duygun M (eds) The handbook of post crisis financial modeling. Palgrave Macmillan, Basingstoke, pp 214–234
Fama E (1965) The behavior of stock market prices. J Bus 38(1):34–105
Fama E (1970) Efficient capital markets: a review of theory and empirical work. J Finance 25(2):383–417
Fama E (1976) Efficient capital markets: reply. J Finance 31(1):143–145
Fama E (1991) Efficient capital markets: II. J Finance 46(5):1575–1617
Fama E (1998) Market efficiency, long-term returns and behavioral finance. J Financ Econ 49(1):283–306
Fama E (2014) Two pillars of asset pricing. Am Econ Rev 104(6):1467–1485
Farmer J (1998) Market force, ecology and evolution (working paper). Santa Fe Institute
Farmer J, Joshi A (2001) The price dynamics of common trading strategies. J Econ Behav Organ 49(2):149–171
Farmer J, Lo A (1999) Frontiers of finance: evolution and efficient markets. Nat Acad Sci USA 96(18):9991–9992
Fisch C, Block J (2018) Six steps for your (systematic) literature review in business and management research. Manag Rev Q 68(2):103–106
Fisher K, Statman M (2000) investor sentiment and stock returns. Financ Anal J 56(2):16–23
Föllmer H, Horst U, Kirman AP (2005) Equilibria in financial markets with heterogeneous agents: a probabilistic perspective. J Math Econ 41(1–2):123–155
Friedman D (2001) Toward evolutionary game models of financial markets. Quant Finance 1(1):177–185
Furubotn E, Richter R (2000) Institutions and economic theory. University of Michigan Press, Ann Arbor
Gaunersdorfer A (2000) Endogenous fluctuations in a simple asset pricing model with heterogeneous agents. J Econ Dyn Control 25(5–7):799–831
Gaunersdorfer A, Hommes C, Wagener F (2008) Bifurcation to volatility clustering under evolutionary learning. J Econ Behav Organ 67(1):27–47
Georges C, Wallace J (2009) Learning dynamics and nonlinear misspecification in an artificial financial market. Macroecon Dyn 13(5):625–655
Gippel J (2013) A revolution in finance? Aust J Finance 38(1):125–146
Glimscher P, Camerer C, Fehr E, Poldrack R (2009) Neuroeconomics: decision making and the brain. Elsevier/Academic Press, Amsterdam
Hayek FA (1945) The use of knowledge in society. Am Econ Rev 35(4):519–530
Hayek FA (1973) Law, Legislation and Liberty, vol I, Rules and Order. University of Chicago Press, Chicago
Hayek FA (1976) Law, Legislation and Liberty, vol II, Rules and Order. University of Chicago Press, Chicago
Hayek FA (1979) Law, Legislation and Liberty, vol III, Rules and Order. University of Chicago Press, Chicago
Hayek FA (1994a) Freiburger Studien, 2nd edn. Mohr Siebeck, Heidelberg
Hayek FA (1994b) Hayek on Hayek: an autobiographical dialogue. University of Chicago Press, Chicago
He X, Li K (2012) Heterogeneous beliefs and adaptive behavior in a continuous-time asset price model. J Econ Dyn Control 36(7):973–987
Hens T (2005) Innovation und Selektion von Anlagestrategien: Eine evolutionäre Betrachtung, Vortrag Institutional Alpine Summit CSAM
Hens T (2006) Foxes and rabbits. CFA Inst Mag 17(2):38–41
Hens T, Schenk-Hoppé KR (2005a) Evolutionary finance: introduction to the special issue. J Financ Math 41(1–2):1–5

Hens T, Schenk-Hoppé KR (2005b) Evolutionary stability of portfolio rules in incomplete markets. J Financ Math 41(1–2):43–66
Hens T, Schenk-Hoppé KR (2006) Markets do not select for a liquidity preference as behavior towards risk. J Econ Dyn Control 30(2):279–292
Hens T, Schenk-Hoppé KR (2009) Handbook of financial markets. Elsevier, Amsterdam
Hens T, Schenk-Hoppé KR, Stalder M (2002) An application of evolutionary finance to firms listed in the Swiss Market Index. Swiss J Econ Stat 138(4):465–487
Hens T, Lensberg T, Schenk-Hoppé KR, Wöhrmann P (2011) An evolutionary explanation of the value premium puzzle. J Evol Econ 21(5):803–815
Herrmann-Pillath C (2002) Grundriß der Evolutionsökonomik, Utb
Hirshleifer J (1977) Economics from a biological viewpoint. J Law Econ 20(1):1–52
Hirshleifer D (2001) Investor psychology and asset pricing. J Finance 56(4):1533–1597
Hodgson G (2004) The evolution of institutional economics: agency, structure and darwinism in American institutionalism. Routledge, Abingdon
Hommes C (2001) Financial markets as nonlinear adaptive evolutionary systems. Quant Finance 1(1):149–167
Hommes C (2009) Heterogeneous agent models in economics and finance. In: Schmedders K, Judd K (eds) Handbook of computational economics, vol 2, Chapter 23. North-Holland, Amsterdam, pp 1109–1186
Hommes C, Huang H, Wang D (2005) A robust rational route to randomness in a simple asset pricing model. J Econ Dyn Control 29(6):1043–1072
Hommes C, Kiseleva T, Kuznetsov Y, Verbic M (2012) Is more memory in evolutionary selection (de)stabilizing? Macroecon Dyn 16(3):335–357
Horst U (2005) Financial price fluctuations in a stock market model with many interacting agents. Econ Theor 25(4):917–932
Jegadeesh N, Titman S (1993) Returns to buying winners and selling losers: implications for stock market efficiency. J Finance 48(1):65–91
Jensen M, Meckling W (1976) Theory of the firm: managerial behavior, agency costs and ownership structure. J Financ Econ 3(4):305–360
Jouini E, Napp C, Viossat Y (2013) Evolutionary beliefs and financial markets. Rev Finance 17(2):727–766
Kahneman D (2011) Thinking fast and slow. Penguin, London
Kahneman D, Tversky A (1979) Prospect theory: an analysis of decision under risk. Econometrica 47(2):263–291
Kahneman D, Tversky A (1984) Choices, values and frames. Am Psychol 39(4):341–350
Kirman A (2010) The economic crisis is a crisis for economic theory. CESifo Econ Stud 56(4):498–535
Krugman P (2009) The return of the depression economics and the crisis of 2008. W. Norton & Company, New York
Ladley D, Schenk-Hoppé KR (2009) Do stylized facts of order book markets need strategic behavior? J Econ Dyn Control 33(4):817–831
Langlois R (1986) Rationality, institutions, and explanation. In: Langlois R (ed) Economics as a process: essays in the new institutional economics. Cambridge University Press, Cambridge
LeBaron B (2000) Agent based computational finance: suggested readings and early research. J Econ Dyn Control 24(5–7):679–702
LeBaron B (2001a) A builder's guide to agent-based financial markets. Quant Finance 1(2):254–261
LeBaron B (2001b) Evolution and time horizons in an agent-based stock market. Macroecon Dyn 5(2):225–254
LeBaron B (2006) Agent-based computational finance. In: Schmedders K, Judd K (eds) Handbook of computational economics, vol 2, Chapter 24. North-Holland, Amsterdam, pp 1187–1233
LeBaron B (2011) Active and passive learning in agent-based financial markets. Eastern Econ J 37(1):35–43
LeBaron B (2012a) Heterogeneous gain learning and the dynamics of asset prices. J Econ Behav Organ 83(3):424–445
LeBaron B (2012b) Wealth dynamics and a bias toward momentum trading. Finance Res Lett 9(1):21–28
LeBaron B (2016) Financial price dynamics and agent-based models as inspired by Benoit Mandelbrot. Eur Phys J Spec Top 225(17–18):3243–3254
LeBaron B, Arthur W, Palmer R (1999) Time series properties of an artificial stock market. J Econ Dyn Control 23(9–10):1487–1516
Leland H, Pyle D (1977) Informational asymmetries, financial structure and financial intermediation. J Finance 32(2):371–387

Lensberg T, Schenk-Hoppé KR (2007) On the evolution of investment strategies and the Kelly Rule—a Darwinian approach. Rev Finance 11(1):25–50
Lensberg T, Schenk-Hoppé KR, Ladley D (2015) Cost and benefits of financial regulation: short selling bans and transaction taxes. J Bank Finance 51(2):103–118
LeRoy S (1976) Efficient capital markets: comment. J Finance 31(1):139–141
Levy M (2005) Is risk-aversion hereditary? J Math Econ 41(1–2)
Levy M, Levy H, Solomon S (1994) A microscopic model of the stock market. Cycles Booms Crashes Econ Lett 45(1):103–111
Li M, Zheng Z (2017) Heterogeneous trading and complex price dynamics. J Econ Interact Coord 12(2):437–442
Lintner J (1965) The valuation of risk assets on the selection of risky investments in stock portfolios and capital budgets. Rev Econ Stat 47(1):13–37
Lo A (2004) The adaptive markets hypothesis: market efficiency from an evolutionary perspective. J Portf Manag 30(5):15–29
Lo A (2005) Reconciling efficient markets with behavioral finance: the adaptive markets hypothesis. J Invest Consult 7(2):21–44
Lo A (2017) Adaptive markets: financial evolution at the speed of thought. Princeton University Press, Princeton
Lof M (2012) Heterogeneity in stock prices: a STAR model with multivariate function. J Econ Dyn Control 36(12):1845–1854
Lopes L (1991) The rhetoric of irrationality. Theory Psychol 1(1):65–82
Luo G (2012) Conservative traders, natural selection and market efficiency. J Econ Theory 147(1):310–335
Lux T (1997) Time variation of second moments from a noise trader/infection model. J Econ Dyn Control 22(1):1–38
Lux T (1998) The socio-economic dynamics of speculative markets: interacting agents, chaos and the fat tails of return distribution. J Econ Behav Organ 33(2):143–165
Lux T, Marchesi M (2000) Volatility clustering in financial markets. Int J Theor Appl Finance 3(4):675–702
Lux T, Schornstein S (2005) Genetic learning as an explanation of stylized facts of foreign exchange markets. J Math Econ 41(1–2):169–196
Malkiel B (1992) Efficient market hypothesis. In: Newman P, Milgate M, Eatwell J (eds) New Palgrave Dictionary of money and finance. Macmillan, Basingstoke
Malkiel B (2003) The efficient market hypothesis and its critics. J Econ Perspect 17(1):59–82
Mandelbrot B (1963) The variation of certain speculative prices. J Bus 36(1):394
Mandes A, Winker P (2017) Complexity and model comparison in agent based modeling of financial markets. J Econ Interact Coord 12(3):469–506
Markowitz H (1952) Portfolio selection. J Finance 7(1):77–91
Marshall A (1898) Distribution and exchange. Econ J 8(29):37–59
Mavroudis K, Nolder C (2011) Fixed-mix rules in an evolutionary market using a factor model for dividends. Int J Theor Appl Finance 14(8):1247–1277
Menger C (1871): Principles of Economics. Braumüller
Menger C (1883) Investigations into the method of the social science with special reference to economics. Duncker & Humblot, Berlin
Merton RC (1973) Theory of rational option pricing. Bell J Econ Manag Sci 4(1):141–183
Miendlarzewska E, Kometer M, Preuschoff K (2018) Neuro-finance, organizational research methods. https://doi.org/10.1177/1094428117730891
Mirowski P (1983) Review of an evolutionary theory of economic change. J Econ Issues 17(3):757–768
Mises L (1940) Nationalökonomie: Theorie des Handelns und Wirtschaftens. Editions Union Genf, Geneva
Mises L (1949) Human action: a treatise on economics. Yale University Press, New Haven
Nawrocki D, Vaga T (2015) A bifurcation model of market returns. Quant Finance 14(3):509–528
Nelson R, Winter S (1982) An evolutionary theory of economic change. Belknap Press, Belknap
Nelson R, Winter S (2002) Evolutionary theorizing in economics. J Econ Perspect 16(2):23–45
Nik M, Maheran M (2009) behavioral finance vs traditional finance. Adv Manag J 2(6):1–10
Nobel Committee (2002) http://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2002/press.html. Accessed 19 Oct 2017
Nobel Committee (2017) https://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2017/press.html. Accessed 21 Oct 2017
North D (1978) Structure and performance: the task of economic history. J Econ Lit 16(3):963–978

North D (1990) Institutions, institutional change and economic performance. Cambridge University Press, Cambridge
North D (1991) Institutions. J Econ Perspect 5(1):97–112
Odean T (1998) Are investors reluctant to realize their losses? J Finance 53(5):1775–1798
Palczewski J, Schenk-Hoppé KR (2009) From discrete to continuous time evolutionary finance models. J Econ Dyn Control 34(5):913–931
Palczewski J, Schenk-Hoppé KR (2010) Market selection of constant proportions investment strategies in continuous time. J Math Econ 46(2):248–266
Palczewski J, Schenk-Hoppé KR, Wang T (2016) Itchy feet vs cool heads: flow of funds in an agent-based financial market. J Econ Dyn Control 63(1):53–68
Palmer R, Arthur W, Holland J, LeBaron B, Tayler P (1994) Artificial economic life: a simple model of a stock market. Physica D 75(1–3):264–274
Parke W, Waters G (2007) An evolutionary game theory explanation of ARCH effects. J Econ Dyn Control 31(7):2234–2262
Penrose E (1952) Biological analogies in the theory of the firm. Am Econ Rev 42(5):804–819
Picot A (1982) Transaktionskostenansatz in der Organisationstheorie: Stand der Diskussion und Aussagewert. Die Betriebswirtschaft 42(2):267–284
Reimann S, Tupak A (2007) Prices are Macro-Observables! Stylized facts from evolutionary finance. Comput Econ 29(3–4):313–331
Rekik Y, Boujelbene Y (2014) Evolutionary finance approach: literature survey. J Econ Finance 3(1):44–53
Richter R, Furubotn E (2010) Neue Institutionenökonomik: Eine Einführung und kritische Würdigung. Mohr Siebeck, Heidelberg
Rosenberg A (1994) Does evolutionary theory give comfort or inspiration to economics? In: Mirowski P (ed) Natural images in economic thought: markets read in tooth and claw, chapter 15, pp 384–407
Ross SA (1973) The economic theory of agency: the principal's problem. Am Econ Rev Pap Proc 63(2):134–139
Roßbach P (2001) Behavioral finance: Eine Alternative zur vorherrschenden Kapitalmarkttheorie? Working paper, Hochschule für Bankwirtschaft, No. 31, Frankfurt a.M
Sandroni A (2005) Market selection when markets are incomplete. J Math Econ 41(1–2):91–104
Schamp E (2012) Evolutionäre Wirtschaftsgeographie: Eine kurze Einführung in den Diskussionsstand. Zeitschrift für Wirtschaftsgeographie 56(3):121–128
Schmidt R (1981) Grundformen der Finanzierung: Eine Anwendung des neo-institutionalistischen Ansatzes der Finanzierungstheorie. Kredit und Kapital 14(2):186–221
Schneider D (2002) Vorläufer Evolutorischer Ökonomik in der Mikroökonomie und Betriebswirtschaftslehre, In: Lehmann-Waffenschmidt M (ed) Studien zur Evolutorischen Ökonomik V: Theoretische und Empirische Beiträge zur Analyse des wirtschaftlichen Wandels, Band 195/V
Schumpeter J (1911) The theory of economic development: an inquiry into profits, capital, credit, interest and the business cycle. Harvard Economic Studies, Harvard
Schumpeter J (1935) The analysis of economic change. Rev Econ Stat 17(4):2–10
Schumpeter J (1942) Capitalism, socialism and democracy. Harper & Row, New York
Schumpeter J (1954) History of economic analysis. Allen & Unwin, London
Sciubba E (2006) The evolution of portfolio rules and the capital asset pricing model. Econ Theor 29(1):123–150
Sewell M (2012) The efficient market hypothesis: empirical evidence. Int J Stat Probab 1(2):164–178
Shapiro D (2009) Evolution of heterogeneous beliefs and asset overvaluation. J Math Econ 45(3–4):277–292
Sharpe W (1964) Capital asset prices: a theory of market equilibrium under conditions of risk. J Finance 19(3):425–442
Shefrin H (2000) Beyond greed and fear—understanding behavioral finance and the psychology of investing. Harvard Business School Press, Harvard
Shefrin H, Statman M (1985) The disposition to sell winners too early and ride losers too long: theory and evidence. J Finance 40(3):777–790
Shiller R (1990) Market volatility and investor behavior. Am Econ Rev 80(2):58–62
Shiller R (2000a) Irrational exuberance. Princeton University Press, Princeton
Shiller R (2000b) Measuring bubble expectations and investor confidence. J Psychol Financ Mark 1(1):49–60
Shiller R (2003) From efficient markets theory to behavioral finance. J Econ Perspect 17(1):83–104
Shiozawa Y (2004) Evolutionary economics in the 21 century: a manifesto. Evol Inst Econ Rev 1(1):5–47

Siegel L (2017) What we can learn from Andrew Lo's adaptive markets, advisor perspectives (June 26, 2017)
Simon H (1955) A behavioral model of rational choice. Q J Econ 69(1):99–118
Simon H (1991) Bounded rationality and organizational learning. Organ Sci 2(1):125–134
Spremann K (1988) Reputation, garantie und information. Zeit- schrift für Betriebswirtschaft 58(1):613–629
Stangl W (2016) Bedeutung der Rahmenbedingungen für das Lernen, http://arbeitsblaetter-news.stangl-taller.at/bedeutung-der-rahmenbedingungen-fur-das-lernen/. Accessed 06 Nov 2018
Statman M (1997) Behavioral finance: past battles and future engagements. Financ Anal J 55(6):18–27
Statman M, Caldwell D (1987) Applying behavioral finance to capital budgeting: project terminations. Financ Manag 16(4):7–15
Streissler E (2000) Internationale Finanzmärkte aus einer von Hayek inspirierten Sicht, ORDO: Jahrbuch für die Ordnung von Wirtschaft und Gesellschaft, vol 51, pp 75–96
Streit M, Mummert U, Kiwit D (1997) Views and comments on cognition, rationality, and institutions. J Inst Theor Econ 153:688–692
Subrahmanyam A (2007) Behavioural finance: a review and synthesis. Eur Financ Manag 14:12–29
Suryawanshi P, Jumle A (2016) Comparison of behavioral finance and traditional finance: for investment decisions. Int J Commer Bus Manag 5(3):81–85
Taleb N (2007) The Black Swan: the impact of the highly improbable. Random House, New York
Thaler R, Benartzi S (2004) Save more tomorrow: using behavioral economics to increase employee saving. J Polit Econ 112(1):164–187
Thaler R, Sunstein C (2008) Nudge: improving decisions about health, wealth and happiness. Yale University Press, New Haven
Tversky A, Kahneman D (1973) Availability: A heuristic for judging frequency and probability. Cogn Psychol 5(2):207–232
Tversky A, Kahneman D (1974) Judgment under uncertainty: heuristics and biases. Science 185(4157):1124–1131
Tversky A, Kahneman D (1981) The framing of decisions and the psychology of choice 211(4481):453–458
Tversky A, Kahneman D (1992) Advances in prospect theory: cumulative representation of uncertainty. J Risk Uncertain 5(4):297–323
Veblen T (1898) Why is economics not an evolutionary science. Q J Econ 12(4):373–397
Wilhelms E, Reyna V (2014) Neuroeconomics, judgment and decision making. Psychology Press, Abingdon
Williamson O (1975) Markets and hierarchies. Free Press, New York
Williamson O (1996) The mechanisms of governance. Bus Hist Rev 70(4):594–596
Wilson T, Schooler J (1991) Thinking too much: introspection can reduce the quality of preferences and decisions. J Pers Soc Psychol 60(2):181–192
Winter S (1987) Natural selection and evolution. In: Eatwell J, Milgate M, Newman P (eds) The New Palgrave Dictionary of economics, vol 3. Macmillan, Basingstoke, pp 614–617
Witt U (1987) Individualistische Grundlagen der evolutorischen Ökonomik, Mohr Siebeck
Witt U (1999) Bioeconomics as economics from a Darwinian perspective. J Bioecon 1(1):19–34
Witt U (2003) The evolving economy: essays on the evolutionary approach to economics. Edward Elgar, Cheltenham
Witt U (2004) On the proper interpretation of evolution in economics and its implications for production theory. J Econ Methodol 11(2):125–146
Witt U (2008) What is specific about evolutionary economics? J Evol Econ 18(5):547–575
Wu B, Duan T, He J (2016) Dynamics evolution of trading strategies of investors in financial market. Comput Econ 48(1):1–18
Youssefmir M, Huberman B (1997) Clustered volatility in multiagent dynamics. J Econ Behav Organ 32(1):101–118