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Social science goes quantum: explaining human decision-making, cognitive biases and Darwinian selection from a quantum perspective

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Abstract
The social and economic sciences are grounded on the basic assumption that social life, decision-making behavior, and consciousness are classical physical and therefore material phenomena. Quantum social science, a new research area, which refers to the knowledge and interpretations of quantum physics, is challenging this assumption. This paper gives an overview of quantum social science and explains quantum decision theory on the one hand with a focus on the cognitive biases first elaborated by Kahneman & Tversky, and on the other hand by Darwin´s theory of evolution.

Keywords Social science · Quantum physics · Decision-making · Cognitive biases · Behavioral economics · Evolution theory

JEL classification A12 · B59 · D91

1 Introduction

The findings of quantum physics at the beginning of the 20th century changed the way of viewing the concept of reality. The results of quantum theory have been confirmed in particular in physics, and many scientists agree with the basic findings (see e.g. Herbert, 1985; Feynman, 1994; Weinberg, 1995; Friedman, 1997; Rosenblum/

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Kuttner, 2006; Greene, 2011; and Susskind, 2014). Whereas in classical physics the properties of real material objects (e.g. a ball) can be precisely measured using mathematics, in quantum physics, there are only probabilities of finding certain properties through measurement. These probabilities take the form of wave functions, which are associated with different simultaneous states (groundbreaking Schrödinger, 1926; Greene, 2011). However, unlike in classical physics, where one can accurately measure an object's momentum or location, wave functions represent only potential realities, not actual ones (Weinberg, 1995).

How can a link to social science be derived now? It is difficult to grasp and one of the most incomprehensible secrets of how the indeterminate quantum world leads to the determinate classical world (including our social life), especially when considering that quantum mechanics subsumes classical physics, whereas its practical applicability is limited to subatomic particles. This process leading from the quantum world to macroscopic reality is called decoherence in physical science (Zeh, 1970). What if social life is not determined by the classical world but instead by quantum in the form of wave functions? This (social life) would also include economics and its research areas, such as decision-making theory. Of particular interest for the paper is the psychological decision theory including cognitive biases, fundamentally shaped by Nobel laureate behavioral economists Kahneman and Tversky (Tversky & Kahneman, 1973, 1974, 1983; Kahneman & Tversky, 1979, 1984; Kahneman, 2011). In addition to this special feature of cognitive biases, human decision-making behavior in general should also be viewed from the perspective of a quantum Darwinism with the aim of designing a new quantum model of decision-making behavior. The research questions are therefore as follows: First, how can findings from quantum physics be transferred to social sciences (including economics), and which new perspectives result? Second, how can (behavioral) decision theory be interpreted differently in the light of quantum physics? Third, how can the perspective of a quantum Darwinism complete human decision-making behavior?

The paper is structured as follows. Section 2 presents a short overview of quantum physics and its fundamental experiments, followed by a summary of decision-making theory and related cognitive biases as elaborated by Kahneman & Tversky in Sect. 3. Section 4 transfers selected knowledge and interpretations of quantum physics into the social world and takes a critical appraisal of the term "quantum social science", especially with a focus on cognitive biases and Darwinian selection. Section 5 concludes the paper.

2 Quantum theory: experiments and interpretations

This chapter provides social scientists (including economists) with a brief overview of the seminal experiments in quantum physics as well as their findings and interpretations. This should enable them to develop reasonable, well-informed knowledge to bring quantum physics and social science closer together.

2.1 Two-slit experiment and collapse of the wave function

Starting from the findings of Planck and Einstein that light can be both waves and particles (which seems contradictory to Newton's classic either-or physics), De Broglie showed theoretically and experimentally with the Two-slit experiment in 1924 and 1926 that matter can behave like a wave and electrons are not only tiny objects but also waves (De Broglie, 1924; and more general Zukav, 1979; Herbert, 1985; Greene, 2011; Susskind, 2014). In this two-slit experiments, a kind of particle gun shoots a mass of electrons toward a screen of two splits. While these electrons pass through the slits their location of hits is represented on a photographic screen (Davisson & Germer, 1927; Nadeau & Kafatos, 1999). If then one slit is closed, the distribution of hits is located in front of the open slit. If the situation is changed (the open slit is closed and the other one opened), a similar result across the second slit occurs, which could be expected if the electrons were particles. Thus, one might assume that when both slits are open, the result is a sum of the distributions. Surprisingly, that is not the case. Instead, a typical interference pattern by waves emerges. Therefore, it seems that each electron slides through both slits simultaneously and thus behaves like a wave (Wheeler, 1978; Greene, 2011).

What happens when detectors are placed on the slits for closer monitoring? In this case, the wave pattern disappears suggesting that electrons are particles for the whole time (Herbert, 1985; Friedman, 1997). This leads to the so-called observer or measurement effect. Accordingly, measuring or observing the electrons at the slits gives a different result than not measuring, or to put in another way: as long as the electron is not being observed it behaves as if it is a wave, and as soon as it is observed it behaves as if it is a particle (Weinberg, 1995). This implies that in the quantum area, the observer and the observed establish their own single system, unlike in the classical world where matter or things are seen as separate from each other (Malin, 2001). The next question that arises is what exactly are these strange waves?

The mathematical side of these waves was discovered by Schrödinger (Schrödinger, 1926), according to whom the wave function stands for the potential of all outcomes (it can also be said: all realities) that might be observed when performing a measurement. Therefore, all of the wave´s possible states have the potential to exist simultaneously in a so-called superposition (Albert, 1992). If a concrete measurement is performed, the wave collapses into particles, which means that the probability of all the possible outcomes that are not actually observed goes to zero and that which is observed goes to one (and this is what we can see then in the classical world).

2.2 Entanglement

In quantum physics, entanglement (the topic and relevance of entanglement was acknowledged and awaraded with the Nobel Prize in Physics 2022, see Nobel Committee, 2022) means that a composite physical system, e.g. a system with several particles, viewed as a whole, assumes a well-defined state, without being able to assign a well-defined state of its own to each of the subsystems (Bengtsson & Zyczkowski, 2006). This phenomenon does not exist in classical physics since composite systems are always separable and Einstein argued to this point of entanglement that quantum physics must be incomplete (Einstein et al., 1935; the so-called EPR-effect). Precisely, he spoke of a spooky action at a distance effect. Later, Bell (1966) and Gisin et al. (1989, 1999) showed that entanglement of particles and non-locality (i.e., that causal influence can propagate faster than the speed of light) exist even over extremely long distances.

Thus, it can be concluded that a system of two particles A and B, which move in opposite and far away directions after the interaction, "communicate" with each other such that if one particle is changed (e.g. momentum) the other particle instantaneously (i.e., faster than light, see Gisin et al., 2008) changes in the same way. Therefore, each particle knows what is happening to the other, without any signal being transferred (Hardy, 1998).

2.3 Uncertainty principle

The uncertainty principle of Heisenberg (also called the unsharpness relation) states that it is impossible to measure the momentum and location of a particle simultaneously (Heisenberg, 1925). That means, the more precisely we measure the momentum of a particle, the less precise is its location and vice versa. Thus, the particle has either an exactly defined position or an exactly defined momentum, but not both at the same time (Malin, 2001). In combination with the wave function, the uncertainty principle expresses the wave character of matter.

The next step is to ask how to interpret these fundamental experiments and findings of quantum physics with regard to what reality is and how the world actually works. A closer look at the interpretive literature emphasizes that there are two schools of thought (for a good overview see Wendt, 2015): the instrumentalist one, and the realist one. The concept of instrumentalism (also called the Copenhagen interpretation, see, extensively, Howard, 2004) goes back primarily to Bohr's work of 1927 (which was based on an exchange of ideas with Heisenberg), according to whom the question of what the quantum world really is will not be answered, leading Bohr to focus on what knowledge can be gained about the quantum world (Honner, 1987). Thus, the concept of instrumentalism is not concerned about reality per se, but about the description of reality (Shimony, 1978). In Bohr's opinion, quantum systems can only be recognized through a description of the entire experimental situation (e.g. observer and measurement device) and thus, unlike macroscopic objects, cannot confirm that certain properties are inherent in quantum systems (D´Espagnat, 1995).

In contrast, the concept of realism tries to tell something about how reality by quantum physics really is. Here, there are two directions of interpretation. The first one is the Many Worlds Interpretation of Everett (1957). Accordingly, it is assumed that if a wave function is measured, all its possibilities are actualized in different worlds (Butterfield, 1995; Barrett, 1999). Therefore, each measurement causes the universe to split into separate universes (this is also called a multiverse) and this infinite number of universes exists simultaneously. Later, the Many Worlds Interpretation was split off by the Many Minds Interpretation by De Witt (1973), who elaborated that the biggest difference is that observers have specific experiences by consciousness. The second interpretation of the concept of realism is more idealistic, putting consciousness – i.e., the world inside of the observer and matter – even more in the foreground. Hereafter, not only the observer but also the sub-atomic particles possess a kind of mentality (Ward, 2014), also known as panpsychism. A panpsychist interpretation of quantum theory changes a lot (see Bohm, 1951). According to Bohm and his Mind-Matter Theory (1990), the quantum field contains active information (similar to the function of information in the macroscopic world, but more understood to be objective rather than a measure of our knowledge, see Pylkkänen, 2007), which organize the movement of the quantum particles.

In summary, it can be stated that quantum theory challenges the metaphysical assumptions on which the classical worldview is based, especially materialism, determinism, the subject-object distinction, the role of consciousness, and the absoluteness of space and time (Wendt, 2006, 2015). If someone takes a closer look at the role of interpretation of consciousness from the point of view of quantum physics, social scientists (including economists) will immediately acknowledge the relevance of these findings for human decision-making processes. From the point of view of classical physics, consciousness is seen as something material, while quantum physics meanwhile speaks of a quantum consciousness that can be extended to all social life (see e.g. Schrödinger, 1944; Hameroff & Penrose, 1996; Ho, 1997; Glymour et al., 2001; Manousakis, 2006; Aerts et al., 2010; Igamberdiev, 2012). In the two subsequent chapters, therefore, the foundations of decision theory (including cognitive biases) and the context between consciousness, quantum physics, social science, and decision-making theory are discussed and reinterpreted.

3 Decision-making theory and cognitive biases

The fundamental task of decision-making theory is to analyze the consequences of decisions (Edwards, 1954; Petersen, 2011), with social science distinguishing between normative and descriptive decision theory. The normative way is based on the rational choice theory and gives the individual a kind of frame how to behave rationally (Eisenführ et al., 2010). Rationality can be summarized in two ways (see, e.g., for social and economic science: Smith, 1776; Weber, 1922; Parsons, 1937; Neumann & Morgenstern, 1953; Savage, 1954; Simon, 1959). On the one hand, the path to the decision (also called e.g. procedural rationality) must be rational (this includes, for example, that the goals and preferences are clear or that no cognitive biases are included, which means that expectations are formed on the basis of objective data). On the other hand, the decision must be internally consistent (inter alia, this includes that the choice of alternatives depends only on its consequences or that the decision is transitive, meaning that it is free of illogical). Especially in economics, the construct of economic man or homo oeconomicus (as introduced by Mill, Pantaleoni, and Pareto in the late 19th century, see, extensively, Bee & Desmarais-Tremblay, 2023) found its way through the concept of rationality and was fundamental to neoclassical theory (see basically Menger, 1871; Walras, 1874). This homo oeconomicus is a kind of representative agent for economic subjects, who always maximizes his benefit when making decisions (Persky, 1995; Hartley, 1996).

Furthermore, economists prefer to distinguish between decisions made under certainty and decisions made under uncertainty or risk (seminal, see Knight, 1921;

Eisenführ et al., 2010). The former means that the decision-maker knows for certain (p = 1) the environmental situation that will occur and can therefore predict all the consequences of an action. Instead, the latter describes decision-making in situations in which the occurrence of future environmental conditions cannot be predicted with certainty. Thus, the effects of an action chosen remain unknown ex-ante. The decision-maker faces a choice between different alternatives, which depend on the possible environmental conditions (Kochenderfer, 2015; Yoe, 2019): either, a decision under risk, or a decision under fundamental uncertainty according to Knight (1921). A decision under risk means that the decision maker is objectively or subjectively aware of the probabilities of occurrence of the environmental conditions that depend on the decision. Furthermore, he is able to quantify the outcomes in each scenario, enabling him to quantify expectations, scatterings, and further measures. In contrast, a decision under fundamental ("Knightian" or "radical") uncertainty implies that the decision maker is only aware of the possible environmental states that are dependent on his decision, but he cannot make any statements about the probabilities with which these environmental states will occur, as he does not know every possible scenario, not to mention their consequences (see Kay & King, 2020; as a recent overview, also Kay, 2020).

The descriptive/positive way of observation of decision-making (also called behavioral economics) means that science is looking at real decision situations or in other words, how human actors actually behave – in contrast to normative approaches considering the recommendable or even optimal behavior. The pioneers of descriptive decision theory and thus Behavioral Economics, which is linked to cognitive psychology and sociology, were Kahneman & Tversky in the early 1970s (see, retrospectively, Kahneman, 2011; in addition to cognitive biases, Kahneman et al. have recently researched the term "noise" in the context of cognitive psychology, which describes the often unusually wide range of judgments between different experts, see Kahneman et al., 2021). Their fundamental work dealt with heuristics and cognitive biases of decision makers, of which the representativeness bias, the anchoring bias, and the availability bias (Tversky & Kahneman, 1973, 1974) are particularly well-known. A heuristic is defined as a fast way of processing information (also called mental shortcut) and problem-solving, which often leads to sub-optimal results (Myers, 2012; Gigerenzer, on the other hand, shows the useful side of heuristics in his research, see Gigerenzer et al., 2000; Gigerenzer & Gaissmaier, 2011).

- The representativeness bias means that individuals search for stereotypical patterns in facts or data, but at the same time neglect statistical basics (Tversky & Kahneman, 1974; Shiller, 1990). For example, managers overestimate the chances of success of merger transactions, even though most transactions fail with regard to shareholder value (see, e.g., Bradley et al., 1988; Agarwal et al., 1992; and the recent meta-study by Renneboog & Vansteenkiste, 2019).
- The anchoring bias states that individuals often base their estimates or forecasts on certain initial data (e.g. numbers that serve as an anchor). As a result, the adaptation to the anchor happens too slowly and leads to misjudgments (Kahneman, 2011). This can be relevant when making financial decisions, as individuals prove

in gambling shows that the betting decision depends heavily on the initial dollar values of a clue (Jetter & Walker, 2017).

- Finally, the availability bias confirms that information that can be easily accessed by the brain (here the so-called retrieval fluid in the brain plays an important role, see Schwarz et al., 1991) tends to be overrated. The clarity, conspicuousness, or drama of the respective information has a particular influence on the availability (Tversky & Kahneman, 1974). Thus, in a quick assessment of travel expenses, consumers tend to be influenced by the availability of daily or monthly payment plans, resulting in daily payments rated twice as high as a single payment each month (Riggs & Yudowitz, 2021).

The research on cognitive biases by Kahneman & Tversky has clarified that the widely accepted and normative rational choice theory is not absolutely correct due to systematic biases of individuals relative to rational predictions. Regardless of the preference of economics in general, and financial economics in particular, "Investors were normal before they were described as rational in the early 1960s, and they remain normal today" (Statman, 2005, p. 36). The axioms and the whole theory of rational choice in decision-making are based on a classical form (related to classical physics) of logic, which means an either-or logic (Wendt, 2015). Here, things are separated and have exactly defined properties in contrast to quantum physics. Quantum physics also has the chance to better explain anomalies in human behavior under uncertainty using quantum decision theory (the first thinker of quantum decision theory was Bohm, 1951; Aerts & Aerts, 1995 and Deutsch, 1999 followed later), which will be explained in more detail in the following chapter.

4 Quantum physics, social science, and decision-making

As already mentioned at the end of Chapter II, the terms social science, consciousness, and decision theory are to be reinterpreted below in the light of quantum physics. The first ideas for a so-called quantum social science (see for this term, Haven & Khrennikov, 2013) in form of quantum vitalism can be traced back to Bohr in the 1930s (Bohr, 1933). Bohr extended the principle of uncertainty into the biological area. This was the starting point for the new research field of quantum biology, which is now one of several lines of thought within the new research area of quantum social science (see Fig. 1). In some cases, however, these research fields are also mixed up and cannot be clearly separated (e.g. quantum mind and quantum consciousness). The overview in Fig. 1 and the following discussion thus addresses the first research question. For further analysis and to answer the second and third research questions, the focus of the following discussion is placed on quantum Darwinism (as part of quantum biology) and quantum decision theory (as part of quantum economics). The other two areas of Fig. 1 will not be addressed. In short it can be said that quantum mind and matter on the one hand focus the relationship between mind and body (also known as the mind-body problem, which is fundamental for social science, see e.g. Kriegel, 2004) and on the other hand addresses the revived topic of panpsychism (see basically, Whitehead, 1929; Dyson, 1979). Quantum consciousness and brain deals

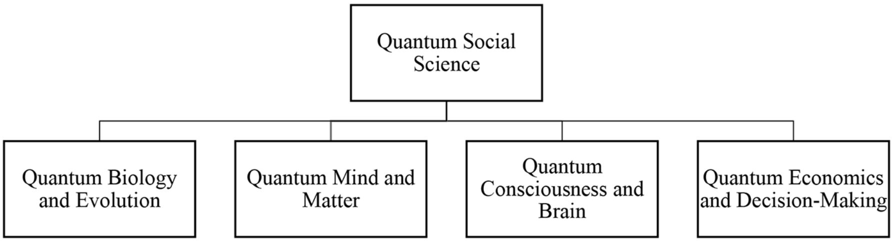

Fig. 1 Overview of research lines of quantum social science

with the quantum brain theory (see basically, Glymour et al., 2001; Igamberdiev, 2012), which hypothesizes that quantum processes at the elementary level are amplified and kept in superposition at the level of the organism, and then, through downward causation constrain what is going on deep within the brain (Gabora, 2002).

As already said, the beginnings of quantum biology thinking can be attributed to Bohr in the early 1930s, who saw a connection between quantum physics and life (science) insofar as quanta could affect living cells of an organism (Bohr, 1933). Equally relevant in terms of quantum biology is Schrödinger's classic "What is Life"? (Schrödinger, 1944). In this regard, Schrödinger put forward the thesis that life obeys new laws that have their roots in the more deeply ordered world of quantum physics. In recent years, technology has enabled research below the cellular level and shows that e.g. birds exploit non-local connections with the earth´s magnetic field for navigation or that plants use quantum effects in photosynthesis (see Josephson & Pallikari-Viras, 1991; Lloyd, 2011). The topic of quantum models of evolutionary processes is also closely connected to quantum biology (see e.g. McFadden, 2001; Gabora et al., 2013). McFadden applies quantum physics to DNA and claims that mutations driving evolution are not random.

Another approach in the context of quantum biology and the focus of the paper is quantum Darwinism according to Zureck (Zureck, 2003, 2009). Quantum Darwinism describes the transition of any conceivable quantum system with its huge potential for variations to the very limited set of classical states by means of a selective process similar to evolution theory. The quantum system in question reacts in a way that adapts to its environment, with the environment as a factor exerting selective pressure on the states (Zureck, 2009). Insofar as each quantum system consists of more or less redundant variations of the classical states that are selected out and represent this information, the environment is understood as a collection of observers who agree on a classical state with the quantum system observing backwards at the moment of decoherence (this state is preferred to all other variants, see Blume-Kohout & Zureck, 2006).

In contrast to the first three lines in Fig. 1 quantum economics (the term was already mentioned in 1979 by the economist Samuelson, see Samuelson, 1979) is a more mathematical tool at its core (see e.g. Schaden, 2010; Khrennikov, 2015; Orrell, 2020b) using quantum probabilities (this can be described as the next-simplest form of probability after the usual one, which allows for effects such as interference and entanglement). In this view quantum probability is a type of mathematics which can be applied to different areas as appropriate, without needing to provide a reductive explanation in terms of a link to subatomatic physics. The field of quantum finance (see e.g. Schaden, 2002; Baaquie, 2007, 2009; Orús et al., 2019; Lee, 2020; Orrell, 2016, 2018, 2020a; Arioli & Valente, 2021; Holtfort, 2022) as part of quantum economics is closely linked to the use of mathematics, quantum probabilities and principles of quantum physics (also called quantum-like). Schaden for example looks at interest rates and coupon bonds from the perspective of quantum mathematics (Schaden, 2010). On the other hand, Orell considers the quantum duality of money in the context of the uncertainty principle of Heisenberg (Orell, 2018). According to this, money is on the one hand a concrete concept of a number (e.g. an economic entity can assign a precise number to the bank note), on the other hand it is unclear whether this number also corresponds to the value (value is therefore a fuzzy concept). Baaquie uses quantum mathematics for modeling the theory of options by referring to quantum path integrals (Baaquie, 2007). Holtfort outlines a thought concept of a quantum capital market due to entanglement of investors, which could explain e.g. herd behavior and price bubbles (Holtfort, 2022). He views the individual investor as a quant at the micro level who behaves differently than she or he should at the macro level in form of market efficiency (for the concept of market efficiency see Fama, 1970). Thus, market anomalies (e.g. momentum effect or small firm effect) can also be explained which, similar to how quantum physics does not adhere to the laws of classical physics, cannot be reconciled with classical capital market theory (as elaborated by, e.g., Markowitz, 1952; Sharpe, 1964).

Another area of quantum economics, which is particularly relevant for the progress of the paper is quantum decision theory. Quantum decision theory can be of of immense importance for both social science and economics (e.g. in human behavior or related to the view on separation respectively entanglement of human beings/institutions, like legal or cultural norms – as elaborated by Douglass North, see, extensively, North, 1990; in brief also North, 1991). This is dealt with in great detail below, in terms of the topic of the paper, and above all focuses again on the connection to cognitive biases according to Kahneman & Tversky. Quantum decision theorists have stated that their quantum models can explain systematic anomalies in human behavior under uncertainty (see e.g. Busemeyer & Bruza, 2012; Pothos & Busemeyer, 2013). This is done through three lines of argumentation (see, in more general, Wendt, 2015), which are elaborated hereafter.

4.1 Order effects

Order effects mean that the order in which information is presented seems relevant for decision making (see for social science e.g. Hogarth & Einhorn, 1992; Moore, 2002 and similar for behavioral economics, called primacy, recency or a kind of anchor effect, see e.g. Tversky & Kahneman, 1974; Trotman & Wright, 2000; Kahneman, 2011; Arikan et al., 2019). This effect has a great impact regarding the differences between classical and quantum physics, as in the former interactions between objects and measurement devices are weak while in the latter they are strong (Atmanspacher & Römer, 2012). It, therefore, depends on whether the measurement process leads to changes in the system or not (changes can be identified yet by a new measurement).

Commutativity (no changes in the system; commutativity is a principle of mathematics) means in this context that the state of the world is being independent of the observer, or non-commutativity implies, accompanied by the breakdown of the subject-object distinction, that the observer is participating in the quantum system (Wendt, 2015). This is similar to the uncertainty principle of Heisenberg by measuring the momentum or location of a particle (see Chapter II).

4.2 Probability judgment

The significance of non-commutativity in human cognition can be explained psychologically by the assignment of probabilities to uncertain facts. The so-called conjunction fallacy is of relevance here (Tversky & Kahneman, 1974, 1983; their respective Linda experiment belongs to the field of representativeness bias, see Chapter III). Conjunction fallacy means that in considering the conjunction of two events, where one of which is a subset of the other, the probability of the less inclusive event cannot be greater than that of the more inclusive one. In the case of the Linda experiment, subjects rated (after receiving the information that Linda majored in philosophy, is intelligent and interested in issues such as discrimination and social justice) the probability that Linda is a bank teller and in the feminist movement higher than the probability that Linda is just a bank teller (see Kahneman, 2011). According to classical probability theory, the second statement must be of higher probability (a subset can never be mathematically more probable than a total set). An explanation of this cognitive bias can be enlightened by quantum decision theory, which uses quantum probabilities rather than classical (Franco, 2009; Yukalov & Sornette, 2009; Busemeyer et al., 2011). Thereby, the following is assumed: Considering a subject's beliefs and knowledge in an n-dimensional space (also called Hilbert space), each dimension in this space represents a combination of different concepts, events, and situations in social life (all of which are superposed as possibilities in the mind), there will be concepts or events that are inconsistent (i.e. cannot be experienced together) and are therefore in a dimension that is called incompatible (in quantum physics, the term incompatible, according to the uncertainty principle, refers to observables that cannot be measured simultaneously, such as momentum and location of particles). However, since we have already learned from quantum physics that the first measurement influences the outcome of the second, their joint probability cannot be determined (Busemeyer et al., 2011).

If we now look at the subjects of the Linda experiment, who were asked to decide which of the two descriptions of Linda is more likely to be true, we can state that answering the bank teller question is against the background of the predetermined information of Linda difficult, whereas the conjunctive question (Linda is both feminist and bank teller) represents incompatible dimensions of the space for the subjects (Busemeyer et al., 2011). Therefore, the questions must be considered one after the other, which causes the mind to project quantum physical first into the feminist sub-space, assessing the likelihood, then turn to the alternative bank teller subspace, which will include the judgment that Linda is a feminist. However, in this way, some of the predetermined information details will be eliminated by the mind, making it easier for the subject to think of Linda as a feminist bank teller than that she is a bank teller alone (Wendt, 2015). The quantum decision theory has yet another argument regarding the probability bias in the Linda experiment. The subject´s mind has to deal with incompatible states, which leads to interference in the quantum sense (Yukalov & Sornette, 2009; Haven & Khrennikov, 2013). This interference pattern "increases" the probability in contrast to classical probability theory (where the probability of the union of two possible facts can be smaller than each individual fact alone).

4.3 Preference reversals

Human beings can be irrational not only in judging probabilities but also in how they form preferences (Lichtenstein & Slovic, 1971; Grether & Plott, 1979; Kahneman & Tversky, 1984; Tversky et al., 1990; Slovic, 1995; Kahneman, 2011). In an experiment, subjects were asked to determine the amount of damage to be paid to victims of violent crime. The questionnaire involved the case of a man who lost the use of his right arm as a result of a gunshot wound while involved in a robbery at a neighborhood store (see Miller & McFarland, 1986; Kahneman, 2011). The subjects were then given the following information: There were two stores near the victim's home, with the man frequenting one more than the other. Now, the subjects were asked to consider either only one scenario (between-subject design) or two scenarios simultaneously (within-subject design), which are described as follows. First, the robbery happened at the store that the man frequented. Second, the man's regular store was closed for a funeral, so he shopped at the other store, where he was shot. According to classic decision theory, the amount of damage should be the same in both cases, since the permanent disability is the same and the location of the injury should not matter (Kahneman, 2011; such judgments often are affected by a cognitive bias and also the wide range of damage amounts that different insurance experts calculate based on the very same set of information, thus contradicting the assumption of rationality, see Kahneman et al., 2021).

However, the results of the experiment show that it makes a difference whether the subjects are shown both scenarios or just one. In the case of one scenario subjects demanded a higher amount of damage for scenario 2 than for scenario 1 (Miller & McFarland, 1986). If both scenarios were assessed at the same time (which is rather rare in real life), the amount is lower. The discrepancy between a separate and joint judgment causes preference reversal and leads to a violation of the transitivity of the rational choice theory. Quantum decision theory has an alternative framework for explaining preference reversal. The solution by several quantum decision theorists is found in type indeterminacy as a superposition (see above all Lambert-Mogiliansky et al., 2009; Lambert-Mogiliansky & Busemeyer, 2012 as well as Khrennikov, 2010; Khrennikova et al., 2014). That means, as long as a person´s state is in a quantum physical superposition of all the possible types (e.g. Rational man & Kahneman-Tversky man) relevant to the experimental situation of preference reversal, the question is, are these different types compatible, or not (see Wendt, 2015). If they are, then rational choice theory takes over and if they are not (similar to the momentum and location of a particle), types cannot have well-defined values at the same time (Lambert-Mogiliansky et al., 2009). The superposition state is not determined to a special type until the measurement (here the preference decision; thus a decision or choice is seen as something similar to the result of a quantum physical measurement, see Lambert-Mogiliansky et al., 2009) is done and therefore the wave function collapses to a special single type.

In summary, it can be said that the social and economic sciences, including cognitive knowledge, could be at the beginning of a revolutionary movement (especially in the explanation of anomalies in contrast to a classical view), similar to physics at the beginning of the 20th century with quantum physics. Against the background that quantum decision theorists have not yet ventured into an intensive theoretical exchange on a social and economic level (see for similar argumentation Wendt, 2006, 2015), but rather remain in the physical-scientific world, which is also reflected in the corresponding scientific publications, the arguments for a stronger penetration of economic literature, in particular, can be summarized as follows:

- Quantum decision theory is a kind of holistic approach including the whole brain, the emotions (with Kahneman-Tversky man behavior), and sub-conscious (see Yukalov & Sornette, 2009).
- Quantum decision theory calls into question the subject-object separation and therefore no well-ordered mind is given, which makes accurate predictions in uncertain environments (see Wendt, 2015).
- Quantum decision theory challenges the idea of rational utility maximization by the assumption of a superposition of the mind (see Lambert-Mogiliansky et al., 2009).

The previous examples of quantum decision theory (including the scientific discussion) have dealt mainly with two states (rational versus biased) in the superposition of the mind of the decision-maker. This perspective of the decision set in the superposition can be extended via the already mentioned concept of the Hilbert space (see Fig. 2). Accordingly, the decision-maker in the economic or social-scientific sense

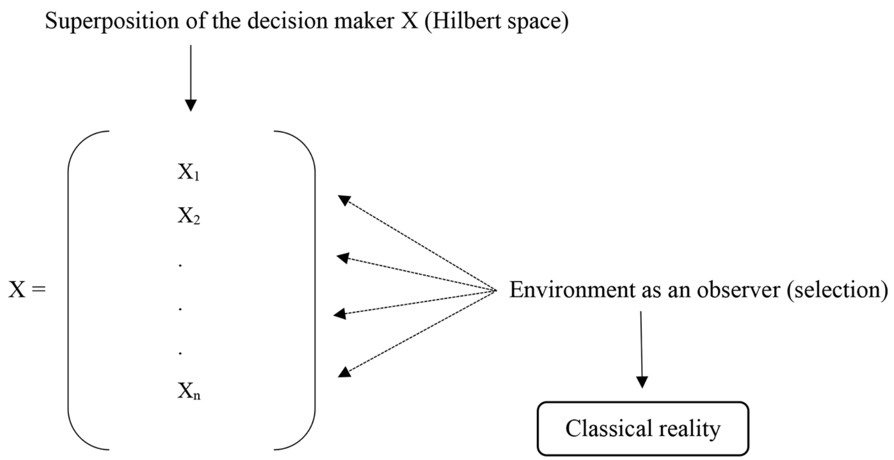

Fig. 2 Darwinian perspective of quantum decision theory

could, for example, also take the position of the bounded rational (for the concept of bounded rationality, see Simon, 1955, 1991), heuristically-intuitive (for the concept of frugal heuristics, see Gigerenzer, 2000, 2007) or biologically-adaptive (for the relevance of adaption in economics, see Lo, 2004, 2017) decision-maker.

On the other hand, the concept of quantum Darwinism has shown that the environment has an influence on the quantum system, which can thus also be transferred to the quantum decision system (see also Fig. 2). The selective pressure of the environment (which acts here as an observer or witness) leads to the fact that from a set of decision states (superposition) a certain new one, which can assert itself against the others, begins to be consolidated in classical reality (this is then called decoherence). In the sense of Darwin´s evolution theory, the successive interactions between these states and their environment then reveal that they are particularly stable towards it, and therefore more likely to survive and evolve than many other options of a quantum decision system.

A Darwinian perspective of quantum decision theory can thus better explain the transition from superposition to classical reality using a selective process of the environment. This concept with the environment as an observer might also explain why in particular situations it is better to decide in a certain way, while in other situations another type of decision is more advantageous.

5 Conclusion

Since the 1930s, we know that the experiments and interpretations of quantum physics have led to a new understanding of reality. Terms like wave-particle dualism, the collapse of the wave function, entanglement, uncertainty, superposition, and non-subject-object separation combined with consciousness have become fundamental. These concepts and perspectives could also have an enormous impact on decision theory in the social and economic scientific world, although not much of it has arrived yet (e.g. in economic journals). Nevertheless, the theoretical framework of quantum decision theory with the concept of superposition is already well-advanced and also scientifically justified. As Russell and Kant yet stated, classical physics describes matter only in terms of its properties and behavior but not in terms of what is "inside" (see Chalmers, 2010), which also applies to the social and economic sciences.

In connection with the quantum Darwinism approach borrowed from biology and evolution theory, quantum decision theory can also experience an improvement. This, above all, with regard to the concept of decoherence, i.e. the transition of the quantum (decision) system to classical reality by the selective pressure of the environment. These findings of quantum decision theory and quantum Darwinism can certainly be fruitful and invigorating in the future for social science, economics and decision-making. All in all, it can therefore be stated that human beings probably know little about the true nature of reality and the decisions associated with it. So perhaps we should be comfortable with the fact that human beings are entangled and a kind of walking wave functions (see Wendt, 2015) in a permanent state of superposition.

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Declarations

Conflict of Interest The authors declare that there is no conflict of interest.

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