DOI: 10.52950/ES.2024.13.2.008

NEUROECONOMICS - A REVIEW OF THE INFLUENCE OF NEUROTRANSMITTERS ON THE BEHAVIOUR AND DECISION-MAKING OF INDIVIDUALS IN ECONOMIC MATTERS

JIRI ROTSCHEDL, JAN NEUGEBAUER, MAREK VOKOUN, VLADIMÍR BARÁK

Abstract:

Neuroeconomics is a modern interdisciplinary approach that explores the interplay between economic theories and the biological and physiological processes that influence human decision-making. This article explores the differences between traditional economic concepts, such as the "homo economicus" model, and neuroeconomics approaches that emphasize the importance of biological mechanisms. A key part of the analysis is the study of the role of neurotransmitters such as dopamine, acetylcholine, noradrenaline, and serotonin and their influence on decision-making processes. Measurement and manipulation techniques are also considered to map these processes and provide new insights into the behavior of individuals in economic situations, particularly in the context of impulsivity and impatience. The behavioral dimension of neuroeconomic models is also discussed, linking biological and economic aspects of human behavior. In this context, the paper highlights the controversial nature of the general conclusions, especially given the multidimensionality of human heterogeneity and the limits of experimental research, often influenced by the unavailability of technical facilities. Attention is also paid to the ethical and practical challenges posed by neuroeconomics, including the potential negative consequences for health, decision-making, and manipulative practices. From an interdisciplinary perspective, the article explores the contributions of neuroeconomics to health economics and social policy. The authors conclude that this innovative approach contributes to a deeper understanding of human decision-making and confirms the importance of the complex interplay between biological, behavioral, and economic aspects of human existence. This work highlights that neuroeconomics has the potential to become a key tool for improving quality of life and enhancing scientific knowledge at the interface of different disciplines.

Keywords:

neuroeconomics, dopamine, serotonin, acetylcholine, oxytocin, noradrenaline, intertemporal decision making, risk perception, social preferences, neuroleadership, motivation, reward, trust

JEL Classification: D87, D81, D91

Authors:

JIRI ROTSCHEDL, Prague University of Economics and Business, Faculty of Economics, Department of Economics, Czech Republic, Email: jiri@rotschedl.com

JAN NEUGEBAUER, Jan Evangelista Purkyně University in Ústí nad Labem, Faculty of Social and Economic Studies, Czech Republic, Email: st102396@students.ujep.cz

MAREK VOKOUN, Jan Evangelista Purkyně University in Ústí nad Labem, Faculty of Social and

Economic Studies, Czech Republic, Email: marek.vokoun@ujep.cz
VLADIMÍR BARÁK, Prague University of Economics and Business, Faculty of Economics, Department of Economic and Social Policy, Czech Republic, Email: vladimir.barak@vse.cz

Citation:

JIRI ROTSCHEDL, JAN NEUGEBAUER, MAREK VOKOUN, VLADIMÍR BARÁK (2024). Neuroeconomics - a review of the influence of neurotransmitters on the behaviour and decision-making of individuals in economic matters. International Journal of Economic Sciences, Vol. XIII(2), pp. 129-149., 10.52950/ES.2024.13.2.008

Acknowledge:
The paper was prepared as part of a research project supported by the VŠE grant IG504024 (55/2024): The Impact of Long-Term Care Reform in the Czech Republic on Social and Health Services for the Elderly in 2024–2025.

1 From classical economics to neuroeconomics

The actions and decisions of individuals have been the subject of study for centuries. This issue has been dealt with by various scientific disciplines, including economics, psychology, sociology, neurobiology, and biology. Each discipline approaches the issue slightly differently, with different goals, assumptions, and approaches. If we look at the issue of individual behavior and decision-making from some perspective, we can see that the different disciplines (economics, psychology, biology, or neurobiology) are essentially layers of an onion.

The outer shell and the uppermost shell are observed and studied by classical economics, which idealizes man (the onion), and virtually models him into the already known "homo economicus", which is characterized by stable preferences, and axiomatically defined rationality. Classical economists are not interested in the reasons why an individual behaves and makes the decisions he does. It is irrelevant since the commonly known "homo sapiens" is not and cannot be equivalent to "homo economicus" which is like a "human model" by analogy to the "animal models" used in biology and medicine. However, just as animal models (most often rats) differ, albeit slightly, from the real human organism, so too does the human model (homo economicus) differ from the real human (homo sapiens).

Therefore, classical economists do not go into the depth of the onion at all and observe its decision-making and behavior as a model onion without emotions and without being influenced, for example, by the external environment. P. A. Samuelson supported this approach with his paper on revealed preferences (Samuelson, 1938, 1948) . The classical economist most often studies how an individual behaves outwardly and does not need to know the reasons why he behaves that way. Samuelson defined weak axioms of revealed preferences - WARP - in his paper, which were later extended by Houthakker to strong axioms of revealed preferences - SARP (Houthakker, 1950) . Samuelson and Houthakker's approach rested on the assumption that one can observe expressed preferences over the entire demand function of an individual. This approach would be extended in 1967 to be more consistent with reality, i.e., that observers can only see a finite set of an individual's choices (Afriat, 1967) . Afriat introduced "cyclical consistency" as a sufficient condition for utility consistency. Thus, eventually, Varian modified the name and introduced the notion of general axioms of revealed preference - GARP - instead of cyclical consistency (Varian, 1982) . Thanks to this theory, classical economists today can model utility functions for behavioral models based on revealed preferences using linear programming or other approaches (Demuynck & Hjertstrand, 2019) . However, this approach is still only an analysis of the resulting behavior and decision-making of individuals without knowing the motives that lead consumers to make such expressions.

In addition to manifested preferences, there is also the notion of rationality, which received an axiomatic definition on a mathematical basis in the mid-20th century.

The second layer of our onion is the layer of behavioral economists who are not satisfied with the approach described above. Theories that were developed without experimental validation and that were later challenged were refuted, especially by behavioral economists or psychologists. For example, P. Samuelson's theory of the exponential discounting function (Samuelson, 1937) was refuted by experiments that were more consistent with a hyperbolic discounting function. The reasons why Samuelson's exponential model did not match the real-life behavior of individuals in experiments lay in the assumptions that Samuelson defined. Individuals appeared to have a dynamic degree of time preference. Similarly, the expected utility theory (Bernoulli, 1738) failed to describe why we value small and large amounts of gains and losses differently, and why our preferences for expected utility are unstable over time.

Behavioural economics represents a minor stream of economic thinking that essentially follows the original approaches of the Austrian school of economics (the non-mathematizing branch), which strongly advocated methodological subjectivism (subjective preferences, subjective decision-making and action, etc.The distinction between the layer of the onion studied by classical economists and the layer that captivated behavioural economists in particular with their experiments can be seen in the contributions of R. Thaler, who came up with the notion of ECONS and HUMANS. Basically, these two terms describe the aforementioned Homo Economicus (ECONS) and Homo Sapiens (HUMANS), see (Thaler & Sunstein, 2008). The key role in this field is the prospect theory, for which the Nobel Prize was awarded to D. Khaneman. Observing the manifestations of choice has been shown to be insufficient, and behavioral economists have contributed to shifting the understanding of human behavior and decision making.

The third layer that lies beneath the aforementioned layers is the field of psychologists, who go even further than behavioral economists. Psychologists are interested in the deeper nature and cause of how people behave and make decisions. They work with certain mental models and programs. They can also go into the biological basis to some extent, but that is the domain of neuroscientists, psychiatrists or neurologists, and biologists play an important role after all. The decision-making and behaviour of individuals also has genetic and epigenetic origins.

In this paper, we will try to map economic behaviour and decision-making of individuals from the perspective of the last layer, i.e. from the perspective of neuroscience, and we will therefore delve into the perspective of neuroeconomics, which links economics with neurobiological essence.

2 Methodology of neuroeconomics

Research methodologies in the field of neuroeconomics are multidisciplinary and scientific studies in neuroeconomics, if they are to be based on neuroscience, psychology, and economics, require knowledge of economic models and econometrics, for which we subsequently verify causality through psychological or behavioral experiments and then build on them by examining their consistency and biological substrate through methods in neuroscience.

We consider neuroeconomics as a subfield of economics that does not come from comprehensive economic theories but focuses on the search for the nature of behavior and decision-making of individuals in different situations. It thus provides classical economists with feedback on the extent to which (at the biological level) economic phenomena arise and how the behavior of real individuals (Humans) is likely to differ from that of the model individuals (Econs) that economics makes extensive use of.

To study economic phenomena in terms of their physiological stimuli, we need to know the methods used by neuroscientists, be they neurologists, psychiatrists, neurobiologists, etc. It should be noted that the methods used in neuroscience are either exact or based on the observation of phenomena through imaging.

For the scientific investigation of economic decision-making, behavior, and actions of individuals on devices that are now available mainly for medical purposes and are in short supply, neuroeconomics will have to be satisfied with simple experiments that are therefore not only related to the brain but rather to other biological processes in the body. These include, for example, measuring hormone levels (in the laboratory or using rapid tests) while solving an experimental task. Such experiments are more cost-effective than, for example, functional MRI.

The methods used in neuroscience can measure signals between neurons directly or indirectly. However, the appropriate method for research varies depending on the functions to be investigated. The subject is a very challenging discipline that would take a publication in itself, rather than a brief insight into the subject.

The basic breakdown of methods in neuroscience is:

a) **Measurement techniques** - correlational (measures changes in the brain when an individual performs cognitive activities)
b) **Manipulation techniques** - causal (techniques examine how disruptions in brain processes affect the behaviour of individuals)

Measurement techniques are inherently correlational because it is not always certain that the representation of active brain regions during cognitive performance is definitely associated with the activity in question - it cannot be proven that the activity in the region under investigation is actually necessary for the function in question. In contrast, manipulation techniques are causally relevant to experiments because changes to the brain (manipulation of neurotransmitter levels, stimulation of brain regions) do indeed affect an individual's behavior.

2.1 Measuring techniques

Before we get into what methods belong in measurement techniques, we need to explain what "action potential" is. An action potential is a signal fired from a neuron along its axon towards the synapse and is manifested by a change in the tension of the axon membrane. The voltage across the membranes generates an electric field and an associated magnetic field, which can be measured by various instruments - directly or indirectly. The action potential triggers the release of neurotransmitters (dopamine, serotonin, etc.) into the synaptic cleft and these bind to receptors on the dendrites. Therefore, we speak of "axonal signalling" (sending a signal) and "dendritic integration" (receiving a neurotransmitter). These processes require large amounts of energy - glucose and oxygen. Both glucose and oxygen can be used in another method as markers to which the radioactive isotopes used in some methods bind.

The main measuring techniques are:

- **Singl-unit extracellular recording** (an invasive direct method aimed at measuring action potentials in single neurons; it is very rare and is mostly performed in individuals who have electrodes inserted into the brain for non-research reasons, e.g. for the treatment of epilepsy or other neurological diseases).
- **Electroencephalograph - EEG** (non-invasive method, focused on sensing electrical fields, the disadvantage is inaccurate spatial localization, the advantage is the lower cost of EEG than e.g. MEG or fMRI)
- **Magnetoencephalography - MEG** (a non-invasive method that focuses on sensing magnetic fields is basically similar to EEG but focuses on magnetic fields)
- **Positron emission tomography - PET** (non- invasive method, the individual is given an isotope, which binds to glucose as a carrier. The isotope then decays into radioactive positrons. PET then measures the gamma-ray signaling caused by the positron striking the

electrons, and at the point of higher glucose consumption (at the site of dendritic integration) the gamma rays imaged by the tomography are concentrated and therefore a map can be created showing the site of activity in the brain)

- **Functional magnetic resonance imaging - fMRI** (non-invasive method based on magnetic resonance imaging and the blood oxygenation-level-dependent effect, hereafter referred to as BOLD. Oxygen increases contrast and, as mentioned above, the need for not only glucose but also oxygen is increased during the transmission of signals between neurons. Oxygen therefore changes the contrast of the imaging site on MRI.

A detailed description of the methods used in neuroscience is provided, for example, by (Ruff & Huettel, 2014).

2.2 Handling techniques

As already mentioned, manipulation techniques can be used when we need to verify causality. The previous techniques are only focused on correlation, however, if a location in the brain with higher activity in the experiment is identified (e.g., making a choice), it does not mean that if we were able to exclude these locations, such a choice would be identical to the experiment.

Manipulation techniques stimulate the brain with controllable electrical currents in specified areas of the brain. The first scientific experiments with manipulation techniques on humans have produced the first mapping of sensory, motor cognitive and other functions of the human cerebral cortex.

If we have the ambition to test for a causal relationship in our research, two of the most common techniques are used to do so:

a) **Transcranial magnetic stimulation** (TMS)
b) **Transcranial direct current stimulation** (tDCS).

TMS stimulates neurons through electromagnetic induction. A small coil generates a magnetic field as the electric current passes through it. This magnetic perpendicular to the axis of the coil penetrates through the skin into the brain and due to the laws of physics, under certain circumstances (change of magnetic pulses) an electric current is generated in the brain. The coil applied to the skin at the point we want to test then stimulates the neurons at the site to be tested. The disadvantage of this technique is that it can stimulate parts of the brain close to the skin, as the magnetic field is weak in deeper parts of the brain and would reach through more layers of brain tissue.

The second method (tDCS), which is based on uniform current, is easy to perform and does not require laboratory equipment. Individuals are connected to the head anode and cathode, and a direct electric current is passed between them to stimulate neurons in the pathway between the two electrodes. The most effective expression is just below the electrodes, while an increase in neuronal activity will take place below the anode and a decrease in neuronal activity will take place below the cathode. Therefore, in studies, the anode is called the "active electrode" and the cathode is referred to as the "reference electrode".

This method exhibits inertia, which makes it possible to observe changes in the behaviour of individuals for several minutes after the stimulation itself. The advantages of this stimulation method include its cost. Since the actual course of the experiment does not need to be perceived by the individual, (double) blind studies can be performed using this method. In addition to the advantages, there are a number of disadvantages - it is less spatially resolved than TMS and this may affect the interpretation of the results. Another disadvantage is that the stimulation is not temporally defined (inertia).

It is therefore up to the researcher to choose which method to use to stimulate the neurons. If he or she needs to conduct the experiment in such a way that the subjects do not notice when the experiment is occurring or not occurring, then tDCS is the only free method. If one needs to stimulate a precise location in the research within a precise time frame, the TMS method is the appropriate choice.

In addition to these non-invasive methods, there are also invasive methods, which are mainly used in animal models. I will not assume that neuroeconomists have bred laboratory animal models for experiments of an invasive nature, so I will refer to other literature sources that deal with such methods (Ruff & Huettel, 2014). Of note are studies that are based on research on people with lesions in the brain. People who have been found to have lesions may have behavioural changes, and this has enabled neurologists and neurosurgeons in particular to uncover relationships between brain regions and behavioural manifestations in the past.

The text describing methods in neuroscience was drawn from the text (Ruff & Huettel, 2014). Therefore, for those interested in designing research studies in the neurosciences, I recommend this literature review to add additional insights beyond the scope of this book.

In addition to the above mentioned methods of brain research, we can direct neuroeconomics research to the mere increase or decrease of selected hormones in the blood. These methods are not demanding and require access to a laboratory to perform a laboratory test (unless strip tests sensitive to the substances being tested are available).

2.3 Central nervous system mediator system

In order to understand the behavior and actions of individuals, we need to know the basic mediator systems that actively participate in human behavior through the synthesis of key neurotransmitters. These include in particular: acetylcholine, dopamine, noradrenaline and serotonin. Of course, these are not all the neurotransmitters that neurons synthesize - I could mention histamine, glutamate, GABA and others.

In order for neuromodulators to be synthesized, neurons must have a supply of the chemicals from which they are synthesized. For example, tryptophan is necessary for the synthesis of serotonin. Some neuromodulators are synthesized and then stored in so-called synaptic vesicles. When a neuron needs to send a signal, it is released from the vesicle into the synaptic cleft (the space between the axon and the dendrite or other receiving tissue). The neuromodulator activates receptors on the target neuron (postsynaptic receptors), or reuptake of the neuromodulator back into the axon is also activated, where it is then recycled or otherwise used. Further, it may activate receptors on the axon (presynaptic receptors) or it is degraded by enzymes.

Given the thoroughly mapped possibilities of what can happen with neuromodulators, it is then easy to induce stimulation or attenuation of a given neuromodulator through pharmacological interventions in specific parts of the brain. This then allows the role of these substances on decision-making and behaviour to be experimentally verified. A number of experiments of this type are performed in animal models (most commonly laboratory mice or rats), as these are **invasive manipulation techniques**. Such experiments are also subject to strict ethical considerations and approval by the ethics committee of the research facility. It is essential to note that in addition to mice, rats and chimpanzees are used for the choice of animal models. These representatives of the animal kingdom are neurologically similar to the neurobiological systems of the human brain.

Experiments on humans are of a rather different nature. Studies often look at people who have lesions in certain parts of the brain that affect the production of neurotransmitters or even affect the function of those parts of the brain. It is then possible to compare individuals with and without lesions to see how they affect decision-making or other behaviours. (Crockett & Fehr, 2014).

Influencing neurotransmitter synthesis is done by agonists or antagonists that bind to receptors. However, it depends on whether these are receptors on the dendrite (i.e. postsynaptic receptors) or receptors on axons (i.e. presynaptic receptors). In general, the effects of agonists and antagonists in occupying pre- and post-synaptic receptors is presented in the following table.

Table 1 Effects of agonists and antagonists according to binding to receptor types

RECEPTOR	AGONIST	THE ANTAGONIST
POSTSYNAPTIC (ON THE DENDRITE)	**Increase in** neuromodulator function	**Decrease in** neuromodulator function
PRESYNAPTIC (ON THE AXON)	**Decrease in** neuromodulator function	**Increase in** neuromodulator function

Source: own processing dl (Crockett & Fehr, 2014)

3 Intertemporal decision making of individuals from a neuroscience perspective

The most common role of dopamine in economic issues is related to intertemporal decision-making. In fact, this area of inquiry is very common in individuals with certain psychological disorders, such as ADHD, or in particular, hyperactivity spectrum disorder, which is associated with impatience (Rotschedl, 2022). Economic tasks that focus on intertemporal decision making also affect the perception of risk or uncertainty. We consider the present as a certain phenomenon, while the future state is uncertain. There are risks that we will not live to see the future. In addition, there are other risks that determine the function of discounting future value.

There are a number of studies in animal models investigating D1 and D2 receptors in the context of delayed reward. A meta-analysis focusing on D1 and D2 receptor agonists and antagonists and their effects on discounted behaviour (Castrellon et al., 2021) showed inconsistent results. Thus, in animal models, it cannot be conclusively confirmed that it is possible to pharmacologically influence the intertemporal decision-making of individuals, especially those with hyperactive disorder and impulsive behaviour.

Based on some human studies, dopamine has been shown to play a significant role in delayed reward experiments (Pine et al., 2010). This study combined both pharmacological and imaging (fMRI) methods. Pharmacologically, three substances were administered:

- **Placebo**
- **Haloperidol** (D1 and D2 receptor antagonist, an older drug used to treat schizophrenia - an antipsychotic)

- **Levodopa**, or also L-DOPA (a precursor of dopamine, i.e. it is converted to dopamine, used in the treatment of Parkinson's disease, so-called antiparkinsonian).

Substance administration was supplemented by a functional MRI of the brain during the performance of choices between small-early and large-delayed rewards. The study was based on a hyperbolic form of the value discounting function (Mazur, 1987) . Amplification of dopamine activity in the brain increases impulsivity. It showed that future reward declined more rapidly, i.e., the decline in future value was significantly more pronounced than for placebo. The results of the imaging technique used in the task allowed the identification of the site of higher activity - the *striatum*. As the delay of future rewards increased, the activity of different parts of the brain involved in intertemporal choices decreased (*Striatum*, *Insula*, *Subgenual cingulate,* and lateral and *Orbitofrontal cortex*). The result did not differ between placebo and Haloperidol administration, however, the dopamine precursor Levodopa led to even higher activity in the mentioned areas. Conclusion: Improving dopamine function with Levodopa increased discounting rates, leading to a reduction in the subjective value of delayed rewards (Pine et al., 2010) .

Thus, it appears that acting on D1 and D2 receptors through Haloperidol did not affect discounting in the mentioned study, whereas the dopamine precursor does affect discounting. The study confirms previous conflicting research on the effects of D1 and D2 receptors on discounting conducted in animal models, see meta-analysis (Castrellon et al., 2021) . Recent studies in humans show that when D2 receptors are blocked, discounting is reduced (Soutschek & Tobler, 2023; Wagner et al., 2020) .

Economic decision-making is not just about what future reward I will get but rests on balancing that reward with the costs we have to incur. From a psychological point of view (as long as it is not a monetary cost) we can talk about effort. The balancing between benefit and cost is a fundamental economic question and the resulting difference between future reward and effort can be represented by a profit function, which should be a decreasing hyperbolic function that goes negative at one point. This is the point at which the individual chooses immediate value rather than waiting for the future.

To illustrate, we can give an example. Which option would you choose? Would you order a pizza with delivery, which will be more expensive (by shipping), plus you have to wait for it, or would you go to a nearby pizzeria to get the pizza yourself, you will get it faster, but you have to make an effort for this option. How will such a decision differ when you are in a hurry when it is raining or other factors? A number of aspects will influence our preferences.

Second example: what restaurant would you choose? Do you have a choice of an average restaurant around the corner from where you live or do you choose a very well-rated restaurant but you have to walk 2 km to get there? How would your decision change if you had/did not have a car? How would your decision change if the weather is bad?

Walking a long distance in bad weather requires a lot of effort and it is a question of how this effort is perceived from the perspective of each individual. Some people will seek out the outdoors and will place a very low value on the effort, while others may place a high value on the effort. The two hypothetical individuals are likely to make different choices.

Effort will therefore play a significant role, and studies are emerging that have addressed these issues. It can even be said that in recent years, specific models have been used to show why earlier studies of the role of D1 and D2 receptors in human or animal models have proved contradictory.

Thus, dopamine plays an important role in intertemporal decision making based on cost-benefit comparisons, where cost is mainly the effort to achieve a particular benefit. In cost-benefit decisions, dopamine may play a dual role (Soutschek et al., 2023):

- promoting psychologically proximate options (e.g. earlier and safer rewards),
- calculating which costs are still acceptable for a given reward and which are not.

Authors of the study (Soutschek et al., 2023) conclude that reduced D2 stimulation tends to increase willingness to bear **the costs of delay** and **risk**, i.e., waiting for later rewards, taking riskier options, whereas increased D1 and D2 receptor stimulation increases willingness to bear the costs of effort. The authors were able to use a novel approach to confirm the role of dopamine and D1 and D2 receptors on conflicting decision making using a process **model of drift diffusion** **[1]**(Soutschek & Tobler, 2023).

Acetylcholine, which binds to M1 receptors, appears to play a role in discounting. D2 receptor activity plays a role particularly in both **delay** and **effort cost**. Acetylcholine, which is bound by M1 receptors, may have a more specific role particularly in effort processing (Erfanian Abdoust et al., 2024).

Acetylcholine is therefore a very important neurotransmitter, and by influencing it we can improve the ability to learn and concentrate, but also motivate you to be active. However, we need to beware of disruptions in the balance between cholinergic and dopaminergic signalling, which can lead to pathological reward-seeking, where an individual exhibits excessive and uncontrollable reward-seeking behaviour, such as substance abuse. Acetylcholine plays a role in modulating how the brain interprets and responds to rewarding stimuli. This modulation is key to the brain's ability to discriminate between different stimuli and focus on those that are **of greatest value**, an essential mechanism for effective decision-making and adaptive behaviour (Grossberg et al., 2016; Ruan et al., 2022).

Thus, it appears that the domaniergic and cholinergic pathways will play an important role in neuroeconomics. The manifestation of our decision-making in economic tasks originates in these neurotransmitters. By being involved in the **differentiation of stimuli with different values**, they will be behind, for example, the economic theory of indifference curves and may contribute to explaining on what basis individuals make individual evaluations of different options, i.e., also why each individual has different preferences. Preferences are a manifestation of what an individual gives more or less weight or value to.

The key neurotransmitters include noradrenaline (norepinephrine). Noradrenaline is formed from dopamine by dopamine-beta-oxidase and adrenaline is then formed from noradrenaline (L. Hess & Sliva, 2021). Noradrenaline together with dopamine influence our alertness. If these hormones are deficient, we feel boredom and are not sufficiently aroused. The relevance of noradrenaline in the context of individuals' intertemporal choice or risky behavior is very rare. However, it appears that there may be a link. However, this area is insufficiently researched to draw reliable conclusions.

[1] The Drift Diffusion Model (DDM) simulates how individuals gradually gather information when deciding between two options, and how this information leads to the final decision. Drift represents the shifting of our decision, while diffusion represents the fluctuation of information and the mind's hesitation about the choice. We can think of DDM, for example, in choosing a meal at a restaurant, where we might consider: unhealthy but tasty food or healthy and less tasty food.

"...*Norepinephrine-elevating drugs, such as the norepinephrine reuptake inhibitor atomoxetine, may be an effective treatment for ADHD, suggesting a possible role for norepinephrine in regulating impatient decisions."* (Crockett & Fehr, 2014).

The economic question of postponing or not postponing consumption is related to impatience, which we also mentioned with dopamine. However, it turns out that impulsive behaviour is also fundamentally influenced by serotonin. Experiments on impatience, or impulsivity, have been conducted on humans by reducing dietary tryptophan intake; this form of dieting (acute depletion[1] of tryptophan) is thought to lead to a decrease in serotonin in the individual's body. Subsequent experiments among individuals on the diet have not always been conclusive. Some studies have shown no significant difference in impulsivity between individuals on and off the diet (Dougherty et al., 2015). However, studies in animal models (which can be more invasive and thus often more accurate) and other studies in humans have instead reached these conclusions, see (Schweighofer et al., 2008). The authors of this study state, "*The combined results of our previous and current studies suggest that serotonin may modify the rate of delayed reward discounting through modulation of specific loops in parallel circuits of the corticobasal ganglia*."

Study (Schweighofer et al., 2008) concluded that:

- **low serotonin levels** lead to increased selection for small rewards, i.e. steep discounting
- **high serotonin levels** lead to increased selection for large delayed rewards, i.e. shallow discounting

4 Decision making under uncertainty and risk from a neuroscience perspective

It appears that people with Parkinson's disease who are taking drugs that promote dopamine production, especially D2 receptor agonists or Levodopa or dopamine supplementation alone, develop gambling during treatment and stop after discontinuation (Grall-Bronnec et al., 2016; Imamura et al., 2006). These studies, although not involving large numbers of individuals suggest that dopamine will play a role in risk perception. Untreated patients with Parkinson's disease have marked risk aversion (Cherkasova et al., 2019).

The greater propensity for risk in the case of dopamine has a genetic basis in the case of the dopamine D4 receptor (see text at the beginning of this chapter). The longer DRD4 gene is associated with, for example, adrenaline-seeking sports. Another study suggests that in addition to the D4 receptor, the remaining D1, D2 receptors are involved in risk perception. (Gabriel et al., 2021) and D3:

- D1 and D2 receptor antagonists = reduces risk choice.
- D1 and D2 receptor agonists = increases risk choice.
- D3 receptor agonists = reduce risky choices.
- D3 receptor antagonists = increase risk choice.

However, in the medial prefrontal cortex, the receptors have different effects:

- D1 receptor antagonists = reduce risky choices.

[1] Depletion = reduction

- D2 receptor antagonists = increases risk choice.

Research in animal models (rats), humans and monkeys shows that after a reduction in tryptophan intake, behaviour changes to more risk-taking. In classic loss aversion tasks (small certain reward or large but uncertain reward), large uncertain reward dominated over small but certain reward when serotonin was reduced (R. D. Rogers, 2011).

However, I know from the prospect theory of D. Kahneman and A. Tversky that individuals discount differently not only small and large amounts, but especially that they value losses and gains differently. "Loss aversion" is responsible for this. **Serotonin contributes to loss aversion**, and if an individual with elevated serotonin is exposed to a game in which he can either sacrifice a small amount or play a game of not having to pay anything or having to pay more, then he chooses to gamble. He is therefore loss averse, see (Campbell-Meiklejohn et al., 2011; Crockett et al., 2012).

Another study also brought into play the influence of an individual's surroundings. (Bellucci et al., 2022) found that individuals exposed to social uncertainty were more likely to take risks, both in low-gain gambles and high-loss gambles. In the second part of the study, individuals (the experimental group) were given the drug citalopram[1] and were found to be more likely to choose risky gambling with low gains and high losses, however, in both the group exposed to social uncertainty and the group exposed to non-social uncertainty.

However, research on risk behaviour still needs to continue. For the detailed knowledge of how both serotonin and dopamine act (in interaction) has not yet been fully explored.

5 Leadership and social preferences from a neuroscience perspective

However, the more important role of dopamine is in the area of management, or leading people and motivating them. More dopamine is released when we get an unexpected reward than when we expect a reward. (Mirenowicz & Schultz, 1994).

Higher dopamine levels according to studies (Crockett et al., 2015; Pedroni et al., 2014; Sáez et al., 2015) show that people:

- have a greater aversion to differences between their own and others' rewards,
- have less resistance to inflicting pain for pay
- have more selfish behaviour (if it cannot be punished)

Adam Smith built, in simplified terms, his classical economic theory on the invisible hand of the market, which is represented, for example, by **selfish action**, virtually maximizing utility or profit for each subject participating in the exchange. When two entities, buyers and sellers, face each other, the selfish actions of both parties lead to a market efficient outcome, i.e. goods are bought and sold at prices and quantities in the best combination for each party. The seller achieves the maximum possible price, the buyer achieves the lowest possible price. Of course, this principle will work provided that both parties have perfect information, e.g. about the quality of the goods. Thus, if all

[1] Citalopram is a medication for depression that works by blocking serotonin reuptake (the principle of serotonin reuptake is described in the introduction). By blocking reuptake, there is a higher transmission of serotonin between the axon and the dendrite at the synapse, and serotonin then acts more intensely. There are a total of two ways to conduct these experiments on the effects of serotonin on behavior in humans. Either the serotonin precursor is inhibited or enhanced (tryptophan doses are decreased/increased) or we can give the test subjects any reuptake blocker that will increase transmission at the synapses. In this second option of increasing the intensity of serotonin action, it is necessary that the test subjects do not have a long-term dietary tryptophan deficiency.

actors maximize their own benefits and behave selfishly, the whole market can be expected to achieve efficient outcomes and maximize the satisfaction of the needs of the counterparties.

However, individuals are not just selfish. It turns out that they have a social dimension to their thinking, so in economic parlance we could say that they have **social preferences**. Social preferences can be positive (to benefit someone else at one's own expense - altruists) or negative (to harm someone else).

Social studies suggest that dopamine is involved in social interactions. Often this area is explored through a game of take it or leave it. (Crockett et al., 2013; Sanfey et al., 2003; Swiderska et al., 2023; van 't Wout et al., 2006). The findings are consistent - people are more likely to reject offers from other people than from a computer. It turns out that dopamine (instead of serotonin, which is more closely related to social behaviour) may be responsible for this behaviour. Cooperation with a computer or with a human suggests that social behavior (in the case of cooperation with a human) is different. The game is primarily about accepting an offer that we consider fair. Research suggests that our sense of fairness is in fact self-oriented: We perceive unfair offers as displays of dominance and reject them to avoid imposing a subordinate position (Yamagishi et al., 2012).

Findings about dopamine have overlap with leadership, particularly in terms of motivation, reward and the higher incidence of selfish behaviour in teams for some individuals. Selfishness as determined by dopamine may have its origins in innate predispositions.

Managing teams and people is very often focused on creating a state of flow (Rock, 2010). To create flow we will also need another hormone which is noradrenaline. *Noradrenaline is formed from dopamine by dopamine beta-oxidase and then* adrenaline *is formed from noradrenaline* (Hess & Sliva, 2021). Noradrenaline together with dopamine affects our **alertness**. If these hormones **are deficient, we feel boredom and are not sufficiently aroused**.

The combination of the right levels of dopamine and norepinephrine is essential for maintaining **attention**, and some authors believe that the right combination is behind the ***flow*** state. If norepinephrine levels are too high, a stress response occurs. Higher concentrations of noradrenaline in the central nervous system are encountered in people who are shy and have a fast metabolism (Hess & Sliva, 2021).

Another neurotransmitter that is involved in social preferences and is therefore important for guiding people is serotonin. Research on serotonin shows that it is involved in social behavior in both animals and humans. Desert saranchata, which have two phases - a **solitary phase** (avoiding each other) and a **migratory phase** (congregating in numerous flocks). On a neurobiological level, serotonin is responsible for the change. Higher levels of it led to a shift from "hating each other" to "cooperating in a flock" (Anstey et al., 2009; S. M. Rogers & Ott, 2015; Tanaka & Nishide, 2013). For example, migratory saranchids are similarly affected.

The effects of serotonin are also observed in other animals (fish, birds and mammals). Based on research in both animals and humans, it appears that serotonin is a neurotransmitter that is significantly involved in social preferences. On the one hand (when serotonin function is elevated), both humans and animals behave prosocially, are more cooperative, or have a heightened sense of group membership. On the other hand (when serotonin function is reduced), people behave aggressively and antisocially.

The relationship between serotonin and social preferences can be tested in cooperative games. For example, in a prisoner's dilemma in which an individual decides whether or not to cooperate, we can influence test subjects with tryptophan or other methods and evaluate whether or not the willingness to cooperate increases. We can also extend the experiments to fMRI or even invasive methods, which in these cases tend to be applied to animal models.

Research on fMRI during a take-it-or-leave-it task (the ultimate task) showed that unfair offers elicited activity in brain regions related to emotion (anterior insula) and cognitive function (dorsolateral prefrontal cortex). Once an individual in the experiment decided not to accept an unfair offer, activity in the anterior insula increased significantly, suggesting that emotions in particular play a significant role in this type of decision-making.

Social interaction is also influenced by another key neurotransmitter - oxytocin. Oxytocin overlaps into the area of leading people, working with people in a team, and therefore more for the area of management and leadership. Research suggests that nasal administration of oxytocin significantly increased positive communication behaviors in the event of a couples conflict discussion and subsequently reduced cortisol levels (compared to a control group) (Ditzen et al., 2009). Thus, it appears that, in addition to the effects of oxytocin on sexual behavior, it plays an important role in social interactions between people and, ultimately, e.g. between pets (Johnson et al., 2021; Marshall-Pescini et al., 2019). Oxytocin is also important in group-related behaviors, in the **choice of an attitude towards a stranger** or a group member. Exogenous administration of oxytocin enhances prosocial behavior and increases it (Florea et al., 2022).

For the everyday life of economists and managers, it is therefore of great benefit, especially in behavior that will promote cooperation. Social contact - e.g. **shaking** hands with strangers - is an important moment for joint negotiations and contracting.

6 Discussion

This interdisciplinary field, which explores the brain's approach to influencing economic decision-making, is closely related to other branches of economics, such as Health Economics. The intersection of these two fields offers interesting considerations of biological equipment in the context of formulating our health decisions and influencing overall economic systems themselves.

Within the Health Economics perspective, we can focus on the context of health decision making. Neuroeconomic studies point to the influence of emotions, so current state of mind is directly dependent on impulsivity and social norms more than rational considerations over costs and benefits. Thus, we can observe economic values and scarcity theories here as well. Especially if people are more burdened by morbidity and thus encounter health facilities many times more often (DeStasio et al., 2019; Pearson et al., 2018; Runge et al., 2024). This also involves a psychological process cultivated by personality development and socialization under the influence of education. It involves thinking about risk and reward. Studies agree on the brain settings and expectations that are shaped over developmental time. Neuroeconomics then theorizes from the above findings that the brain is set up to receive mainly immediate rewards. It is for these reasons that unhealthy habits such as smoking, drinking alcohol, taking narcotics or simply eating unhealthy food are on the rise (Camerer & Li, 2021; Kalechstein, 2009; Rangel et al., 2008). It also offers considerations of social comparison as each person compares their current health to others, which may influence their satisfaction and willingness to invest in health. Similarly, neuroeconomic insights may lead to explanations for why people reject costly treatments when they could paradoxically improve their health (Runge et al., 2024).

This leads to critical views of the whole concept, as individual breakdowns lead to reductionism. In this context, this is meant to be a breakdown of human behavior into neurobiological processes, thus getting to the biological roots of behavior itself, although it is still important to remember that this is a multifactorial and multidisciplinary process (Jiang & Sisk, 2019; Neugebauer, 2023) . This also entails a reflection on ethics, for if we know this level, will individuals still have the freedom to choose their thinking, or will it be a synergistic anchoring in a manipulative process to achieve a health goal? Similarly, the neuroeconomic experimental part is very limited, as discussed in the text above. Although some of these critical perspectives seem to be weakly supported, we are getting at the heterogeneity of the overall population, thus the need to appeal to the differences and information processing of each individual. We do not mean this only in the context of health, but more generally towards health, social, and neuroeconomics. It is this multidimensional approach and the heterogeneity of the population that makes it very difficult to create universal models of behavior on which science can build (Camerer & Li, 2021) .

Ultimately, the combination of health economics and neuroeconomics is a great driver and proof of personalized and patient-centered medicine. The foundations of neuroeconomics thus give rise to individual interventions that better match the preferences and biological characteristics of patients. However, it also influences health policies that take into account economic and psychological factors and regulates health communication, which leads to an understanding of health information processing and thus improves its level between health professionals and patients.

The overlap with social care also deserves its examination. Developed countries are facing the phenomena of low birth rates, aging populations, worsening demographic forecasts, and increasing pressure on social and health systems, which are supposed to guarantee adequate health and social care for citizens.

For example, in the care of the elderly or disabled, neuroeconomics can contribute to understanding how families make choices between home care and professional services. These decisions are often influenced not only by economic factors but also by emotional attachments, feelings of responsibility, or social pressure. Clients and their relatives consider the use of services not only based on price but also on the basis of quality. In doing so, the quality and depth of the relationship with the person in need of care are often also taken into account.

We can also note the commercialization of social services even in those countries where social policy remains largely at the will of the government and social services are not fully governed by market mechanisms due to regulation. The private sector offering social services uses elements such as marketing and promotion. In doing so, they quite naturally also make use of a lot of neuroeconomic knowledge.

The overlap of neuroscience into disciplines such as social work and social policy is and will be considerable. For example, neuroeconomic studies show that altruistic behavior, i.e. the willingness to help others, can be conditioned by the activation of specific brain centers associated with reward (Harbaugh et al., 2007) . This explains why people sometimes act altruistically when, from a purely economic point of view, they should prefer their own benefit. This behavior then has overlaps in other areas relevant to the discipline of social work: in the functioning of communities, community centers, voluntary associations, and non-profit organizations and in those activities where issues of social responsibility come to the fore. Note that the experience of many charities in public fundraising confirms that people often prefer to support concrete stories (e.g. sick children or victims of natural disasters) rather than abstract forms of aid such as general contributions to health systems or anonymous individuals. This can be explained, among other things, by the specific decision-making process for endowment activities and voluntary contributions to community projects, health facilities, or charitable activities. For example, individuals may be motivated to support social care on the basis of empathy, which activates areas of the brain associated with the processing of emotions. A number of studies have been carried out and are underway in this area, which could help social care actors to better design services and take them into account in their communication with clients and loved ones.

7 Summary and conclusion

Some studies suggest that, for example, oxytocin could be a substance involved in the formation of trust (Baumgartner et al., 2008; Kosfeld et al., 2005; Mikolajczak et al., 2010). Study (Kosfeld et al., 2005) examines the relationship in the investor game[1] and conversely the study (Mikolajczak et al., 2010) examines the issue using non-financial examples of trust. Both studies have been widely cited however some later meta-analyses or studies point out that studies examining the relationship between oxytocin and trust are not entirely consistent[2] , and therefore their relationship has not yet been established with certainty (Declerck et al., 2020; Nave et al., 2015). The authors of the study (Kosfeld et al., 2005) reported that oxytocin reduces fear of betrayal in social interactions. Is "trust" the same as "fear of betrayal"?

The issue of the influence of neurotransmitters on behaviour and decision-making in individuals is very interesting, but it appears that the current scientific knowledge is far from complete. There are a growing number of studies that confirm some findings and refute others. Therefore, we approach the review we provide here with some caution. Likewise, we also present critical views that consider neuroeconomics as a potential threat in terms of manipulative techniques and minimizing people's own decision-making in the health and social sphere. With this issue comes the Health Economics perspective, which also puts human heterogeneity at the forefront as one of the main factors why we should rather avoid broad conclusions and generalizations to the general population.

Although we present many debatable opinions, both positive and negative, this scientific direction certainly has its place. The whole issue can also be usefully applied, for example, to support communication in health care, social services, leadership support, mentoring, coaching, or the development of empathy across global trends, thus creating a clear boundary between mechanical and human approaches in interpersonal relationships.

References

Afriat, S. N. (1967). The Construction of Utility Functions from Expenditure Data. *International Economic Review*, *8*(1), 67. https://doi.org/10.2307/2525382

[1] In this game, one of the players (the investor) has the opportunity to choose an expensive but credible action by giving money to the other player (the manager). If he chooses to send the money, the experimenter triples this amount. The manager is then informed of the transfer and has a choice – he can either keep the full amount or return part of the money back to the investor. If the investor expresses trust and the manager decides to split the winnings, both players get more than if the investor had not expressed trust. However, trust is a risk for the investor because the trustee can abuse his trust and make his position worse than if he had not trusted.)

[2] In experiments, oxytocin is administered through the mucous membrane in the nose, i.e. by nasal spray. However, nasal administration may not be the most reliable method of administration. The accurate and therefore more reliable dosage of this substance is intravenous. However, this form is not usually favoured by the authors of the studies. This may be one of the reasons why the results of studies are inconsistent.

Anstey, M. L., Rogers, S. M., Ott, S. R., Burrows, M., & Simpson, S. J. (2009). Serotonin Mediates Behavioral Gregarization Underlying Swarm Formation in Desert Locusts. *Science*, *323*(5914), 627-630. https://doi.org/10.1126/science.1165939

Baumgartner, T., Heinrichs, M., Vonlanthen, A., Fischbacher, U., & Fehr, E. (2008). Oxytocin Shapes the Neural Circuitry of Trust and Trust Adaptation in Humans. *Neuron*, *58*(4), 639-650. https://doi.org/10.1016/j.neuron.2008.04.009

Bellucci, G., Münte, T. F., & Park, S. Q. (2022). Influences of social uncertainty and serotonin on gambling decisions. *Scientific Reports*, *12*(1), 10220. https://doi.org/10.1038/s41598-022-13778-x

Bernoulli, D. (1738). Specimen theoriae novae de mensura sortis. *Commentarii Academiae Scientiarum Imperialis Petropolitanae, Tomus V, (In Classe Mathematica)*, 175-192. https://archive.org/details/SpecimenTheoriaeNovaeDeMensuraSortis/page/n17/mode/2up

Camerer, C. F., & Li, X. (2021). Neural autopilot and context-sensitivity of habits. *Current Opinion in Behavioral Sciences*, *41*, 185-190. https://doi.org/10.1016/j.cobeha.2021.07.002

Campbell-Meiklejohn, D., Wakeley, J., Herbert, V., Cook, J., Scollo, P., Ray, M. K., Selvaraj, S., Passingham, R. E., Cowen, P., & Rogers, R. D. (2011). Serotonin and Dopamine Play Complementary Roles in Gambling to Recover Losses. *Neuropsychopharmacology*, *36*(2), 402-410. https://doi.org/10.1038/npp.2010.170

Castrellon, J. J., Meade, J., Greenwald, L., Hurst, K., & Samanez-Larkin, G. R. (2021). Dopaminergic modulation of reward discounting in healthy rats: a systematic review and meta-analysis. *Psychopharmacology*, *238*(3), 711-723. https://doi.org/10.1007/s00213-020-05723-5

Cherkasova, M. V., Corrow, J. C., Taylor, A., Yeung, S. C., Stubbs, J. L., McKeown, M. J., Appel-Cresswell, S., Stoessl, A. J., & Barton, J. J. S. (2019). Dopamine replacement remediates risk aversion in Parkinson's disease in a value-independent manner. *Parkinsonism & Related Disorders*, *66*, 189-194. https://doi.org/10.1016/j.parkreldis.2019.08.014

Crockett, M. J., Apergis-Schoute, A., Herrmann, B., Lieberman, M. D., Müller, U., Robbins, T. W., & Clark, L. (2013). Serotonin Modulates Striatal Responses to Fairness and Retaliation in Humans. *The Journal of Neuroscience*, *33*(8), 3505-3513. https://doi.org/10.1523/JNEUROSCI.2761-12.2013

Crockett, M. J., Clark, L., Smillie, L. D., & Robbins, T. W. (2012). The effects of acute tryptophan depletion on costly information sampling: impulsivity or aversive processing? *Psychopharmacology*, *219*(2), 587-597. https://doi.org/10.1007/s00213-011-2577-9

Crockett, M. J., & Fehr, E. (2014). Chapter 14 - Pharmacology of Economic and Social Decision Making. In P. W. Glimcher & E. Fehr (Eds.), *Neuroeconomics (Second Edition)* (pp. 259-279). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-416008-8.00014-0

Crockett, M. J., Siegel, J. Z., Kurth-Nelson, Z., Ousdal, O. T., Story, G., Frieband, C., Grosse-Rueskamp, J. M., Dayan, P., & Dolan, R. J. (2015). Dissociable Effects of Serotonin and Dopamine on the Valuation of Harm in Moral Decision Making. *Current Biology*, *25*(14), 1852-1859. https://doi.org/10.1016/j.cub.2015.05.021

Declerck, C. H., Boone, C., Pauwels, L., Vogt, B., & Fehr, E. (2020). A registered replication study on oxytocin and trust. *Nature Human Behaviour*, *4*(6), 646-655. https://doi.org/10.1038/s41562-020-0878-x

Demuynck, T., & Hjertstrand, P. (2019). *Samuelson's Approach to Revealed Preference Theory: Some Recent Advances* (IFN Working Paper No. 1274). https://www.ifn.se/wfiles/wp/wp1274.pdf.

DeStasio, K. L., Clithero, J. A., & Berkman, E. T. (2019). Neuroeconomics, health psychology, and the interdisciplinary study of preventive health behavior. *Social and Personality Psychology Compass*, *13*(10). https://doi.org/10.1111/spc3.12500

Ditzen, B., Schaer, M., Gabriel, B., Bodenmann, G., Ehlert, U., & Heinrichs, M. (2009). Intranasal Oxytocin Increases Positive Communication and Reduces Cortisol Levels During Couple Conflict. *Biological Psychiatry*, *65*(9), 728-731. https://doi.org/10.1016/j.biopsych.2008.10.011

Dougherty, D. M., Mullen, J., Hill-Kapturczak, N., Liang, Y., Karns, T. E., Lake, S. L., Mathias, C. W., & Roache, J. D. (2015). Effects of tryptophan depletion and a simulated alcohol binge on impulsivity. *Experimental and Clinical Psychopharmacology*, *23*(2), 109-121. https://doi.org/10.1037/a0038943

Erfanian Abdoust, M., Froböse, M. I., Schnitzler, A., Schreivogel, E., & Jocham, G. (2024). Dopamine and acetylcholine have distinct roles in delay- and effort-based decision-making in humans. *PLOS Biology*, *22*(7), e3002714. https://doi.org/10.1371/journal.pbio.3002714

Florea, T., Palimariciuc, M., Cristofor, A. C., Dobrin, I., Chiriță, R., Bîrsan, M., Dobrin, R. P., & Pădurariu, M. (2022). Oxytocin: Narrative Expert Review of Current Perspectives on the Relationship with Other Neurotransmitters and the Impact on the Main Psychiatric Disorders. *Medicine*, *58*(7), 923. https://doi.org/10.3390/medicina58070923

Gabriel, D. B. K., Liley, A. E., Freels, T. G., & Simon, N. W. (2021). Dopamine receptors regulate preference between high-effort and high-risk rewards. *Psychopharmacology*, *238*(4), 991-1004. https://doi.org/10.1007/s00213-020-05745-z

Grall-Bronnec, M., Sauvaget, A., Perrouin, F., Leboucher, J., Etcheverrigaray, F., Challet-Bouju, G., Gaboriau, L., Derkinderen, P., Jolliet, P., & Victorri-Vigneau, C. (2016). Pathological Gambling Associated With Aripiprazole or Dopamine Replacement Therapy. *Journal of Clinical Psychopharmacology*, *36*(1), 63-70. https://doi.org/10.1097/JCP.0000000000000444

Grossberg, S., Palma, J., & Versace, M. (2016). Resonant Cholinergic Dynamics in Cognitive and Motor Decision-Making: Attention, Category Learning, and Choice in Neocortex, Superior Colliculus, and Optic Tectum. *Frontiers in Neuroscience*, *9.* https://doi.org/10.3389/fnins.2015.00501

Harbaugh, W. T., Mayr, U., & Burghart, D. R. (2007). Neural Responses to Taxation and Voluntary Giving Reveal Motives for Charitable Donations. *Science*, *316*(5831), 1622-1625. https://doi.org/10.1126/science.1140738

Hess, L., & Slíva, J. (2021). *Brain and pharmaceuticals* (1st ed.). Grada Publishing.

Houthakker, H. S. (1950). Revealed Preference and the Utility Function. *Economica*, *17*(66), 159. https://doi.org/10.2307/2549382

Imamura, A., Uitti, R. J., & Wszolek, Z. K. (2006). Dopamine agonist therapy for Parkinson disease and pathological gambling. *Parkinsonism & Related Disorders*, *12*(8), 506-508. https://doi.org/10.1016/j.parkreldis.2006.02.004

Jiang, Y. V, & Sisk, C. A. (2019). Habit-like attention. *Current Opinion in Psychology*, *29*, 65-70. https://doi.org/10.1016/j.copsyc.2018.11.014

Johnson, E. A., Portillo, A., Bennett, N. E., & Gray, P. B. (2021). Exploring women's oxytocin responses to interactions with their pet cats. *PeerJ*, *9*, e12393. https://doi.org/10.7717/peerj.12393

Kalechstein, A. (2009). Neuroeconomics: A Guide to the New Science of Making Choices. *Journal of Gambling Issues*, *23*, 179. https://doi.org/10.4309/jgi.2009.23.10

Kosfeld, M., Heinrichs, M., Zak, P. J., Fischbacher, U., & Fehr, E. (2005). Oxytocin increases trust in humans. *Nature*, *435*(7042), 673-676. https://doi.org/10.1038/nature03701

Marshall-Pescini, S., Schaebs, F. S., Gaugg, A., Meinert, A., Deschner, T., & Range, F. (2019). The Role of Oxytocin in the Dog-Owner Relationship. *Animals*, *9*(10), 792. https://doi.org/10.3390/ani9100792

Mazur, J. E. (1987). An adjusting procedure for studying delayed reinforcement. In *The effect of delay and of intervening events on reinforcement value* (pp. 55-73). Lawrence Erlbaum Associates, Inc.

Mikolajczak, M., Pinon, N., Lane, A., de Timary, P., & Luminet, O. (2010). Oxytocin not only increases trust when money is at stake, but also when confidential information is in the balance. *Biological Psychology*, *85*(1), 182-184. https://doi.org/10.1016/j.biopsycho.2010.05.010

Mirenowicz, J., & Schultz, W. (1994). Importance of unpredictability for reward responses in primate dopamine neurons. *Journal of Neurophysiology*, *72*(2), 1024-1027. https://doi.org/10.1152/jn.1994.72.2.1024

Nave, G., Camerer, C., & McCullough, M. (2015). Does Oxytocin Increase Trust in Humans? A Critical Review of Research. *Perspectives on Psychological Science*, *10*(6), 772-789. https://doi.org/10.1177/1745691615600138

Neugebauer, J. (2023). Regulating the work of medical professionals in a universal health care system through the lens of health economics. *New Perspectives on Political Economy*, *19*(1-2), 26-42. https://doi.org/10.62374/1r9f9c29

Pearson, I., Rothwell, B., Olaye, A., & Knight, C. (2018). Economic Modelling Considerations for Rare Diseases. *Value in Health*, *21*(5), 515-524. https://doi.org/10.1016/j.jval.2018.02.008

Pedroni, A., Eisenegger, C., Hartmann, M. N., Fischbacher, U., & Knoch, D. (2014). Dopaminergic stimulation increases selfish behavior in the absence of punishment threat. *Psychopharmacology*, *231*, 135-141.

Pine, A., Shiner, T., Seymour, B., & Dolan, R. J. (2010). Dopamine, Time, and Impulsivity in Humans. *Journal of Neuroscience*, *30*(26), 8888-8896. https://doi.org/10.1523/JNEUROSCI.6028-09.2010

Rangel, A., Camerer, C., & Montague, P. R. (2008). A framework for studying the neurobiology of value-based decision making. *Nature Reviews Neuroscience*, *9*(7), 545-556. https://doi.org/10.1038/nrn2357

Rock, D. (2010). *How your brain works*. Pragma.

Rogers, R. D. (2011). The Roles of Dopamine and Serotonin in Decision Making: Evidence from Pharmacological Experiments in Humans. *Neuropsychopharmacology*, *36*(1), 114-132. https://doi.org/10.1038/npp.2010.165

Rogers, S. M., & Ott, S. R. (2015). Differential activation of serotonergic neurons during short- and long-term gregarization of desert locusts. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1800), 20142062. https://doi.org/10.1098/rspb.2014.2062

Rotschedl, J. (2022). *Intertemporal consumer decision making : application to selected populations in relation to poverty* [Doctoral Thesis, Prague University of Economics and Business]. https://insis.vse.cz/zp/79861.

Ruan, Y., Li, K.-Y., Zheng, R., Yan, Y.-Q., Wang, Z.-X., Chen, Y., Liu, Y., Tian, J., Zhu, L.-Y., Lou, H.-F., Yu, Y.-Q., Pu, J.-L., & Zhang, B.-R. (2022). Cholinergic neurons in the pedunculopontine nucleus guide reversal learning by signaling the changing reward contingency. *Cell Reports*, *38*(9), 110437. https://doi.org/10.1016/j.celrep.2022.110437

Ruff, C. C., & Huettel, S. A. (2014). experimental methods in cognitive neuroscience. In *Neuroeconomics* (pp. 77-108). Elsevier. https://doi.org/10.1016/B978-0-12-416008-8.00006-1

Runge, C. F., Campbell, J., Runge, C. P., & Kartha, R. V. (2024). Economics, externalities and rare disease. *Rare*, *2*, 100036. https://doi.org/10.1016/j.rare.2024.100036

Sáez, I., Zhu, L., Set, E., Kayser, A., & Hsu, M. (2015). Dopamine Modulates Egalitarian Behavior in Humans. *Current Biology*, *25*(7), 912-919. https://doi.org/10.1016/j.cub.2015.01.071

Samuelson, P. A. (1937). A Note on Measurement of Utility. *The Review of Economic Studies*, *4*(2), 155. https://doi.org/10.2307/2967612

Samuelson, P. A. (1938). A Note on the Pure Theory of Consumer's Behaviour. *Economica*, *5*(17), 61. https://doi.org/10.2307/2548836

Samuelson, P. A. (1948). Consumption theory in terms of revealed preference. *Economica*, *15*(60), 243-253.

Sanfey, A. G., Rilling, J. K., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2003). The Neural Basis of Economic Decision-Making in the Ultimatum Game. *Science*, *300*(5626), 1755-1758. https://doi.org/10.1126/science.1082976

Schweighofer, N., Bertin, M., Shishida, K., Okamoto, Y., Tanaka, S. C., Yamawaki, S., & Doya, K. (2008). Low-Serotonin Levels Increase Delayed Reward Discounting in Humans. *The Journal of Neuroscience*, *28*(17), 4528-4532. https://doi.org/10.1523/JNEUROSCI.4982-07.2008

Soutschek, A., Jetter, A., & Tobler, P. N. (2023). Toward a Unifying Account of Dopamine's Role in Cost-Benefit Decision Making. *Biological Psychiatry Global Open Science*, *3*(2), 179-186. https://doi.org/https://doi.org/10.1016/j.bpsgos.2022.02.010

Soutschek, A., & Tobler, P. N. (2023). A process model account of the role of dopamine in intertemporal choice. *ELife*, *12*, e83734. https://doi.org/10.7554/eLife.83734

Swiderska, A., Krumhuber, E. G., & Kappas, A. (2023). Behavioral and physiological responses to computers in the ultimatum game. In *Research Anthology on Game Design, Development, Usage, and Social Impact* (pp. 1480-1494). iGI Global.

Tanaka, S., & Nishide, Y. (2013). Behavioral phase shift in nymphs of the desert locust, Schistocerca gregaria: Special attention to attraction/avoidance behaviors and the role of serotonin. *Journal of Insect Physiology*, *59*(1), 101-112. https://doi.org/https://doi.org/10.1016/j.jinsphys.2012.10.018

Thaler, R. H., & Sunstein, C. R. (2008). Nudge: Improving decisions about health, wealth, and happiness. In *Nudge: Improving decisions about health, wealth, and happiness.* Yale University Press.

van 't Wout, M., Kahn, R. S., Sanfey, A. G., & Aleman, A. (2006). Affective state and decision-making in the Ultimatum Game. *Experimental Brain Research*, *169*(4), 564-568. https://doi.org/10.1007/s00221-006-0346-5

Varian, H. R. (1982). The Nonparametric Approach to Demand Analysis. *Econometrica*, *50*(4), 945. https://doi.org/10.2307/1912771

Wagner, B., Clos, M., Sommer, T., & Peters, J. (2020). Dopaminergic Modulation of Human Intertemporal Choice: A Diffusion Model Analysis Using the D2-Receptor Antagonist Haloperidol. *The Journal of Neuroscience*, *40*(41), 7936. https://doi.org/10.1523/JNEUROSCI.0592-20.2020

Yamagishi, T., Horita, Y., Mifune, N., Hashimoto, H., Li, Y., Shinada, M., Miura, A., Inukai, K., Takagishi, H., & Simunovic, D. (2012). Rejection of unfair offers in the ultimatum game is no evidence of strong reciprocity. *Proceedings of the National Academy of Sciences*, *109*(50), 20364-20368.