BANCA D'ITALIA
EUROSISTEMA

Questioni di Economia e Finanza

(Occasional Papers)

The case for mindful customer protection: a review and some thoughts on neuroeconomics and neurofinance

by Massimiliano Affinito, Ludovica Galotto and Francesco Privitera

October 2024

Number 888

BANCA D'ITALIA
EUROSISTEMA

Questioni di Economia e Finanza

(Occasional Papers)

The case for mindful customer protection: a review and some thoughts on neuroeconomics and neurofinance

by Massimiliano Affinito, Ludovica Galotto and Francesco Privitera

Number 888 – October 2024

The series Occasional Papers *presents studies and documents on issues pertaining to the institutional tasks of the Bank of Italy and the Eurosystem. The* Occasional Papers *appear alongside the* Working Papers *series which are specifically aimed at providing original contributions to economic research.*

The Occasional Papers *include studies conducted within the Bank of Italy, sometimes in cooperation with the Eurosystem or other institutions. The views expressed in the studies are those of the authors and do not involve the responsibility of the institutions to which they belong.*

The series is available online at www.bancaditalia.it .

ISSN 1972-6643 (online)

Designed by the Printing and Publishing Division of the Bank of Italy

THE CASE FOR MINDFUL CUSTOMER PROTECTION: A REVIEW AND SOME THOUGHTS ON NEUROECONOMICS AND NEUROFINANCE

by Massimiliano Affinito*, Ludovica Galotto** and Francesco Privitera**

Abstract

This paper summarizes the history of neuroeconomics, provides an overview of the current state of the debate, describes the most commonly used analytical tools and reviews some relevant examples from the literature on neurofinance. The goal is to contribute to an understanding of the discipline and to an assessment of its potential benefits for customer protection authorities. Our review shows that the debate between proponents and sceptics over the use of neuroscience tools in economics is ongoing and often heated. However, we also point out that even those who are critics tend to recognize that neuroeconomics can, in principle, provide a contribution to traditional economics, particularly in the applied domain. Regulators and supervisors could benefit from this contribution by incorporating neuroeconomics-based insights into the design, implementation and monitoring of consumer protection policies such as in the regulatory process and financial education initiatives. Moreover, neuroeconomics experiments can be used to assess consumer protection practices prior to their formal legal mandate. Our review also shows that, despite the large body of work in neurofinance, much research can still be done on customers of banking and financial services and products.

JEL Classification: D11, D18, D87, G21, G41.

Keywords: neuroeconomics, neurofinance, customer protection, decision-making process, biases, cognitive factors.

DOI: 10.32057/0.QEF.2024.888

* Banca d'Italia, Directorate General for Economics, Statistics and Research.

** Banca d'Italia, Directorate General for Consumer Protection and Financial Education.

1. Introduction[1]

Financial customer protection regulators and supervisors design and monitor rules and measures that help consumers in taking financial decisions. Behavioural economics and neuroeconomics are disciplines that study the decision-making process of individuals. Since some years, several authorities and institutions around the world, directly or indirectly involved in the protection of bank and financial customers, have already started to exploit behavioural economics insights as part of their work (Antenucci, Franceschi and Repaci, 2024). The use of neuroeconomics tools as a means of improving regulation and supervision of customer protection is far less widespread, but even in this field there are early examples of supervisory authorities exploring the possibility to enhance the effectiveness of their activities with these tools.[2]

Behavioural economics studies and findings have been extensively used in the activities of regulatory and supervisory authorities, have produced Nobel prizes, even by psychologists in economics, and their relationship and complementarity are now fully accepted. Neuroeconomics is a younger discipline. It was born in the United States at the end of the 1990s. It is an interdisciplinary science that combines neuroscience, economics, and psychology. The most evident peculiarity of neuroeconomics is that it uses medical diagnostic instruments, such as functional magnetic resonance, to analyse what happens in the brain while a person performs a task, and to contribute in this way to the understanding of individuals' decision-making processes and behaviours.

This paper summarizes the history and the current state of the debate on neuroeconomics, describes some of the most commonly used analytical tools, reviews some relevant examples of the literature on neuroeconomics and neurofinance. The aim is to contribute to the understanding of this interdisciplinary science, and to evaluate its potential use and benefits in the institutional environment of economic, regulatory and supervisory authorities, especially those engaged in bank and financial consumer protection. To this end, we have selected in our review especially neurofinance papers that look at decisions of financial actors.

Our review illustrates that the debate between proponents and opponents of the use of neuroscience methods to investigate decision-making processes is still ongoing and often very intense. However, although the positions of the two sides are in many cases very distant, there is a general consensus that neuroeconomics can in principle make a contribution to traditional economics especially in the applied field. One important advantage is that neuroeconomics is particularly suited to conducting experiments even when other data are lacking. Even though 'economics is not a theory of the brain', in order to understand the fundamentals that determine economic decisions, it can learn a lot from the sciences that study behaviour and the mind.

The same is true for economic, regulatory, and supervisory authorities and institutions, especially those concerned with consumer protection. Just as marketing experts are likely to exploit

[1] The authors thank, for their comments, Diletta Antenucci, Magda Bianco, Massimo Coletta, Riccardo De Bonis, Paolo Finaldi Russo, Francesco Franceschi, Tommaso Macrelli, Gioia Repaci, and all participants to the webinar held at the Bank of Italy. The usual disclaimer applies. The views expressed are those of the authors only and do not involve the responsibility of the Banca d'Italia. Contact emails: massimiliano.affinito@bancaditalia.it; ludovica.galotto@bancaditalia.it; francesco.privitera@bancaditalia.it.

[2] Specifically, the study of consumer behavior is one of the goals of the US Consumer Financial Protection Bureau (CFPB), the government agency that carries out oversight tasks to ensure the fairness of banks' and financial institutions' behavior toward customers and to ensure a fair, transparent and competitive market. The CFPB, jointly with the US Department of Justice, has promoted first initiatives aimed at benefiting from neurological evidence in order to strengthen the tools for protecting older people form financial scams.

the understanding of customer decision-making processes to increase profits, regulatory bodies in charge of protecting investors and consumers would benefit from a similar comprehension of decision-making mechanisms to improve the protection framework and even help consumers to defend themselves. Insights from neuroeconomics can be incorporated into the development, implementation, and oversight of consumer protection regulations and policies. For instance, in the legislative and regulation process, employing neuroeconomic experiments offers a proactive means of assessing consumer protection practices before they become legally mandated. Similarly, neuroeconomics insights can be used to enhance effectiveness and calibration of financial education programs. Our review also shows that, despite the massive rise of the number of papers in neurofinance, there is still room and need for further studies regarding the users of banking and financial services and products.

The paper is organised as follows. Section 2 briefly describes the history of neuroeconomics. Section 3 summarizes the debate on neuroeconomics, the criticisms and the potential contribution highlighted by both critics and advocates. Section 4 reviews the neuroscience techniques and methods used by neuroeconomics researchers. Section 5 summarizes the main topics studied by applied neuroeconomists. Section 6 provides an overview of applied works of neuroeconomics and neurofinance relevant to finance and consumer financial protection. Section 7 contains some concluding remarks.

2. A very brief history of neuroeconomics

Probably the single most important factor that has enabled the birth of neuroeconomics was the invention in the 1990s of new diagnostic ‘brain imaging’ tools, in particular the functional magnetic resonance imaging (fMRI). These sophisticated, non-invasive, brain investigative techniques were developed for medical diagnostic purposes, and have increasingly found their way into our daily lives. But they also represented a revolution from a neuroscience perspective, as they enabled for the first time to use scientific instruments to visualize what happens in the brain while a person performs a task. Before the advent of brain imaging technologies, these kind of experiments were rarely possible as the available techniques were invasive and not suitable for humans. These studies were primarily conducted, with significant limitations, in human patients with brain lesions or on laboratory animals. The advent of brain imaging technologies facilitated researchers in exploring whether there is a biological basis for economic decision theories, and get to the bottom of the psychological factors that influence decisions (Bossaerts and Murawski, 2015). The first three studies utilizing fMRI were published in the same year, in 1992, marking a pivotal moment in the field (Bandettini et al., 1992; Kwong et al., 1992; and Ogawa et al., 1992).

The use of these innovative techniques found fertile ground in the debate within economic theory. In this respect, and very simplistically, it is possible to describe the emergence of neuroeconomics as one of the steps in the evolution of the theory of consumer choice.

Since its foundation, economic theory has adopted models and approximations of individual behaviour, and has assumed that the details of how the brain works are unknown or even irrelevant. In the study of consumer behaviour, in particular, economists have always relied on two main pillars: consumer utility maximization and the revealed-preference theory. Consumer utility maximization assumes that agents are perfectly rational and make efficient use of all available information to get the most out of scarce resources. The revealed-preference theory, introduced by Paul Samuelson in 1938, postulates that unobservable preferences can be inferred from observable decisions. In a way, Samuelson's theory is a very elegant way of using the available information, i.e. observable choices to theorize about unobservable factors such as preferences.

These assumptions and simplifications have proven to be, even today, excellent tools. It is also true, however, that economic models are by their very nature unable to capture the full range of human motivations, reasoning and impulses and thus economists necessarily simplify, stylize, and select what to include, being aware of the simplifying nature of their deliberate assumptions that enable the construction of the models. Doing so, their models have allowed to describe and explain many crucial features of the real economy. Nevertheless, it is also widely recognized that they cannot provide all the answers, and explain all human decisions and behaviour. In particular, the decision-making of real agents operating in society is very different from what one would expect from a rational agent who single-mindedly maximises a utility function (Camerer et al, 2005; Bernheim, 2009; Fumagalli, 2010; Vromen, 2011; Glimcher and Fehr, 2013; Levine, 2011; Signorini, 2019).

The initial spark of interest in gaining a more nuanced understanding of human decision-making emerged through the criticism of traditional microeconomics and the introduction of the 'bounded rationality' theory. Developed by Herbert Simons in the 1950s, who later received the Nobel prize in 1978, the theory of bounded rationality allowed for the first time to take into account individual's limitations into economic modelling (Visco and Zevi, 2021).

The critique to traditional models and assumptions broadened with the advent in the 1960s of behavioural economics, a theory rooted in the belief that incorporating psychological insights can improve economic analysis, as intuition and emotions often carry more weight than reason when making decisions. Pioneers in this field include Daniel Kahneman and Amos Tversky, who propose a theory of utility maximization that takes into account people's cognitive biases (Kanheman and Tversky, 1979). For these studies, Kahneman – a psychologist – earned the Nobel prize in economics in 2002 (Tversky had died prematurely a few years earlier). Over time the list of cognitive distortions has continued to expand (Kahneman, 2003 and 2011; Glimcher and Fehr, 2013), and to influence economic modelling (DellaVigna, 2009; Viale et al., 2018; Zevi, 2018).[3] The awarding of the Nobel prize in economics in 2013 to Robert Shiller, the father of behavioural finance, and in 2017 to Richard Thaler, for further studies in the field of behavioural economics, testifies that the link between economics and psychology is now fully accepted.

During the same time, experimental economics gained prominence, allowing economists to observe how consumer behaviour changes when some variables of the experiment change, thus gaining a more sophisticated understanding of individual decisions. Experimental economics proved that the integration of psychological methods can improve the testing of economic theories, as laboratory experiments, even if mostly limited to simulated environments, provided evidence that the effects of certain biases on consumers' decisions are systematic.

Finally, between the late 1990s and early 2000s, neuroeconomics took the investigation of consumer preferences one step further by adding the neurological skills and the scientific (medical) analytical tools previously unavailable. For the first time, these tools promised to examine individual preferences almost directly, revealing what lies behind economic decisions.

[3] It includes: (i) the fact that outcomes are generally evaluated against a reference point (anchoring effect), which means that different reference points influence perceptions of gains and losses; (ii) the influence of the way information is presented on decision making (framing effect); (iii) a preference for immediate gratification that leads to decisions that do not maximise long-term net effects (present bias).

Since its advent, interest in neuroeconomics has grown tremendously. In the early 2000s, few scholars from separate communities of behavioural economists and cognitive neuroscientists led to the formation of the Society of Neuroeconomics (Camerer et al., 2004; Glimcher and Rustichini, 2004; Camerer et al., 2005). Then, as Glimcher and Fehr (2013) report, the number of scientific papers using the keywords 'brain' and 'decision making' has risen from less than 4 to almost 200 per year since the 1990s, with the number doubling approximately every three years. Konovalov and Krajbich (2019) report that the annual number of neuroeconomic papers has roughly doubled since 2005.

Over the past three decades, the discipline of neuroeconomics and the application of neuroscience methods to economic decision making have generated both attraction and suspicion, leading to considerable and heated debate among economists (Marchionni and Vromen, 2010; Serra, 2020). Even the titles of the papers are expressive. Camerer et al. (2004) title their paper *Neuroeconomics: why economics needs brains*. Subsequently, Gul and Pesendorfer (2005) pen a broad critique of neuroeconomics titling their study *The case for mindless economics*, to which Camerer (2008) responds with a new work and a new title: *The case for mindful economics*.

The objectives of neuroeconomics and its role in contributing to economics have been sources of ongoing debate, even within the community of neuroeconomists. The manifesto by Camerer et al. (2005), acknowledging internal disagreements among neuroeconomists, lays out two alternative concepts of neuroeconomics: the first, later defined *radical approach*; the second *incremental approach* (Fumagalli, 2010; Vromen, 2011; Serra, 2020). Although this distinction is gradually losing relevance in light of recent advances, it remains a useful framework for summarizing the ongoing debate.

The radical approach, initially dominant, posits that neuroscience could develop alternative theories of decision-making, defining new scientific domains and breaking down old frontiers between disciplines (Camerer et al., 2005). In a nutshell, the radical approach proposes to reshape economics through the insights and discoveries of neuroscience. In this approach economics could even be viewed as a service to neuroscience (Serra, 2020).

Later on, the incremental approach gained prominence. This approach proposes that neuroeconomics, operating within the boundaries of 'traditional' methodologies, can contribute to the general understanding of phenomena, through the appropriate inclusion of new (biological and neurological) variables and adjustments into models of economic decision-making. In this view, neuroscience can be considered as 'serving' economics (Serra, 2020) and has been labelled as "behavioural economics in the scanner" (Vromen, 2011).

3. The debate on neuroeconomics: criticisms and potential contribution

In this Section we summarize the debate on neuroeconomics, describe some of the initial criticisms of neuroeconomists to 'traditional' economics, and the main responses of economists, and then summarize recent developments in the literature that show that convergence and collaboration are possible.

For the sake of simplicity and brevity, we focus on two of the neuroeconomists' main criticisms of 'traditional' economic models. First, neuroeconomists argue that 'traditional' economics suffers from a circular conundrum. Samuelson's theory of revealed-preferences claims that unobservable preferences can be inferred from observable decisions. However, this leads circularly to using these inferred forces to predict behaviour. Neuroscientists emphasize this weakness, and highlight that circular assumptions of economics lead to unreliable predictive models (Glimcher and Rustichini, 2004; Camerer et al., 2004; Glimcher and Fehr, 2013). Second, neuroeconomists criticise the assumption that consumer preferences are always and necessarily complete, transitive and symmetrical. Instead, they point out that preferences are 'state-dependent' (where the states are meant to be internal to the body), and this implies that the standard assumptions can no longer hold, in the sense that preferences can be temporally inconsistent, incoherent, and incomplete.[4] Therefore, neuroeconomists conclude that the standard findings deriving from traditional models result questioned. Importantly, these deviations are not random, but systematic, and have significant effects, which are large enough to contradict several results expected on the basis of standard theory (Glimcher and Rustichini, 2004; Camerer et al., 2004; Glimcher and Fehr, 2013). In the view of neuroeconomists, economists oversimplify human behaviour, completely neglect the emotional aspects and present *homo oeconomicus* differently from a human being, while they emphasize that the decisions of *homo oeconomicus*, like all human decisions, can only be understood if also brain evidence, as well as emotional activation and strategic interaction, are taken into account.[5] Moreover, they highlight state-dependence is 'contagious' across people and responses are correlated, so that internal states can become macroeconomic states (Bernheim 2009; DellaVigna, 2009; Glimcher et al., 2011; Viale et al., 2018; Zevi, 2018).[6]

On their side, 'traditional' economists defend the need of using simplified models as simplifications are an artificial means for stripping economic agents of less fundamental characteristics and focusing instead on their core traits. They also claim that deviations from those simplifications are random disturbances that have no systematic or significant impact. They are aware that these simplifications are often very crude; however, their idea is that the model predictions can remain nevertheless *approximately* true. An incorrect description of a single human being turns out to be *on average* a good predictor of many human economic agents. Traditional economists also argue that rationality is not an assumption in economics but a methodological stance, and that the methods of standard economics are much more flexible than it is assumed in the neuroeconomic critique and are perfectly suited to deal with inconsistent preferences, mistakes, and biases. The decision-maker may be learning about a relevant preference parameter, over time (Gul and Pesendorfer, 2011; Vromen, 2011; Levine, 2011; Serra, 2020).

While neuroscientists acknowledge that economics achieved much success sidestepping economic agents of many characteristics and recognize the utility of simplifications, they highlight that the several simplifying assumptions appear weak or insufficient to describe and study the real human decisions, and believe that a growing familiarity with brain functioning could lead to better theories for relevant economic domains, such as dysfunctional consumption, business cycle, stock market fluctuations, advertising effectiveness (Gintis, 2004). Neuroeconomists highlight that the

[4] A problem with preferences is that there are different types of utilities which do not always coincide. Kahneman (1994) distinguishes four types: remembered utility, anticipated utility, choice utility and experienced utility. Remembered utility is what people recall liking; anticipated utility is what they expect to like; choice utility is what they reveal by choosing (classical revealed preference); and experienced utility is what they actually like when they consume. It is likely that the four types of utility are produced, to some extent, in separate brain regions. If the different types of utility are produced by different regions, they will not always match up. When decisions are rare, like getting pregnant, deciding whether to go to college, signing up for pension contributions, buying a house, or declaring war, there is no reason to think the four types of utility will necessarily match up. This possibility is important because it means that the standard analysis of welfare, which assumes that choices anticipate experiences, is incomplete.

[5] Neuroeconomists state that the properties of the brain are rapid and often implicit (subconscious); they depart the most from conscious deliberation that may take place in complex economic decisions. Neuroeconomics does not deny the importance of deliberation; nevertheless, the presence of other mechanisms just means that the right models should include many components and how they interact.

[6] The mechanism is similar to that of Keynes's 'animal spirits', as neuroscientists themselves point out.

human brain is the building block of economic systems, and that neuroscience allows for the first time to understand it. Camerer et al. (2004 and 2005) and Camerer (2007) explain this opportunity with an analogy that has become very famous in the debate on neuroeconomics. They claim that neuroeconomics may open up the 'black box' of the brain as much as organizational economics opened up the 'black box' of the firm. In fact, in the studies on firm functioning, traditional models treated the firm as a black box (which produces output based on inputs of capital and labour, and a production function), while more modern views have 'opened the firm' studying, for example, the contracting practices, and how capital owners hire and control labour. Neuroeconomists argue that neuroeconomics can do the same with the brain, that is, neuroeconomics could model what goes on inside the consumer mind just as organizational economics models what goes on inside firms.

Traditional economists simply reject the analogy between neuroeconomics and brain, and organizational economics and firms. They argue that the internal workings of the firm fall squarely within the boundaries of economics already before the opening of the box, because firm workings concern organized exchange between individuals, which by definition take place not only within markets but also exactly within firms. In contrast, the internal workings of the mind is out of the scope of economics because 'the mind is not an economic institution'.[7] Economists completely dispute that any aspect of economic decision making is by definition an aspect of economics, and believe that economics should continue to focus on observable choices and behaviours, and maintain their agnosticism about decision-making processes (Bernheim, 2009; Fumagalli, 2010; Levine, 2011; Vromen, 2011; Dean, 2013). Gul and Pesendorfer (2005 and 2011) conclude that economics and psychology are different sciences, address different questions, utilize different abstractions, address different types of empirical evidence, study different kinds of behaviour and focus on different variables that influence behaviour.[8]

Some economists also dispute that neuroeconomics is a valid discipline, that is, they question reliability and trustworthiness of the results of neuroscience as proper of a good science (Dean, 2013). They suspect that neuroimaging methods do not provide a direct measurement of neural activity, and that the results of such studies are therefore inevitably subject to the interpretation and bias of researchers. Similarly, the relationship between brain activity and behaviour is not well understood. This criticism, referred as 'reverse inference', stems from the fact that the same brain regions may be involved in multiple cognitive processes, and therefore activity in those regions alone may not be sufficient to identify the specific cognitive process taking place. Furthermore, these economists assert that both the generalizability of the results and the external validity of neuroeconomics are questionable, as the experimental design in laboratories may not be generalizable to the complex, real-world decision scenarios, and the quantity of data is scarce (Rubinstein, 2008; Harrison, 2008), although sample sizes in neuroeconomics (which are traditionally limited due to the high cost of the experiments) increase over time (Serra, 2020).[9]

[7] Moreover, ironically, economists also noticed that models of neural processes are themselves black boxes. Bernheim (2009) claims that 'we are dealing not with a single black box, but rather with a Russian doll.' And he also adds: 'A mainstream economist might also take a prescriptive interest in the organization of firms; economic analysis can help to diagnose and fix a company that allocates resources inefficiently. In contrast, the diagnosis and treatment of poorly performing brains is traditionally the province of psychologists and psychiatrists, not economists.'

[8] Gual et al. (2008) claimed that economists should not adopt the goals and methods of psychology, since it is likely that the economists' model of the individual is not suitable for psychologists' goals.

[9] Finally, some economists also accuse neuroeconomics of paternalism, as neuroeconomic welfare analysis assumes a relationship between the economist and the economic agents that is similar to the therapist-patient relationship. Kahneman (1994) himself suggests that there is '...a case in favour of some paternalistic interventions, when it is plausible that the state knows more about an individual's future tastes than the individual knows presently.'

The debate on neuroeconomics is still ongoing. So far, the prevailing consensus points out that the neuroeconomics is unlikely to revolutionize economics, and that the initial neuroeconomic critique of standard economics, at least that of the so-called radical approach, was likely to be excessive. Konovalov and Krajbich (2019) summarize this debate noticing that the opponents of neuroeconomics criticize neuroeconomists because the first neuroeconomists misunderstood the traditional economic methodology and underestimated the flexibility of standard models. Nonetheless, the debate tends to recognize on both sides that neuroeconomics can in principle provide a significant contribution to conventional economics. It is more or less the same position of the so-called incremental approach of neuroeconomics. The contribution of neuroeconomics to the understanding may occur in a number of ways (Bernheim, 2009; Fumagalli, 2010; Vromen, 2011; Levine, 2011; Serra, 2020).

First, neuroeconomics can help to improve traditional economic models. Detailed knowledge concerning the neural processes of decision making may in fact help economists to discriminate between theories and choose between models. Moreover, neuroscience may be able to add precision to functions and parameters, and then to better construct and interpret standard economic models (Rustichini, 2005).

Second, a great potential exists for neuroeconomics in the area of normative economics. Bernheim (2009) highlights that neuroeconomics can improve welfare analysis in two ways. First, by shedding light on the manner in which the brain processes factual information, it can provide objective criteria for excluding certain choices for the purposes of welfare analysis. Second, by studying passive neural responses, it would enable to conduct choice-based welfare analysis even when no choice is actually done or possible. This means that neuroeconomics could facilitate the study of preferences, even when they are not directly revealed by actions, and thus provide insights into preferences that may otherwise remain hidden.

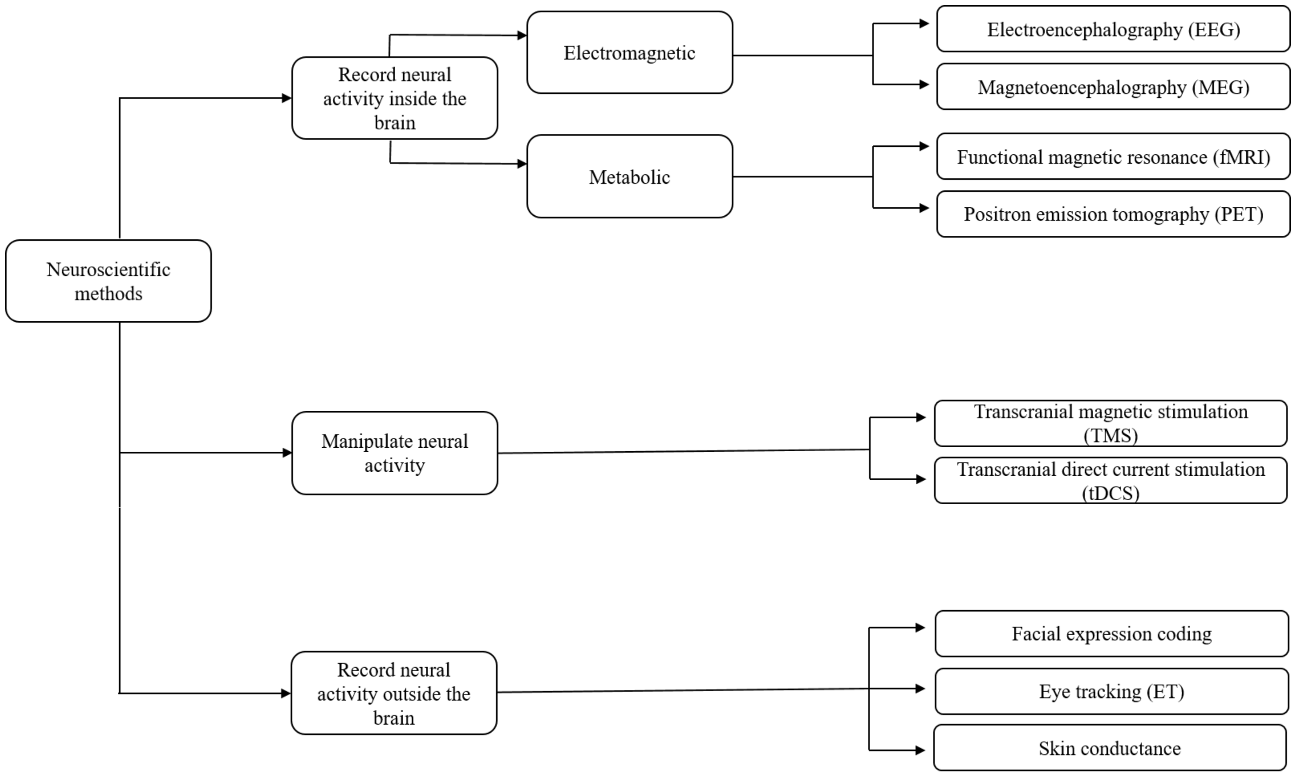
Third, the contribution of neuroeconomics can be particularly relevant in the applied domain, as it both makes available new data and helps to manage the omitted variable problem. Indeed, the data required by economists to address questions of interest are often unavailable, and are rarely generated under ideal conditions. Neuroeconomics could contribute to the general understanding of phenomena through the inclusion of new (biological) variables. Notably, neuroscience can not only provide new (kinds of) data when other sources of data are unavailable, but it can also provide a comparative advantage when other data are unreliable or even biased, as is often the case with surveys and self-reports because respondents often lack objective, introspective access, especially to emotions and feelings. Since neuroscientists ‘‘ask the brain, not the person’’, their direct measurements generate more reliable data. Therefore, the new variables measured by neuroeconomics can be used in otherwise conventional economic analyses. Moreover, still in the applied domain, thanks to the new methods of analysis and the new types of data, neuroeconomics can also overcome the limitations of omitted variables. Applied economists often worry that the explanatory variables of their regressions may be correlated with unobserved aspects of preferences, which in turn lead to biased estimations and findings on people’s behaviour. Neuroeconomists can identify the exogenous neural traits that are associated with specific preferences, and such data can then be used by conventional economists to create proxies that can eliminate or mitigate the omitted variables problem.

4. Neuroscience methods

As mentioned in Section 2, progresses in neuroeconomics were mostly enabled by the development in the early 1990s of non-invasive neuroscience techniques. For the first time, researchers could observe or actively manipulate the brain activity of healthy individuals during decision making and thus investigate the neural foundations of human behaviour (Engelmann et al., 2019).

The available neuroscience tools fall into three categories[10]: (i) neuroimaging techniques, which record neural activity inside the brain; (ii) neural properties' manipulations, which allow stimulating a precise brain area; and (iii) physiological proxies for brain activity, which record neural activity outside the brain. Below, for each category, we briefly describe their use, and elements of strength and limitations.

Figure 1.
Most common neuroscience methods



Source: Authors' adaptation from Lim (2018).

[10]Other less used techniques exist. For example, more invasive neuroscience methods such as electrophysiology, which have a long tradition in cognitive neuroscience, have also been applied to questions that are important to behavioural economics. However, due to their invasive nature, these experiments are rare and mostly applied to animals or during surgeries (Engelmann et al., 2019).

a) *Neuroimaging techniques*

Neuroimaging, or brain imaging, techniques allow researchers to record neural activity over time while a subject performs a cognitive, perceptual or motor task. The experiment scheme usually consists in comparing people performing different tasks—an ‘experimental’ and a ‘control’ one. The differences between images allow the researcher to study the areas which are differentially activated by the task itself (Camerer et al., 2005).

Various imaging techniques capture ‘brain images’ in distinct manners.: electroencephalography (EEG) and magnetoencephalography (MEG) directly measure the brain's electromagnetic activity; functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) capture changes in cerebral blood flow or metabolism.

Within the first group, EEG, one of the oldest neuroscience techniques, measures the brain's electrical activity using electrodes placed on the subject's scalp; instead, MEG measures the fluctuations in the magnetic field resulting from neuron activation using a scanner placed over the subject’s head. Both EEG and MEG have very good temporal resolution (i.e., they record neuronal activity in the order of milliseconds), which makes them suitable for studying changes in brain activity over time (Borawska, 2016). However, these techniques have poor spatial resolution, i.e. they do not allow accurate discrimination between different brain regions (Kable, 2011). Unlike EEG, MEG requires large equipment, which makes it harder and more expensive to implement.

On the other hand, fMRI and PET capture the metabolic demand associated with neuronal communication and are therefore indirect measures of neuronal activity. The most widely used fMRI method is BOLD (blood oxygen-dependent) imaging, which records changes in blood oxygen levels over time by applying a strong magnetic field to the subject during a task. The underlying operation of the fMRI scanner relies on the magnetic properties of a blood component, haemoglobin, which has different magnetic properties depending on whether or not it is bound to oxygen. Neurons that are actively contributing to a particular behaviour consume more oxygen, so by tracking oxygenated haemoglobin, the fMRI scanner can determine where more activity is occurring. PET works similarly, but is performed by injecting a radioactive tracer into the subject's blood before the experiment begins. The PET scanner then measures the local concentration of this marker in the brain (Charron et al., 2008).

Although each method has its own advantages and weaknesses, the review of the literature shows that fMRI is by far the most commonly used technique in cognitive neuroscience in general (Xue et al., 2010; Kable, 2011), and in neuroeconomics in particular (Engelmann et al., 2019). This is because it is a relatively easy to perform, non-invasive, and available technique. Among the neuroimaging techniques, fMRI provides the best combination of spatiotemporal resolution and anatomical coverage, and also allows for many repeated trials, ensuring that more sophisticated experimental designs and analyses can be conducted (Kable, 2011). Compared to EEG and MEG, fMRI has higher spatial resolution, which means that the exact source of a specific brain activation can be located more easily and with greater accuracy. Compared to PET, fMRI is less invasive as it does not require the injection of a radioactive isotope into the participant's bloodstream, which would limit the number of measurements that can be performed on a given individual (Kable, 2011). Nevertheless, fMRI also has some limitations. First, the fMRI has a limited temporal resolution, as the BOLD response is low (Xue et al., 2010). Second, on the practical side, experiments that require head or large body movements are not possible. Third, there are restrictions on the subjects eligible for testing: for instance, individuals contraindicated for MRI due to medical reasons (e.g., metal implants), children, and those with claustrophobia. Additionally, fMRI studies are associated to notable costs. Finally, fMRI falls short in establishing direct causal relationships between brain activity and behaviour compared to techniques allowing manipulation of neural properties.

b) Techniques that allow manipulation of neuronal properties

A typical experiment using a stimulation method consists in inducing an artificial, local, and non-permanent perturbation of brain activity in subjects performing a task (treated group), and observing the effects on behavioural performance compared to a group whose stimulation was only simulated (control group). In these cases, techniques such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) are typically used to experimentally manipulate psychological states or behaviours.

In a TMS study, a small coil is placed on the scalp of the subject and induces electrical currents in specific brain regions by applying a magnetic pulse (Walsh and Cowey, 2000). Instead, in a tDCS study, a low constant electrical current is applied to the scalp for a short period of time via patch electrodes. Both TMS and tDCS can promote or inhibit the emission of electrical signals by a neuron, depending on the intensity and frequency of magnetic stimulation in the case of TMS or the polarity of stimulation in the case of tDSC (Charron et al., 2008).

Unlike all other neuroeconomics methods, brain stimulation techniques directly affect the activity of specific areas, thus allowing researchers to observe the effects of an increase or decrease in the stimulated brain region on behaviour. Thus, these techniques make it possible to get as close as possible to inferring a causal relationship between the observation of a neuronal activity and the appearance or disappearance of a behaviour normally associated with that neuronal activity. For this reason, they are also defined as tests of necessity and sufficiency, whereas brain imaging tests are considered tests of association (Kable, 2011). Interestingly, depending on the protocol, TMS and tDCS might allow an individual subject to be his or her own control, i.e., to observe his or her behaviour under and without stimulation (Charron et al., 2008).

On the other hand, these techniques only act directly on neurons near the cortical surface, i.e., the outer layer of the brain, and do not allow reaching deeper brain regions, as it is the case with imaging techniques (Engelmann et al., 2019, Charron et al., 2008). Another practical problem is the exact localization of the area of interest on the scalp of the subject to which the TMS pulse is to be applied (Engelmann, 2019). A serious limitation arises in the interpretation of the results, because if behavioural effects of a perturbation are found in a particular area, this does not necessarily mean that this area is the only one involved in the process under study or that its role in the process is understood in any way (Charron et al., 2008; Vaidya et al., 2019). To demonstrate a causal role of a particular brain area in a behavioural process, converging evidence from a combination of TMS and other techniques is often preferred (Engelmann et al., 2019).

c) Physiological tools

A third group of techniques consists in measuring physiological indicators (proxies) of brain activity. The underlying assumption is that by measuring activities such as eye movements, breathing, facial expression or heart rate, researchers can obtain information about the internal functioning of the brain and gain insights on decision making.

One of the most widespread methods explores eye movements, studied mostly with the eye-tracking technology, which measures visual attention by recording eye fixation points. Eye-tracking was first employed for research purposes in the late nineteenth century by using invasive techniques that require contact lenses. Modern eye-tracking devices use sensors placed on table-tops or in special glasses that infer gaze direction from patterns of infrared light reflected from the cornea during normal eye movements. They were introduced in the late 1990s and became rapidly diffused, especially in market analysis, thanks to their low cost and natural use (Liu and De Goeji, 2020). Moreover, and notably, the eye-tracking method uses devices that are outside the physical sphere of the subject, who can thus behave naturally during the experiment.

Another related technique is pupillometry, which allows measuring changes in pupil diameter in response to stimuli normally associated with *arousal* (Bell et al., 2018). Pupillometry is often employed in studies attempting to measure attention, mental load and memory (van der Wel and van Steenbergen, 2018).

A different method consists in measuring emotional responses to stimuli through facial expression coding, the reading of muscle movements in the face. A typical experiment relying on facial expression analysis employs a video camera to capture facial images, which are then coded manually by a researcher or automatically using computer software (Bell et al., 2018). Similarly, facial electromyography (EMG) involves placing electrodes on the face to detect and record electrical activity generated by facial muscles. In consumer science, EMG has shown to be especially effective in evaluating consumer opinions about products (Lajante and Ladhari, 2019). Finally, heart rate - through Electrocardiology (ECG) -, respiration rate, and skin conductance measure arousal. Physiological techniques tend to be less costly and easier to use, as they require simpler equipment. However, they capture less precise information about the mechanisms of the human brain.

Recent technological developments allow the simultaneous application of multiple methods, typically the combination of fMRI with TMS-fMRI or EEG-fMR. Multi-methods approaches can support more solid claims about neural activity-mental function relationships, as they are based on converging evidence gathered from tests of association (e.g. fMRI), tests of necessity and sufficiency (e.g. TMS) between brain activity and behaviour (Kable, 2011). Importantly, the use of a multi-method approach may favour that the weakness of one method is compensated for by another instrument. However, some authors pointed out that, despite the strength of these approaches, converging evidence from different methods still has room for improvement (Kable, 2011).

Finally, neuroeconomic experiments can also use drugs that interfere (enhance or attenuate) with the activity of a certain neural correlate, i.e. the brain activity that corresponds with a particular cognitive process. A typical experiment consists of dividing a sample of people into two groups, giving one subgroup a drug and the other subgroup a placebo tablet and seeing how they behave in an experimental setting. If no other variable changes between the two groups, the differences in the behaviour can reasonably be linked to the activity of the neural correlate with which the drug interfere (e.g. Nadler et al., 2015; Mazar et al.,2016).

5. Topics in applied neuroeconomics

In response to criticisms of the validity of the discipline and its utility for economics, while many neuroeconomists focused on building a more solid theoretical foundation to support the novel field, many others, over the past 30 years, have sought direct applications of neuroscience to economic problems, applying it to a wide range of topics (Bernheim, 2009; Gul and Pesendorfer, 2011; Glimcher, 2011; Konovalov and Krajbich, 2019).

In the early days several applied studies focused on identifying the neural correlates of economically relevant phenomena. In other terms, they aimed at localizing the brain regions where activity corresponds to decisions on specific economic issues. This stream of research includes, for example, studies on the neural correlates of expected value (Breiter et al., 2001), cooperation (McCabe et al., 2001), reward (Erk et al., 2002), risk (Smith et al., 2002).

At that time, the development of applied neuroeconomics benefited greatly from the existence of a well-codified set of behavioural experiments, which often formed the basis for the development of applied neuroeconomic studies (Houser and McCabe, 2009). Many neuroeconomists replicated behavioural experiments, recreating game theory exercises in a laboratory setting to understand the neural mechanisms underlying strategic interactions between economic agents. Neuroeconomists replicated both competitive games, such as the matching pennies game and the rock–scissor–paper game, and cooperative games, such as the Prisoner's Dilemma, the ultimatum game, the investment game and the trust game (for a comprehensive review, see Krueger et al., 2008).

One application of these behavioural experiments within a neuroeconomic framework is exemplified by the work of Sanfrey et al. (2003). They replicated the ultimatum game, a cooperative game commonly used to investigate human behaviour in relation to fairness and social norms. In the ultimatum game, one person (the proposer) offers another person (the responder) a share of money. If the responder refuses the offer, neither person receives any money. Through fMRI scans of the receiving players, Sanfrey et al. (2003) discovered that offers triggered activation not only in regions associated with monetary evaluation but also in areas linked to emotions tied to the perception of the proposer's fairness, such as anger and disgust for an unfair offer. Similarly, de Quervain et al. (2004) recreated in a neuroeconomic setting a slightly modified version of the ultimatum game, in which the recipient has the option to punish a possible unfair behaviour by the proposer, but paying a cost. Using PET, they showed that punishing violations of social norms (i.e., in this case the unfair offer), even if it is associated with a monetary cost, is balanced at the level of the brain by activation of the area associated with the reward, and thus is chosen.

Since then, the applied works of neuroeconomics have addressed many fields. Among the many applications, there are two that are closer to bank customer protection: consumer neuroscience and neurofinance.

Consumer neuroscience is a subfield of neuroeconomics that deals with consumer choice problems in the business environment. Consumer neuroscience is generally considered synonymous with neuromarketing, the discipline that studies how to encourage consumers to buy and how to make successful market products and services. McClure et al. (2004), one of the earliest studies in this area, was about the impact that brands have on consumers. Specifically, they studied the relative preference for two types of ‘culturally familiar’ beverages - namely, Coke and Pepsi - which are almost identical in their chemical composition but are often chosen for cultural reasons. They conducted a series of blind and non-blind tests and obtained evidence of strong neuronal activity related to memory processes (hippocampus and dorsolateral prefrontal cortex) in relation to the drink labelled ‘Coke’, regardless of whether it was actually Coke or Pepsi. This opened the possibility that neural techniques can measure marketing interventions and provide practical insights to increase market shares and profits.

Later, consumer neuroscience has evolved greatly (Hubert, and Kenning, 2008; Karmarkar and Plassmann, 2019). It has helped consumer research to gain new insights into various aspects, such as branding (e.g., brand perception, evaluation, preferences), advertising (e.g., attention, affect, memory), pricing (e.g., cost consciousness), product packaging and design, advertising, and new product development (Agarwal and Dutta, 2015 and Lim, 2018).

The second field of interest is neurofinance. Neurofinance can be defined as a subfield of neuroeconomics that studies the activity of the brain in the decision-making processes of financial actors, focusing in particular on how the brain processes financial information and how this information is used to take financial decisions. This can, in turn, allow to gather useful insights concerning financial actors and any presumed irrationality in their behaviour with respect to classical models, as captured by robust empirical evidence accumulated over the years, especially in light of the recent financial crises.[11] Research in this area has touched, to various degrees, different topics, such as household finance, individual and aggregate trading behaviour, payment systems or the salience of financial documents.

6. A review of applied neuroeconomic studies in finance and consumer neuroscience

In this Section we overview some examples of studies of neuroeconomics in banking and finance, which are also of interest from a consumer protection perspective.[12] The Section is divided into five subsections. The works of subsections from *a)* to *c)* can be considered as belonging to neurofinance. The works of subsections *d)* and *e)* can be considered part of consumer neuroscience; they are also interesting because represent the most relevant papers of neuroeconomics in banking.

a) Financial decision making: Asset valuation and risk attitude

Neuroeconomics emerged as a discipline aimed at analyzing decision-making processes. In its applications in finance, it has been used to improve the understanding of financial decisions, in particular how individuals formulate and update their expectations regarding the value and risk of various financial assets and the role of emotions in financial decisions. This area of analysis can be categorized into three main groups of work.

First, numerous works have focused on studying the neural mechanisms that underlie financial decision-making, encompassing both inputs of the decision process (value signals or subjective evaluations) and the outputs (expected outcomes). These stream of work showed that two brain regions − the striatum and ventromedial prefrontal cortex (vmPFC) − consistently correlate with subjective values (e.g., Bartra et al., 2013; Clithero and Rangel, 2014; Kanayet et al, 2014), and are generally involved in storing, learning and updating values. Other works have analysed the process of learning and updating financial values, revealing that human learning does not occur optimally, such as through Bayesian updating (Sutton and Barto, 1998).[13] While Bayesian updating assumes that individuals adjust their beliefs in an optimal manner utilizing all available information, empirical evidence suggests humans lean towards learning through reinforcement learning algorithms. These

[11] See Campbell (2016).

[12] We exclude, therefore, any work concerning irrationality and financial decision making that has a purely behavioural approach with no neural foundations (unlike, for example, the literature review on financial decision making, psychology and neuroscience by Frydman and Camerer (2016)), which for instance leads to excluding the many behavioural works emerged over time, amongst which those concerning managers in financial institutions and how they interact with investors (See, for example, Ben-David et al. (2013), Malmendier et al. (2011), Francis et al. (2014) and Larcker and Zakolyukina (2012)).

[13] In Bayesian updating, which is traditionally used in neoclassical models, the probabilities attributed to all possible outcomes are updated after observing a new event.

algorithms operate by iteratively comparing expectations with actual outcomes, and then updating predictions based on the individual's learning rate. This adjustment process incorporates past prediction errors, defined as the disparities between previously estimated values and the actual rewards received.[14]

Second, recent studies have focused on how the brain tracks and identifies not only the outcome value of financial assets, but also other characteristics, such as variance and skewness, which provide additional insights into the risk and potential return characteristics of an asset.[15] This research has shown that humans have the ability to track these higher statistical moments. Notably, the anterior insula, previously associated with processing adverse emotions like anxiety and regret, has been implicated in this tracking process. Other studies focused on analysing how humans learn correlations between outcomes, a critical aspect for economic agents, especially in finance. Modern portfolio theory (Markowitz, 1952) is a cornerstone in our comprehension of financial markets, formalizing risk-minimization and the role of correlation between asset returns in optimizing portfolios for maximal returns while minimizing variance. Neuroeconomics research tried to understand both how the brain tracks individually the value and risk of assets, and whether and how the brain is able to process the correlation between different assets.

Wunderlich et al. (2011) addressed this question by scanning (using fMRI) 16 individuals performing a laboratory game simulating a simple portfolio optimization problem. Participants had to adjust the weights/coefficients of the linear combination between two assets, whose outcomes were correlated but with a probabilistically changing correlation over time, meaning that individuals had to continuously update their estimate of the correlation structure. Subjects were rewarded according to how well they performed compared to a hypothetical optimal strategy. The results showed that individuals effectively learned outcome correlations, dynamically adapting their decisions, with correlation representations localized in the right midinsula and accompanied by a learning prediction error signal. These results align with modern portfolio theory, affirming humans' ability to grasp correlations and manipulate them when necessary, consistent with Markowitz's prerequisites for an optimal portfolio strategy. The results were also relevant because they identified the brain region involved in these decisions, and showed that it is different, slightly posterior, to the one interested in tracking the variance alone, underlining the complexity and specificity of the brain process.

A third group of studies has tried to find out whether and to what extent emotions can influence economic decision making, for example the willingness to take risks. Kuhnen and Knutson (2005) were the first to investigate whether the neural activation associated to an emotion predict a certain kind of financial decision. They tested two contrasting hypotheses: one proposing that undifferentiated arousal is related to both risk-taking and risk-aversion, implying a less clear-cut role for emotions;[16] the other suggesting that positive emotions (such as excitement) are associated with gain expectation and encourage risk-taking decisions, while negative feelings (such as anxiety) drive risk-aversion.[17]

[14] Schultz et al. (1997) first showed that dopamine neurons in macaques reflected properties of reinforcement learning. Later, O' Doherty et al. (2003), McClure et al. (2003) and Hare et al. (2011) have found correlations between prediction errors estimated behaviourally and brain activity in the ventral striatum. Finally, Caplin and Dean (2008) have provided a set of axioms defining the principles that underlie reward prediction errors, and Rutledge et al. (2010) found that activity in the striatum and vmPFC, among others, satisfies such set of axioms.

[15] See Mohr et al. (2010), Preuschoff et al. (2006) and (2008), and Christopoulos et al. (2009) for the variance; Symmonds et al. (2010) for the skewness.

[16] See Lo and Repin (2002).

[17] See Knutson and Cooper (2005) and Paulus et al. (2003).

The authors analysed 19 subjects, including both financial experts and non-experts (amongst whom the results were not significantly different), who were asked to make choices in a Behavioural Investment Allocation Strategy (BIAS) task, consisting of 20 blocks of 10 trials. Subjects had to select between two stocks and one bond while being scanned with an fMRI. During each block, one stock was randomly assigned as 'good', while the other was assigned as 'bad', with the good stock having a higher expected value than the other,[18] while the value of the bond remained fixed. In addition to a fixed reward, cash could be earned at the end of the experiment if the task was performed successfully. The authors then compared the investment choices of the subjects versus those of a hypothetical rational, risk-neutral agent maximizing expected utility, dividing any deviation between risk-seeking and risk-averse mistakes. The neural focus was on two regions: the nucleus accumbens (for which previous evidence showed activation in anticipation of gains and correlation with positive feelings), and the anterior insula (for which there was evidence of activation in anticipation of losses and of a correlation with negative feelings). The brain images showed that the nucleus accumbens was activated in anticipation of both risky choices and risk-seeking mistakes, while the anterior insula was activated in anticipation of both risk-free choices and risk-averse mistakes.[19] The results were therefore consistent with the second hypothesis, according to which there are two distinct neural mechanisms through which emotions affect individual choices concerning risk, and which, when over-activated, can lead to investment mistakes.

Knutson et al. (2008) further investigated the issue by means of exogenous emotional cues. To a sample of 15 hetero young males they showed both erotic pictures (as a positive exogenous emotional cue), and pictures of spiders (as a negative stimulus). Both behavioural self-reports and fMRI scans showed that the exogenous positive stimuli affected investments, while this was not the case for negative stimuli. They also showed that brain activity increased in the nucleus accumbens, that is, the same region the previous study had shown to play a role in driving risky decisions; conversely, no effect was found in the anterior insula following negative stimuli. These results confirmed the findings of the previous study with regard to the important role played by nucleus accumbens in driving individuals' risk taking, and therefore of the effect of positive emotional cues on risk-taking.

b) Individual investor trading decisions

An area where deviations from rational optimal decisions occur more frequently is trading decisions of individuals. Empirical evidence has shown a disparity between the expected decisions of investors based on traditional 'rational' models (Fama 1965 and 1970) and their actual investments. Neurofinance has addressed two problems in particular: the 'disposition effect' and the 'repurchase effect'.

The expression 'disposition effect' was coined by Shefrin and Stratman (1985), who revealed a general tendency among investors to sell stocks that had appreciated since purchase ('winning stocks'), while holding stocks whose price had fallen ('losing stocks'). Subsequent research confirmed these results and showed that less sophisticated investors, potentially more in need of protection, exhibit a stronger disposition effect.[20]

[18] More in detail, the "good" stock first-order stochastically dominated the "bad" stock.
[19] A risk-seeking mistake was defined as a situation in which the participants took choices that were too risky compared to those of a rational agent maximizing his utility in a classical model; vice-versa for risk-averse mistakes.
[20] Odean (1998); Genesove and Mayer (2001); Grinblatt and Keloharju (2001); Feng and Seasholes (2005); Frazzini (2006); Dhar and Zhu (2006); Jim and Scherbina (2011).

These results were interesting as they contradicted traditional trading models, based on the maximization of utility. Private information could comply with these results even within a traditional framework (for example, if investors were to sell stocks that they knew would then perform poorly and hold on losing stocks that they knew would rebound), but the average return of sold 'winning stocks' resulted higher than that of held 'losing stocks' (Odean, 1998). Additionally, tax-related incentives predicted a greater propensity to sell stocks with unrealized losses (paper losses), further contrasting with the observed disposition effect.

In order to explain the disposition effect, several studies have proposed behavioural economics models, such as an irrational belief in mean-reversion (Odean, 1998; Weber and Camerer, 1998; Kaustia, 2010; Barberis and Thaler, 2002), prospect theory preferences (Weber and Camerer, 1998; Barberis and Xiong, 2009; Kaustia, 2010; Talpsepp et al, 2014)[21] or realization utility theory (Shefrin and Statman, 1985; Barberis and Xiong, 2012; Ingersoll and Jin, 2013). While making predictions consistent with the disposition effect, these models posed significant challenges in empirical tests due to their reliance on emotions and feelings of investors, and on their drivers of utility, which are challenging to capture through behavioural self-assessments.

In this perspective, cognitive neuroscience offered a pivotal tool to test the validity of these models by examining directly at the neural level. Specifically, this was possible for the realization utility theory. This theory states that investors derive (dis)utility directly from the realization of gains (losses) on the stocks and risky assets that they hold, with a positive (negative) burst of utility from selling at a gain (loss) that is proportional to the size of the gain (or loss).

In order to test the realization utility theory, Frydman et al. (2014) performed a study on 28 students at Caltech, with an average age of 25, who traded in an experimental stock market in an fMRI scanner. The stock market was set up in order to give participants the opportunity to buy or sell assets, ensuring that choices that would lead to a disposition effect were unequivocally suboptimal from the point of view of a traditional model (that is, stock prices followed a Markov chain that induced a positive autocorrelation in price changes, meaning that the price of 'winning stocks' would continue to rise and conversely those of 'losing stocks' would continue to fall). In order to isolate the brain regions relevant to the analysis, Frydman et al. (2014) focused on the ventromedial prefrontal cortex (vmPFC), which has been shown to be involved in calculating the values associated to different decisions (decision values), and the ventral striatum (vSt), which measures changes in the expected net present value of lifetime utility due to new information. Frydman et al. observed that more than two thirds of sales decisions were suboptimal, and that neural activity in the aforementioned areas was consistent with the hypothesis they formulated based on realization utility theory. Specifically, activity in the striatum peaked when selling a winning stock, whereas there was no spike when deciding not to sell winning stocks, in line with a change in the net present value of utility occurring when selling winning stocks, but not when holding onto them.

Dorow et al. (2017) replicated the experimental protocol introduced by Frydman et al. (2014) in a different cultural setting, using the less intrusive, but also less accurate, EEG in a sample of 12 undergraduates (enrolled in economics, accounting or management) and 5 professionals. They found in general that brainwave activation was positively related to returns, and that there was disposition effect amongst undergraduates, while professionals were more likely to escape it, which is consistent

[21] In particular, the disposition effect would be consistent with agents that are risk-averse to gains, such as when the price goes above the reference purchase price, while being risk-seeking on losses, such as when the price is below the purchase price.

with previous findings in the literature that less sophisticated investors are more exposed (Da Costa et al., 2013).

Previously, on the other hand, Brooks et al. (2012) had found evidence in contrast with these findings, with neural activity suggesting an irrational belief in mean reversion as the main cause behind the disposition effect, rather than prospect-theory risk preferences or behaviour consistent with realization utility theory.[22] However, the experimental design was different: 38 college students were scanned with fMRI and prices followed a random walk, and participants did not have the possibility of buying and selling assets as in Frydman et al. (2014), but could only hold or sell an asset initially assigned to them. Brooks et al. (2012) acknowledged that such differences in experimental design could explain the lack of results consistent with the realization utility theory – that is, with individual differences in the disposition effect that did not correlate with the magnitude of the neural response in the valuation-related brain areas. The different price structure may also have affected the results, since random walk rather than Markov chain prices (which led to positive autocorrelation) made the mean-reversion hypothesis less clearly irrational for participants.

The second topic concerning discrepancies between individual investor trading theories and actual decisions regarded the 'repurchase effect'. This is a well-known empirical fact, primarily studied by Strahilevitz et al. (2011): investors are less likely to repurchase a stock when its price has risen after selling rather than when the price has fallen. The 'repurchase effect' is in contrast with classical models of investor behaviour, since utility should be a function of consumption, and investment decisions should not be affected by whether a stock was previously owned. Frydman and Camerer (2016) formalized a theoretical model to explain this phenomenon, which built on the regret-devaluation mechanism from social psychology. In this model the price rise of a stock after its sale implied a negative utility burst, which was further exacerbated if the stock were successively rebought. Again, testing this model through self-assessment surveys (aimed at capturing personal feelings such as regret) incurred in a number of biases, while neural studies were appropriate. Frydman and Camerer (2016) focused on activity in the ventral striatum, which the neuroscience literature had found to respond to both prediction errors and regret signals. They ran an experimental setup equal to the one implemented by Frydman et al. (2014), with fMRI scans on 22 Caltech students, allowing them to measure both the repurchase and disposition effects. Their results showed that the average subject exhibited a strong repurchase effect, and that it was indeed driven by neural activity in the ventral striatum, with different responses to price changes depending on whether a subject owned or not a stock. Moreover, evidence from the vmPFC also suggested that the disposition and repurchase effects were strongly correlated, implying a possible common psychological basis, and highlighting that the same individuals incurred, to a similar degree, in different cognitive biases, which underlined their relevance for customer protection policies.

c) Financial bubbles

Individual trading decisions can significantly affect aggregate outcomes, potentially leading to phenomena like financial bubbles, where asset prices soar far above their intrinsic economic value. Neuroeconomics is well suited for analysing financial bubbles because it allows for the exploration of neural mechanisms underlying price bubble formation, including psychological factors such as euphoria or irrational exuberance, which are challenging to assess using traditional methods or

[22] If asset prices were to converge to their mean over time, holding on to losing stocks and selling willing ones would be an optimal strategy.

behavioural self-evaluations.[23] Several applied studies in neurofinance have examined financial bubbles, broadly categorized into three groups.

First, the most ambitious neuroscientific study on financial bubbles is by Smith et al. (2014), who tries to identify brain areas active during the formation of price bubbles. They used 16 experimental market sessions with an average of 20 traders (2 or 3 were neurally examined through fMRI). In the experiment, they created financial assets with a fixed intrinsic value over 50 trading periods, implying that from a rationally optimal perspective the prices should not vary over time. Their main finding was that the activity in the Nucleus accumbens (NAcc), a brain area involved in the attribution of subjective value to assets, was closely associated to that of financial bubbles. In particular, traders more involved in buying were driven by exuberant valuations (which should lead, theoretically, to greater reward); while traders who sold before the burst were driven by 'neural early warnings'. Overall, these dynamics were consistent with the idea that bubbles were driven by bounded rationality and emotions. Smith et al. (2014) also suggested that the slope of the buy/NAcc relation could provide a new 'neuro-behavioural metric' to measure the financial cost of irrational exuberance. This could then be used as a reference in other contexts where people misjudge the value of actions or events, both broadly speaking (e.g., eating habits, drug addictions) and in specific economic sectors (e.g., to assess clients' behaviour in the build-up of bank runs).

Second, De Martino et al. (2013) investigated the role of social components in price bubbles. The authors studied those brain regions that neuroscientific studies had already shown to be involved in the valuation of assets (i.e., vmPFC), or in the representation of the mental state of other individuals (i.e., medial prefrontal cortex – dmPFC). The latter, in particular, was related to the so-called 'theory of mind', which referred to the ability of individuals of taking into account the intentions of other people and thinking strategically.[24] In the study, 21 participants were given a cash endowment of 60 dollars and were scanned with fMRI while trading in six experimental market sessions (three of which were bubble markets with market prices above the intrinsic value of the assets; the prices were taken from a similar experiment ran in a previous study and therefore independent from the subjects' choices). Participants had to choose, at random intervals, whether to buy or sell their shares and, if so how many; following their choice, an update about the others' portfolios (cash and number of shares held) was displayed. The results showed that measures of activity in those brain regions were associated with the propensity to buy, by tracking the presence of strategic agents in the market. More in detail, the "social signals" computed in the dmPFC affected the valuation of assets in the vmPFC, and increased the propensity to ride a bubble and lose money. This means that incorporating inferences about the intentions of other individual while making value judgments in financial markets could lead to the formation of market bubbles, highlighting therefore possible side effects of strategic thinking, at least when financial bubbles are considered.[25]

A third group of studies addressed the issue of financial bubbles adopting varied approaches. For example, Toma and Miyakoshi (2020) followed an approach based on an inexpensive and easy-to-use brain computer interface to establish whether the EEG power changes reflected those in the stock prices in a financial bubble. They set up an experiment with 28 participants, including both financial professionals and students in economics, and focused on the frontal cortex region of the

[23] See for example Flood and Garber (1980) and Kindleberger and Aliber (2005).

[24] See Gallagher and Frith (2003) for further discussion.

[25] The results of De Martino et al. (2013) stand in contrast with those of Bruguier et al. (2010). They scanned with fMRI 38 subjects operating in experimental markets, some of whom received a signal about their dividend ('insiders'), unlike others ('uninformed traders'). Bruguier et al. (2010) found that the ability to predict price changes in markets with informed traders is correlated with the social signals received by uninformed traders.

brain, which previous evidence had shown to be relevant for decision making.[26] Their results showed a negative correlation between activity in the lateral frontal region, which was responsible for value-based choices, and stock price dynamics.

Efremidze et al. (2017) used an experimental trading setup to test the role of 'reinforcement learning' on bubbles, that is, they explored whether a slower rate of learning could lead to larger bubbles. To this end, they gave naltrexone, a drug that slows reinforcement learning by inhibiting the binding of dopamine in the ventral striatal region, to some of the participants, and a placebo to the others. The study included a relatively large number of participants, 178, although prevalently very young (average age of 19.6 years with a standard deviation of 1.6). The results showed that asset prices were larger in the trading sessions where naltrexone was used rather than the placebo, both in terms of amplitude and deviation from the fundamental value.[27] In particular, the differences between the two subsets did not show up immediately, but only in later trading periods, consistent with the hypothesis of reduced reinforcement learning. This result suggested for example that greater exposure to trading, even during asset price booms and busts, could be beneficial to the general welfare and reduced the frequency of bubbles.

Nadler et al. (2015) tested the role of testosterone in the formation of financial market bubbles. The authors exogenously elevated testosterone in male traders and tested testosterone's effect both on their trading behaviour in experimental asset markets and on the size and duration of asset price bubbles. Using both aggregated and individual trading data, they found that testosterone led to larger and longer-lasting bubbles by inducing high bids and slow incorporation of the asset's fundamental value. These findings highlighted the role of hormones on decision-making and the possible risks of receiving exceptionally positive and unmotivated feedbacks.

d) Payment methods and spending decisions

Applied neuroeconomics has devoted much attention to the topic of payment methods and spending decisions, pointing to several studies from psychology, behavioural economics and finance that had provided evidence that payments are not analytical processes based only on individual preferences and prices. The theoretical formalization of the psychological mechanisms governing spending decisions was pioneered by Prelec and Lowestein (1998), which modelled the existence of a hedonistic process that takes place during the payment decision: during purchases people experience a trade-off between the pleasure of the acquisition and the 'pain of paying'.

Numerous neuroeconomic studies have devoted efforts to scientifically validate this struggle between conflicting emotions, providing evidence that the act of paying activates neural circuits associated with both pain and satisfaction. Knutson et al. (2007) were the first to explore which neural circuits are activated when a person pays for a product or sees an excessive price, and whether the activation of these regions could predict purchasing decisions. They conducted an experiment with 26 adults, who were scanned with an fMRI while performing several purchase trials following a four-phases structure called 'Save Holdings or Purchase' (SHOP) task. In each SHOP, subjects had to (i) see a product, (ii) see its price, (iii) decide whether or not to buy the product, and finally (iv) wait a few seconds before the next trial. The authors found that, while considering a product, individual

---

[26] In particular, the lateral frontal cortex is involved in value-based choices, whereas the centro-frontal cortex is involved in risk-taking.

[27] The amplitude of a bubble is defined as the difference between the highest and lowest average per period price deviation from fundamental value divided by the initial fundamental value of the stock.

preferences activated the neural circuits associated with expected gains (nucleus accumbens), and, when observing an excessive price, activated the circuits associated with negative emotions, such as pain and fear (insula)[28] and deactivated brain regions associated with weighing potential gains and losses (mesial prefrontal cortex). This was the first neurological evidence of the existence of the 'pain of payment'. Moreover, Knutson et al. (2007) proved that including neuroeconomics variables into the statistical model helped predict purchase decisions beyond self-reported economic variables (preference and price difference).[29] The results supported the historical notion that individuals have immediate affective reactions to potential gains and losses, which serve as inputs to the decision whether or not to purchase a product. Notably, these results argued in favour of the so-called *incremental approach* (see Section 2).

Mazar et al. (2016) explored the 'pain of payment' hypothesis more in detail, and studied whether the pain felt during a purchase is assimilated to an affective pain (i.e., the pain of being emotionally hurt) or a somatosensory pain (i.e., a physical pain). As a first experiment, the authors compared purchases made with cash with those made with an electric shock. The experiment showed that the two 'means' of payment elicit different neural circuits, confirming that paying with money triggers an affective pain experience (associated with activation in the anterior part of the right insular cortex), as opposed to a physical pain experience felt when 'paying' with an electric shock (associated with the posterior part of the right insular cortex). To further verify this result, they conducted two additional experiments. In the first, 142 people were divided into groups before the shopping task, with subjects randomly assigned to different conceptual primes (i.e., word games unrelated with the purchase decision). One group played with words that evoked affective pain (e.g., grief, sorrow), another group with words that evoked somatosensory pain (e.g., sore, cramps). A third control group did not play any game. The experiment showed that the willingness to pay was lower (and the pain greater) in the group that played with cards that evoked affective pain, while there was no difference in willingness to pay between the group that played with cards that evoked somatic pain and the control group. In their last experiment, Mazar et al. (2016) simulated a clinical drug test by manipulating participants' perception of pain before the shopping task. 123 participants were divided into two groups: one group was told it would receive a drug to either enhance or relieve somatosensory pain (headache, muscle pain, joint pain); another group was told it would receive a drug to enhance or relieve affective pain (anxiety, sadness, social discomfort). Instead, all individuals received the same placebo medication (a starch tablet). Subsequently, the subjects participated in various computerized tests and questionnaires to assess the drug's effect on their cognition and general well-being. They also participated in some product evaluation exercises (e.g., auctioning an Amazon shopping card), which they believed to be a control test. The results of the auctions showed that, while there was no difference between the groups who thought to receive somatosensory medication, participants who believed to be under the effect of an affective pain enhancer showed a higher willingness to pay than those who were told they would receive an affective pain reliever. The author's explanation is that the participants who believed they were receiving the affective painkiller mistakenly attributed their discomfort to the medication rather than the payment and were therefore more willing to pay.

Numerous neuroeconomic studies have explored how the brain processes various payment methods, notably physical and digital, and their impact on spending decisions. Even though there is

[28] Note that the neural circuits are the same as in Kuhnen and Knutson (2005), as cited in paragraph 3.1.

[29] Specifically, prediction analyses utilized logistic regression to determine whether NAcc activation during the product period as well as MPFC activation and insula deactivation during the price period would predict the subsequent decisions to purchase a product during the choice period, both before and after controlling for self-report variables (i.e., preference and price differential).

not conclusive evidence, the use of cash as a payment method appears to be associated with a stronger perception of the pain of spending, which in turn leads to a greater sense of control over one's expenditures; instead, the use of electronic and digital payments seems associated to a greater propensity to spend money.

Ceravolo et al. (2019) investigated how brain activity changes when using different means of payment (cash, card and smartphone), or the amount paid (€10, €50, €150). In their experiment, subjects were recorded using fMRI while watching video clips that showed a human hand making a payment, each time using a different method or amount of money. The study showed that brain areas involved in the processing of pain (insula) and computational tasks (parietal cortex) and were activated more strongly in subjects who observed the process of a cash payment. This effect was stronger as prices increased.

Banker et al. (2021) explored the different effects of credit cards and cash. They performed an fMRI shopping task in which 28 participants purchased items tailored to their interests. The shopping task followed the same structure as the SHOP experiment by Knutson et al. (2007), but with two important differences: purchases were made using either a personal credit card or cash, and participants spent their own money rather than endowment money. In their experiment, credit card purchases were associated with a strong activation of the reward mechanism (identified with the striatum and ventromedial prefrontal cortex), not related to the product price. In contrast, and differently from the results of the previous experiment, the striatum weakly predicted cash purchases and only for relatively cheap products. Importantly, they found no difference in the activation of the insula between paying with cash and paying with a card. The fact that they found no different activation in the insula (linked to pain) but different activation in the VMPFC suggested that paying with a card was associated with a greater incentive to spend money rather than with a lower pain of paying. This provided evidence in support of the hypothesis that digital means of payment provide a 'step on the gas', that is, they increase motivation to spend. Moreover, the fact that VMPFC activation in credit card purchases is poorly related to price suggests that credit card spending reduces sensitivity to price information.

Banker et al. (2021) explained the divergence of their results compared to Knutson et al. (2007) (i.e., the fact that reward signals were weaker predictors of cash purchases than in the original SHOP task) with the different structure of the experiment. In Banker et al. (2021), participants paid out of their own pocket, while in Knutson et al. (2007) participants used their experimental equipment, possibly leading to a 'house money effect' (i.e., the tendency to take higher risks with money that is perceived as extra). One possible interpretation of these results was that people who used credit cards for their purchases behaved as if they were drawing on an endowment.

Finally, Yu et al. (2022) investigated whether and how, in online shopping, different payment methods influenced consumers' purchase intentions, and in particular whether there were elements of trust and perceived risk related to online shopping. They asked to 27 undergraduates to complete an online shopping task while being recorded by EEG. The shopping task consisted of purchasing 10 products, of which 5 were 'search products' (i.e., items with features that could be known before purchase, such as electronics), and 5 were 'experience products' (i.e., items with features were only known after the use, such as sunglasses or clothes). In each case, they could choose to pay cash on delivery or online. The results showed a stronger purchase intention for search products and for paying online. At the brain level, as expected, the authors found that search products were less associated with risk perception than experience products. Interestingly, for the search products online payment triggered greater risk perceptions than payment on delivery. However, this differential effect was not observed for the experience products. A possible explanation for the discrepancy in risk perception between online payment and payment on delivery for the search products was the spatial distance between online sellers and customers as well as the temporal separation of payment and product delivery. This could be due to the fact that experience products inherently involved higher search costs and purchase risks.

e) How individuals process financial information

A recent area of research in neuroeconomics looked at the form, structure, and content of information documents for financial products, which are to be presented to the clients by financial institutions. This literature explored whether and how the way in which information was presented could influence the decision-making of consumers and investors. The studies provided evidence that attention was limited, and people were not able to process all available information, as was often assumed for the sake of simplicity in economic models. Attention was a key factor because it guided comparison and was related to our preferences. In other terms, all people tended to pay more attention to favoured objects, and the greater the attention, the more likely the choice. These arguments have inspired new theoretical models, such as the theory of 'rational inattention', which has studied how it was rational not to consider all available information. Modifying the simplistic assumption that a rational consumer was able to extract all relevant information could be disruptive. Mainly, it was crucial for the perspectives of financial regulators and consumer protection authorities.

Neuroeconomic studies on the issue usually exploited the eye-tracking method to capture how the consumer's brain distributed attention to different visual stimuli. The eye-tracking method allowed to overcome the problem of self-reported measures of attention, which might be unreliable and non-objective (Camerer et al., 2005). We reviewed three examples.

First, in their 2014 study, Hüsser and Wirth examined the effectiveness of a disclaimer mandated by the Securities and Exchange Commission (SEC) in mutual fund disclosures. This disclaimer aimed to counter 'extrapolation bias' – the mistaken belief in the persistence of past performance. Despite explicitly stating that past performance lacked predictive value and that price changes followed a 'random walk', the disclaimer failed to correct investor behaviour. The experiment involved presenting different versions of a fund prospectus to 100 students. One group received the complete prospectus with a 5-year performance chart and the disclaimer, while another group saw only the performance chart. A third group, serving as a control, received no performance data or disclaimer. Subsequently, participants were asked about their willingness to invest in the fund. Results indicated that past fund performance attracted significant visual attention; additionally, the more attention investors devoted to past performance data, the stronger their intention to purchase. Surprisingly, despite the fact that the disclaimer was the presence of the disclaimer did not mitigate this bias, suggesting its ineffectiveness in reducing extrapolation bias.

Second, Ceravolo et al. (2019b) focused their attention on the Key Investor Information Document (KIID), a document with basic information on mutual fund products that in the European Union has to be presented to investors to allow them to make informed investment decisions, avoid information overload, and ensure a higher level of comprehensibility and comparability. In their study, 19 students were presented with 24 KIIDs, for each of which they were asked to provide a rating. The authors designed four fictitious KIID formats: the structure of the KIID was designed so that the four parts that make up the document (i.e., objective and investment policy; fees; risk and return; past performance) were placed in different locations. It was found that the format had no effect on the subjects' reading path. On average, subjects explored the documents in the same order for each format, i.e., they scanned from top left to top right, bottom left, and bottom right. Notably, the different formats affected the time devoted to each KIID and, even more importantly, their perceived attractiveness. Low-risk products were perceived as attractive when the KIID began with the objectives section or the performance section. In contrast, if the ‘costs and fees’ section was addressed first, this had a negative impact on subjects' attractiveness ratings. In summary, the results showed a clear correlation between the design of the documents and their financial attractiveness.

Finally, Ceravolo et al. (2021) investigated whether subjects base their evaluation on certain elements (leading to biased financial decisions) when trying to extract information from the document created in the European Union for the disclosure of information on payment account fees (called Fee Information Document, FID). They performed a visual search strategy using eye-tracking on 70 subjects, who were shown two FIDs and asked to choose between them. They observed that subjects showed systematic visual anchoring to the upper part of the document corresponding to the ‘Liquidity’ section, where the annual fee was displayed. To test the strength of this anchoring effect, each FID was constructed to create a contrast between the desirability of the payment account based only on the annual fee, and that based on the entire set of fees. The results showed that subjects sometimes failed to recognize the most advantageous products, which was especially the case when the annual fee was high, even if the other fees offset that amount. The data also showed the role of financial literacy in regulating attention, as subjects with low financial literacy were more prone to anchoring errors.

7. Conclusions

This paper reviews the history and debate on neuroeconomics, describes the main brain imaging techniques applied in neuroeconomic studies, and provides an overview of a wide range of works in neurofinance. The goal is to contribute to the knowledge and understanding of this new branch of economics, even in the institutional context of economic, regulatory and supervisory authorities. The main contribution of our work stands in two conclusions.

First, our review briefly summarizes the neuroeconomic critique to traditional economists, and the main criticisms of traditional economists to neuroscientists. We remind that the academic dispute has often been intense, and that, according to the prevailing views, neuroeconomics is very unlikely to revolutionize economics. However, our review also points out that both critics and advocates of neuroeconomics acknowledge that neuroscience can provide a relevant contribution to traditional analyses. Economics is a dismal science, but also very inclusive. Over the centuries, there has been plenty of room for interdisciplinarity: philosophers, mathematicians, historians, lawyers, sociologists, political scientists, statisticians, and, in recent decades, engineers, physicists. Why should not there also be room for psychologists, physicians and finally (?) neurologists and neuroscientists?

In particular, our review emphasizes that the contribution of neuroeconomics can be especially relevant in applied economics, where it can furnish new variables and data, which in turn can be used into otherwise conventional economic analyses. Neuroscience can measure variables even when other data sources are unavailable, also contributing in this way to overcome or at least limit problems of omitted variables, which always worry applied economists. Neuroscience can also measure variables when other data sources are unreliable or biased, as is often the case with surveys and self-reports. In this way neuroeconomics can improve the understanding of decisions, especially of customer decisions, and then help refine the suggestions that the analysis brings to regulators and supervisors, especially for customer protection purposes. Traditional economics makes abundant use of formal models that assume that agents make a rational and efficient use of whatever information is available. While such assumptions are extremely useful for describing and studying crucial features of the real economy, nobody believes them literally. It is now commonly recognized that, when taking decisions, people regularly deviate from certain canons of rationality and find difficult to use information. A better understanding of customers' decision-making processes, and specific choices, may be superfluous in certain analyses but become very useful in others, in particular when the task is reflecting upon the best ways to regulate market conduct in legal detail, and when looking for policies to safeguard the fair conduct of financial institutions.

Second, our paper reviews a broad selection of papers. Among the impressive number of scientific papers that each year deal with the brain and decision making, a relevant part is devoted to neurofinance and consumer neuroscience. The works we reviewed allow to gather useful insights on financial actors, and on their 'irrational' behaviour and on the deep mechanism that guide consumer's actions. Neuromarketing experts are likely to exploit those features of customer decisions, and develop ways to profit from them. Also regulators and supervisors, especially in the area of customer protection, can benefit from a better understanding of consumer behaviour, in order to ensure the fair functioning of the market and the fair conduct of sellers.

The rationale for establishing and developing regulatory and supervisory systems in the area of customer protection already owes much to the disciplines delving into the decision-making processes. Neuroeconomics strengthens our understanding of consumers' and investors' behaviour, thus enhancing our ability to tailor a more effective consumer protection framework and potentially reinforcing supervision operational practices, financial education initiatives and campaigns, and even the legislative process. Many studies of neuroeconomics revealed the emotive sources of the irrational behaviour of financial investors and consumers. These evidences can help financial protection authorities to better design, for example, the pre-contractual information and documents or to better design financial education courses, arming investors with awareness of the biases at play in their decision-making processes, also referring to specific biases arising while using specific products. Likewise, neuroeconomic experiments are able to offer a direct means to assess the effectiveness of consumer protection practices even before their legal enforcement. In principle, regulators could also use such evidence to nudge individuals towards the choice that is in their best interest.

Notably, our review points to directions for future research. First, it shows that in many cases neuroeconomic studies fail to address explicitly the policy implications of the analysis, especially exactly when these have consumer protection implications, which increases the scope for academic and institutional cooperation in realizing the potential of the new discipline. Second, our review also shows that, although the literature of neurofinance has touched, to various degrees, different topics, from household finance, individual and aggregate trading behaviour, payment systems, information in financial documents, there is still much to be done, in particular on the decisions of bank and financial clients.

References

Agarwal, S. and Dutta, T. (2015). "Neuromarketing and consumer neuroscience: current understanding and the way forward." *Decision*, 42, 457–462.

Antenucci, D., Franceschi F., and Repaci G. (2024). "The role of behavioural economics and neurofinance in financial consumer protection policy." *Bank of Italy, Occasional Paper (Questioni di Economia e Finanza)*, 890.

Bandettini, P.A., Wong, E.C., and Hinks, R.S. (1992). "Time course EPI of human brain function during task activation." *Magnetic Resonance in Medicine*, 25, 390–397.

Banker, S., Dunfield, D., Huang, A., and Prelec, D. (2021). "Neural mechanisms of credit card spending." *Scientific Reports*, 11(1), 4070.

Barberis, N. and Thaler, R. (2002). "A Survey of Behavioral Finance." *NBER Working Paper No. w9222*

Barberis, N. and Xiong, W. (2009). "What drives the disposition effect? An analysis of a long-standing preference-based explanation." *Journal of Finance*, 64, 751–784.

Barberis, N. and Xiong, W. (2012). "Realization utility." *Journal of Financial Economics*, 104, 251–271.

Bartra, O., McGuire, J. T., and Kable, J. W. (2013). "The valuation system: A coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value." *NeuroImage*, 76, 412–427.

Bell, L., Vogt, J., Willemse, C., Routledge, T., Butler, L. T., and Sakaki, M. (2018). "Beyond Self-Report: A Review of Physiological and Neuroscientific Methods to Investigate Consumer Behavior." *Frontiers in Psychology*.

Ben-David, I. and Graham, J.R. (2013). "Managerial miscalibration." *Quarterly Journal of Economics*, 128, 1547–1584.

Bernheim, B.D. (2009). "On the potential of neuroeconomics: A critical (but hopeful) appraisal." *American Economic Journal: Microeconomics*, 1(2), 1–41.

Borawska, A. (2016). "Neuroscience Techniques in Economic Experiments." in Nermend, K. and Łatuszyńska, M. (Eds.), *Selected Issues in Experimental Economics* (125-133), Springer.

Bossaerts, P. and Murawski, C. (2015). "From behavioural economics to neuroeconomics to decision neuroscience: The ascent of biology in research on human decision making." *Current Opinion in Behavioural Sciences*, 5, 37–42.

Breiter, H.C., Aharon, I., Kahneman, D., Dale, A., and Shizgal, P. (2001). "Functional imaging of neural responses to expectancy and experience of monetary gains and losses." *Neuron*, 30(2), 619-639.

Brooks, A.M., M. Capra and Burns, G.S. (2012). "Neural Insensitivity to Upticks in Value is Associated with the Disposition Effect." *Neuroimage*, 59(4), 4086–4093.

Bruguier, A.J., Quartz, S.R., and Bossaerts, P. (2010). "Exploring the Nature of 'Trader Intuition." *Journal of Finance*, 65, 1703–1723.

Camerer, C.F., T.H. Ho, and Chong, J.K. (2004). "A Cognitive Hierarchy Model of Games." *Quarterly Journal of Economics*, 119(3), 861–98.

Camerer, C.F., Loewenstein, G., and Prelec, D. (2005). "Neuroeconomics: How Neuroscience Can Inform Economics." *Journal of Economic Literature*, 43(1), 9–64.

Camerer, C.F. (2007). "Neuroeconomics: Using Neuroscience to Make Economic Predictions." *Economic Journal*, 117(519), C26–42.

Camerer, C.F. (2008). "The case for mindful economics." in Caplin, A. and Schotter, A. (Eds.), *Foundations of positive and normative economics* (42-69), New York: Oxford University Press.

Campbell, J.Y. (2016). "Restoring rational choice: the challenge of consumer financial regulation." *American Economic Review*, 106, 1-30.

Caplin A. and Dean, M. (2008). "Dopamine, reward prediction error, and economics". *The Quarterly Journal of Economics*, 123(2), 663–701.

Ceravolo, M. G., Fabri, M., Fattobene, L., Polonara, G., and Raggetti, G. (2019). "Cash, Card or Smartphone: The Neural Correlates of Payment Methods." *Frontiers in Neuroscience*, 13, 1188.

Ceravolo, M.G., Farina, V., Fattobene, L., Leonelli, L., and Raggetti, G. (2019b). "Presentational format and financial consumers' behaviour: an eye-tracking study." *International Journal of Bank Marketing*, 37(3), 821-837.

Ceravolo, M.G., Farina, V., Fattobene, L., Leonelli, L., and Raggetti, G. (2021). "Anchoring Effect in Visual Information Processing During Financial Decisions: An Eye-Tracking Study." *Journal of Neuroscience, Psychology, and Economics*, 15(1), 19-30.

Charron, S., Fuchs, A., and Oullier, O. (2008). "Exploring brain activity in neuroeconomics." *Revue d'économie politique*, 118, 97-124.

Christopoulos, G.I., Tobler, P.N., Bossaerts, P., Dolan, R.J., and Schultz, W. (2009). "Neural correlates of value, risk, and risk aversion contributing to decision making under risk." *J. Neurosci.*, 29, 12574–12583.

Clithero, J. A. and Rangel, A. (2014). "Informatic parcellation of the network involved in the computation of subjective value". *Social Cognitive and Affective Neuroscience*, 9(9), 1289–1302.

Da Costa Jr, N., Goulart, M., Cupertino, C., Macedo Jr, J., and Da Silva, S. (2013). "The disposition effect and investor experience." *Journal of Banking and Finance*, 37(5), 1669-1675.

De Martino, B., O' Doherty, J.P., Ray, D., Bossaerts, P., and Camerer, C. F. (2013). "In the mind of the market: theory of mind biases value computation during financial bubbles." *Neuron*, 79, 1222–1231.

de Quervain, D. J., Fischbacher, U., Treyer, V., Schellhammer, M., Schnyder, U., Buck, A., and Fehr, E. (2004). "The neural basis of altruistic punishment." *Science*, 305(5688), 1254-1258.

Dean, M. (2013). "What Can Neuroeconomics Tell Us About Economics (and Vice Versa)?" in Zentall, D.R. and Crowley, P.H. (Eds.), *Comparative Decision Making* (251-268), New York: Oxford Academic.

DellaVigna, S. (2009). "Psychology and economics: Evidence from the field." *Journal of Economic Literature*, 47, 315–72.

Dhar, R. and Zhu, N. (2006). "Up close and personal: Investor sophistication and the disposition effect." *Management Science*, 52, 726–40.

Dorow, A., Da Costa Jr, N., Takase, E., Prates, W., and Da Silva, S. (2018). "On the neural substrates of the disposition effect and return performance.", *Journal of Behavioral and Experimental Finance*, 17, 16-21

Efremidze, L., Sarraf, G., Miotto, K. and Zak, P.J. (2017). "The neural Inhibition of Learning Increases Asset Market Bubbles: Experimental Evidence." *Journal of Behavioural Finance*, 18:1, 114-124.

Engelmann, J.B., Mulckhuyse, M., and Ting, C.C. (2019). "Brain Measurement and Manipulation Methods." in Schram, A. and Aljaž, U. (Eds.), *Handbook of Research Methods and Applications in Experimental Economics* (142-172), Cheltenham: Edward Elgar.

Erk, M., Spitzer, A.P., Wunderlich, L., Galley, H., and Walter, H. (2002). "Cultural objects modulate reward circuitry." *Neuroreport*, 13, 2499–2503.

Fama, E.F. (1965). "Random walks in stock market prices." *Financial Analysts Journal*, 21(5), 55–59.

Fama, E.F. (1970). "Efficient capital markets: A review of theory and empirical work." *Journal of Finance*, 25(2), 383–417.

Feng, L. and Seasholes, M.S. (2005). "Do investor sophistication and trading experience eliminate behavioural biases in financial markets?" *Review of Finance*, 9, 305–351.

Flood, R.P. and Garber, P.M. (1980). "Market fundamentals versus price-level bubbles: The first tests." *Journal of Political Economy*, 88(4), 745–770.

Francis, B., Hasan, I., Wu, Q., and Yan, M. (2014). "Are female CFOs less tax aggressive? Evidence from tax aggressiveness." *Journal of American Taxation Association*, 36, 171–202.

Frazzini, A. (2006). "The disposition effect and underreaction to news." *Journal of Finance*, 61, 2017–2046.

Frydman, C., Barberis, N., Camerer, C.F., Bossaerts, P., and Rangel, A. (2014). "Using neural data to test a theory of investor behavior: An application to realization utility." *Journal of Finance*, 69, 907–946.

Frydman, C. and Camerer, C. (2016). "Neural Evidence of Regret and Its Implications for Investor Behavior." *Review of Financial Studies*, 29(11), 3108-3139.

Fumagalli, R. (2010). "The disunity of neuroeconomics: A methodological appraisal." *Journal of Economic Methodology*, 17(2), 119–131.

Gallagher, H.L. and Frith, C.D. (2003). "Functional imaging of ‘theory of mind’." *Trends Cogn. Sci.*, 7, 77–83.

Genesove, D. and C. Mayer, (2001). "Loss aversion and seller behavior: Evidence from the housing market." *Quarterly Journal of Economics*, 116, 1233–1260.

Gintis, H. (2004). Towards the unity of the human behavioral sciences. *Politics, Philosophy and Economics, 3*(1), 37-57.

Glimcher, P.W. and Rustichini, A. (2004). "Neuroeconomics: The consilience of brain and decision." *Science*, 306(5695), 447–452.

Glimcher, P.W. and Fehr, E. (2013). *Neuroeconomics: Decision making and the brain.* San Diego: Academic Press.

Grinblatt, M. and Keloharju M. (2001). "What makes investors trade?" *Journal of Finance*, 56, 589–616.

Gul, F. and Pesendorfer, W. (2005). "The Case for Mindless Economics," *ResearchGate working paper*.

Gul, F. and Pesendorfer, W. (2011). "The Case for Mindless Economics." in Caplin, A. and Schotter, A. (Eds.) *The Foundations of Positive and Normative Economics: A Hand Book.* Oxford University Press.

Hare, T. A., Schultz, W., Camerer, C. F., O'Doherty, J. P., and Rangel, A. (2011). "Transformation of stimulus value signals into motor commands during simple choice". *Proceedings of the National Academy of Sciences*, 108(44), 18120–18125.

Harrison, G.W. (2008). "Neuroeconomics: A critical reconsideration." *Economics and Philosophy*, 24, 303–344.

Houser, D. and McCabe, K. (2009). "Experimental Neuroeconomics and Non-cooperative Games." in Glimcher, P.W., Camerer, C.F., Fehr, E., and Poldrack, R.A. (Eds.) *Neuroeconomics* (77-103), Academic Press.

Hubert, M., and Kenning, P. (2008). "A current overview of consumer neuroscience." *Journal of Consumer Behaviour*, 7, 272–292.

Hüsser, A. P. and Wirth, W. (2014). "Do investors show an attentional bias toward past performance? An eye-tracking experiment on visual attention to mutual fund disclosures in simplified fund prospectuses." *Journal of Financial Services Marketing*, 19, 169-185.

Ingersoll, J.E. and Jin, L.J. (2013). "Realization Utility with Reference-Dependent Preferences" *the Review of Financial Studies*, 26(3), 723-767

Jin, L. and Scherbina A. (2011). "Inheriting losers." *Review of Financial Studies,* 24, 786–820.

Kable, J.W. (2011). "The cognitive neuroscience toolkit for the neuroeconomist: A functional overview." *Journal of Neuroscience, Psychology, and Economics*, 4(2), 63-84.

Kahneman, D. and Tversky, A. (1979). "Prospect Theory: An Analysis of Decision under Risk." *Econometrica,* 47(2), 263–291.

Kahneman, D. (1994). "New challenges to the rationality assumption." *Journal of Institutional and Theoretical Economics,* 150, 18—36.

Kahneman, D. (2003). “Maps of Bounded Rationality: Psychology for Behavioral Economics.” *The American Economic Review*, 93(5), 2003, 1449–1475.

Kahneman, D. (2011), “Thinking, Fast and Slow”, New York: Farrar, Straus, and Giroux.

Karmarkar, U.R. and Plassmann, H. (2019). "Consumer Neuroscience: Past, Present, and Future." *Organizational Research Methods*, 22(1), 174–195.

Kanayet F. J., Opfer J. E., and Cunningham W. A. (2014). “The value of numbers in economic rewards”. *Psychological Science*, 25, 1534–1545.

Kaustia, M. (2010). "Prospect theory and the disposition effect." *Journal of Financial and Quantitative Analysis*, 45, 1–36.

Kindleberger C.P. and Aliber, R.Z. (2005). *Manias, Panics, and Crashes: A History of Financial Crises*. Wiley.

Knutson, B. and Cooper, J.C. (2005). "Functional magnetic resonance imaging of reward prediction." *Curr Opin Neurol.*, 18(4), 411-7.

Knutson, B., Rick, S., Wimmer, G. E., Prelec, D., and Loewenstein, G. (2007). "Neural predictors of purchases." *Neuron*, 53(1), 147–156.

Knutson, B., Wimmer, G.E., Kuhnen, C.M., and Winkielman, P. (2008). "Nucleus accumbens activation mediates the influence of reward cues on financial risk taking." *Neuroreport.*, 19(5), 509-13.

Konovalov, A. and Krajbich, I. (2019). "Over a Decade of Neuroeconomics: What Have We Learned?" *Organizational Research Methods*, 22(1), 148–173.

Krueger, F., Grafman, J., and McCabe, K. (2008). "Neural correlates of economic game playing." *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, 3859–3874.

Kuhnen, C.M. and Knutson, B. (2005). "The neural basis of financial risk taking." *Neuron*, 47(5), 763-70.

Kwong, K. K., Belliveau, J. W., Chesler, D. A., Goldberg, I. E., Weisskoff, R. M., Poncelet, B. P., Kennedy, D.N., Hoppel, B.E., Cohen, M.S., and Turner, R. (1992). “Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation.” *Proceedings of the National Academy of Sciences of the United States of America*, 89(12), 5675-5679.

Lajante, M. and Ladhari, R. (2019). "The promise and perils of the peripheral psychophysiology of emotion in retailing and consumer services." *Journal of Retailing and Consumer Services*, 50(C), 305-313.

Larcker, D.F. and Zakolyukina, A.A. (2012). "Detecting deceptive discussions in conference calls." *J. Account. Res.*, 50, 495–540.

Levine, D. (2011). "Neuroeconomics?" *International Review of Economics*, 58(3), 287-305.

Lim, W.M. (2018). "Demystifying neuromarketing." *Journal of Business Research*, 91, 205-220.

Liu, Z. and de Goeij, P. (2020). “Using eye-tracking to understand individual decision-making,” *Netspar Survey Paper 57, Network Studies on Pensions, Aging and Retirement*.

Lo, A.W. and Repin, D.V. (2002). “The Psychophysiology of real-time financial risk processing” *Journal of Cognitive Neuroscience*, 14(3), 323-339.

Malmendier, U., Tate, G., and Yan, J. (2011) "Overconfidence and early-life experiences: the effect of managerial traits on corporate financial policies." *Journal of Finance*, 66, 1687–1733.

Marchionni, C. and Vromen, J. (2010). "Neuroeconomics: Hype or hope?" *Journal of Economic Methodology*, 17(2), 103–106.

Markowitz, H. (1952). “Portfolio Selection” *The Journal of Finance*, 7(1), 77-91.

Mazar, N., Plassmann, H., Robitaille, N., and Lindner, A. (2016). "Pain of Paying? — A Metaphor Gone Literal: Evidence from Neural and Behavioral Science." *Rotman School of Management Working Paper No. 2901808, INSEAD Working Paper No. 2017/06/MKT*.

McCabe, K., Houser, D., Ryan, L., Smith, V., and Trouard, T. (2001). "A functional imaging study of cooperation in two-person reciprocal exchange." *Proceedings of the National Academy of Sciences of the United States of America*, 98, 11832–11835.

McClure, S. M., Berns G. S., and Montague P. R. (2003). “Temporal prediction errors in a passive learning task activate human striatum”. *Neuron*, 38(2), 339–346.

McClure, S.M., Li, J., Tomlin, D., Cypert, K.S., Montague, L.M., and Montague, P.R. (2004). "Neural correlates of behavioral preference for culturally familiar drinks." *Neuron*, 44(2), 379-387.

Mohr, P.N.C., Biele, G. and Heekeren, H.R. (2010). "Neural processing of risk." *J. Neurosci.*, 30, 6613–6619.

Nadler, A., Jiao, P., Johnson, C.J., Alexander, V., and Zak, P.J. (2018) "The Bull of Wall Street: Experimental Analysis of Testosterone and Asset Trading." *Management Science*, 64(9), 4032-4051.

O’Doherty, J. P., Dayan, P., Friston, K., Critchley, H., and Dolan, R. J. (2003). “Temporal difference models and reward-related learning in the human brain”. *Neuron*, 38(2), 329–337.

Odean, T. (1998). "Are investors reluctant to realize their losses?" *Journal of Finance*, 53, 1775–1798.

Ogawa, S., Tank, D. W., Menon, R., Ellermann, J. M., Kim, S. G., Merkle, H., and Ugurbil, K. (1992). “Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging.” *Proceedings of the National Academy of Sciences of the United States of America*, 89(13), 5951-5955.

Paulus, M.P., Rogalsky, C., Simmons, A., Feinstein, J.S., and Stein, M.B. (2003). “Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism.” *Neuroimage*, 19(4), 1439-1448.

Prelec, D. and Loewenstein, G. F. (1998). "The red and the black: Mental accounting of savings and debt." *Marketing Science*, 17, 4–28.

Preuschoff K., Bossaerts P., and Quartz S.R. (2006). "Neural differentiation of expected reward and risk in human subcortical structures." *Neuron*, 51, 381–390.

Preuschoff K., Quartz S.R., and Bossaerts P. (2008). "Human insula activation reflects risk prediction errors as well as risk." *J. Neurosci.*, 28, 2745–2752.

Rubinstein, A. (2008). "Comments on neuroeconomics." in *Economics and Philosophy* (485-494), 24, Cambridge University Press.

Rustichini, A. (2005). “Neuroeconomics: Present and Future.” *Games and Economic Behavior*, 52(2), 201-212.

Rutledge, R. B., Dean, M., Caplin, A., and Glimcher, P. W. (2010). “Testing the reward prediction error hypothesis with an axiomatic model”. *The Journal of Neuroscience*, 30(40), 13525–13536.

Sanfey, A.G., Rilling, J.K., Aronson, J.A., Nystrom, L.E., and Cohen, J.D. (2003). "The neural basis of economic decision-making in the Ultimatum Game." *Science*, 300(5626), 1755-1758.

Schultz, W., Dayan, P., and Montague, P. R. (1997). “A neural substrate of prediction and reward.” *Science*, 275(5306), 1593–1599.

Serra, D. (2020). "Neuroeconomics: reliable, scientifically legitimate and useful knowledge for economists?" *Working Papers hal-02956441*.

Shefrin, H. and M. Statman. (1985). "The disposition to sell winners too early and ride losers too long: Theory and evidence." *Journal of Finance*, 40, 777–790.

Signorini, L.F. (2019), “Opening Remarks,” *Banca d’Italia-FinCoNet international seminar on Behavioural insights for conduct supervision, Rome*, 15 November.

Smith, A., Lohrenz, T., Jing, J., Montague, P.R., and Camerer, C.F. (2014) "Irrational exuberance and neural crash warning signals during endogenous experimental market bubbles." *Proc. Natl. Acad. Sci.*, 111, 10503–10508.

Smith, K., Dickhaut, J., McCabe, K., & Pardo, J. V. (2002). "Neuronal substrates for choice under ambiguity, risk, gains, and losses." *Management Science*, 48, 711–718.

Strahilevitz, M., Barber, B.M., and Odean, T. (2011). "Once burned, twice shy: How naive learning, counterfactuals, and regret affect the repurchase of stocks previously sold." *Journal of Marketing Research*, 48, 102–120.

Sutton, R.S. and Barto, A.G. (1998). "Reinforcement Learning: An Introduction," *IEEE Transactions on Neural Networks*, 9(5), 1054-1054.

Symmonds M., Bossaerts P., and Dolan R.J. (2010). "A behavioural and neural evaluation of prospective decision making under risk." *J. Neurosci.*, 30, 14380–14389.

Talpsepp, T., Vlcek, M. and Wang, W. (2014). "Speculating in Gains, Waiting in Losses: An Experimental Study on the Disposition Effect." *Journal of Behavioral and Experimental Finance*, 2, 31-43.

Toma, F.-M. and Miyakoshi, M. (2021). "Left Frontal EEG Power Responds to Stock Price Changes in a Simulated Asset Bubble Market." *Brain Sci.*, 11, 670.

Vaidya, A.R., Pujara, M.S., Petrides, M., Murray, E.A., and Fellows, L.K. (2019). "Lesion studies in contemporary neuroscience." *Trends in Cognitive Sciences*, 23(8), 653-671.

van der Wel, P., and van Steenbergen, H. (2018). "Pupil dilation as an index of effort in cognitive control tasks: A review." *Psychonomic Bulletin & Review*, 25(6), 2005-2015.

Viale, R., Mousavi, S., Alemanni, B. and Filotto, U. (2018), “The behavioural finance revolution.” Edward Elgar Publishing.

Visco, I. and Zevi, G. (2021). "Bounded rationality and expectations in economics." in Viale, R. (Ed.), *Handbook of bounded rationality* (459-470). London:Routledge.

Vromen, J. (2011). "Neuroeconomics: Two camps gradually converging: What can economics gain from it?" *International Review of Economics*, 58, 267–285.

Walsh, V. and Cowey, A. (2000). "Transcranial magnetic stimulation and cognitive neuroscience." *Nature Reviews Neuroscience*, 1(1), 73-79.

Weber, M. and Camerer, C.F. (1998). "The disposition effect in securities trading: An experimental analysis." *Journal of Economic Behavior & Organization*, 33, 167-184.

Wunderlich, K., Symmonds, M., Bossaerts, P., and Dolan, R.J. (2011). "Hedging your bets by learning reward correlations in the human brain." *Neuron*, 71(6), 1141-1152.

Xue, G., Chen, C., Lu, Z.-L., and Dong, Q. (2010). "Brain Imaging Techniques and Their Applications in Decision-Making Research." *Xin Li Xue Bao*, 42, 120-137.

Yu, H., Liang, Y., Wang, A., Fan, Q., and Jin, J. (2022). "Pay online or pay on delivery? An ERP study of how payment methods affect online purchase decisions for search vs. experience products." *Journal of Economic Psychology*, 91, 102526.

Zevi, G. (2018). "Recent advances in behavioural macroeconomics and lessons for policymakers." in *The behavioural finance revolution* (108-113). United Kingdom:Edward Elgar Publishing.