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A systematic review of the main anomalies in intertemporal choice

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ABSTRACT

Research in the field of intertemporal choice has been growing in recent decades and its contribution is increasingly recognized in various disciplines such as Economics, Psychology, Neuroscience, Medicine, and Political Sciences. This extensive research has mainly focused on the analysis of the anomalies of the DU model, both from an empirical point of view, through the conduct of experiments, and from a theoretical point of view, through the proposal of psychological explanations and alternative models. Given the developments observed in the study of intertemporal choice, it is necessary to identify the contributions which have been provided so far. Therefore, the aim of this paper is to offer a systematic review of the existing literature on anomalies in intertemporal choice which allows researchers from different disciplines to understand the main works in the last 30 years and to be aware of the main gaps and current trends in research. Moreover, some future lines of research are proposed.

1. Introduction

Intertemporal choice is the financial process in which decision-makers presented with two or more outcomes available at different moments in time consider which is their best option (Loewenstein et al., 2003). There are many real situations involving intertemporal choices, such as deciding between spending a certain amount of money today and saving to spend it later; or whether to stop smoking in order to enjoy better health in the future. Intertemporal choice does not only arise in individual preferences. It also affects collective decisions, for example in the areas of health, education, environmental protection, taxation policies, etc.

Early research on intertemporal choice focused on the psychological and social determinants of decision-making. Later, in 1937, Samuelson's Discounted Utility (DU) model emerged, unifying all these factors around a mathematical parameter: the discount rate (Samuelson, 1937). After this, the exponential model became the main paradigm for the evaluation of intertemporal choices. However, from the 1980s onwards, a number of criticisms about this model emerged due to inconsistencies or anomalies shown by decision-makers in numerous empirical studies (Thaler, 1981; Loewenstein, 1988; Green et al., 1997). The main anomalies are the magnitude effect, the delay effect, the sign effect, the sequence effect, the date-delay effect, the delay/speed-up asymmetry, and the interval effect.

Intertemporal choice is a growing multidisciplinary area of research, i.e., it has been analyzed in different fields, including Economics, Psychology, Neuroscience, Medicine, and Political Sciences. In its early days, at the end of the 19th century and beginning of the 20th, this area was mainly investigated by psychologists. Later, after the proposal of the DU model, economists focused their interest on the mathematical analysis of intertemporal choices. However, it was not until the 1990s when an important proliferation of economic, psychological and combined economic-psychological papers appeared. Finally, with the new century, the first neurological, medical, and political science articles on this subject were published.

In the last 30 years, an extensive investigation has been carried out on these anomalies, both from an empirical point of view (Loewenstein and Prelec, 1991; Chapman, 2000), through their analysis by using experiments, and from a theoretical point of view (Loewenstein and Prelec, 1992; Takahashi and Han, 2012) with the proposal of alternative explanatory models. This has led to an increase in the number of publications, possibly stimulated by the Nobel prizes recently granted in the field of Behavioural Economics. Taking into account the recent advances in the study of intertemporal choice, and that the last review of the literature on anomalies was presented by Frederick (Frederick et al., 2002), it is necessary to consider the new contributions on this topic. Therefore, the aim of this work is to carry out a systematic review of the existing literature on anomalies in intertemporal choice which allows

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researchers from different disciplines to be aware of the main works in the last three decades and to be familiar with the main gaps and trends in research on the subject.

The structure of this paper is as follows: Firstly, Section 2 describes the anomalies in intertemporal choice, which is the focus of this systematic review. In Section 3, the methodology employed for the systematic review of relevant literature is defined. Section 4 provides a descriptive analysis of the papers and Section 5 identifies the main contributions. Finally, Section 6 proposes several lines of future research and Section 7 summarizes and concludes.

2. Background

Samuelson (Samuelson, 1937) proposed that it was possible to obtain an accurate measure of an individual's marginal utility by assuming that his/her tastes and the price of goods remained constant over time. In effect, the DU model was based on the following assumptions: utility can only be measured as marginal, individuals behave maximizing their future utilities, and these are discounted at a constant rate. This model was very popular among economists because of its simplicity and similarity to the present financial value and to actuarial models. As a result, it has become a normative model.

Intertemporal choice anomalies are defined as those individual behaviours which contradict the assumptions of the DU model. Thaler (Thaler, 1981) was the first scholar to demonstrate the presence of such anomalies. His study revealed that individuals did not hold their preferences constant, but that these changed over time and depended on the amount. Moreover, he showed different preferences when considering gains and losses. These results were confirmed and extended by many subsequent studies, showing the presence of other anomalies.

On the one hand, research on the anomalies in intertemporal choice focuses on the empirical demonstration of these paradoxes by observing human/non-human behaviour in different types of decision, using different methodologies, and considering different social and psychological factors. On the other hand, from a theoretical point of view, psychological theories have been proposed to explain these anomalies, as well as mathematical explanations supported by discount functions and their properties.

The main anomalies in delay discounting are defined below. The **magnitude effect** is a bias present in intertemporal choice which means that multiplying the magnitude of the outcome by a constant factor greater than 1 may reverse the preference from the smaller, earlier option to the larger, later one. For example, someone may prefer $10 now to $20 in 1 year, but also $200 in 1 year to $100 now. So, the magnitude effect is characterized by a higher discount rate for small rewards than for large ones (Kirby et al., 1999; Schoenfelder and Hantula, 2003; Andersen et al., 2013).

The **delay effect** is an anomaly of intertemporal choice in which, as the deferral of both options is increased by a constant, there is a reversal of preferences from the smaller, sooner outcome to the larger, later one. It is therefore also known as preference reversal (Green et al., 1994; Kirby and Herrnstein, 1995; Bocquého et al., 2013). For example, someone might prefer $10 today to $20 in one year, but if the time horizon of both preferences is increased by 2 years, then someone might prefer $20 in 3 years to $10 in 2 years. Therefore, the temporal discount rate decreases as the time until receipt of the reward increases. A specific case of the delay effect is the immediacy effect, in which more immediate options are given a greater weight. Thus, the highest discount rates apply for shorter delays (Kirby and Herrnstein, 1995; Scholten and Read, 2013; Green et al., 2005).

The **sign effect** or gain-loss asymmetry consists in higher discount rates for decisions involving gains than those involving losses. For example, a gain of $100 at the present time may be indifferent to a gain of $200 in a year, but a loss of $100 at the present time would also be seen as the same as a loss of $150 in a year. In this example, it can be seen that gains are discounted more than losses (Benzion et al., 1989; Chapman and Winquist, 1998; Estle et al., 2006).

The **delay/speed-up asymmetry** implies higher discount rates for decisions involving delayed rewards than for decisions involving immediate rewards (Benzion et al., 1989; Shelley, 1993; Malkoc and Zauberman, 2006). Loewenstein (Loewenstein, 1988) demonstrated that individuals were willing to pay $54 to receive a video player immediately, when reception was scheduled after one year, but those who were to receive it immediately were willing to pay $126 to postpone receipt by one year.

The **sequence effect** displays a preference for sequences of increasing outcomes. Thus, whilst for individual outcomes there is a positive time preference, for sequences there is a negative time preference (Loewenstein and Prelec, 1991; Chapman, 2000). Chapman (Chapman, 1996) showed that, in the short term, decision-makers prefer increasing sequences of money and health, because they expect to improve their position in the long term. For very long-term sequences in monetary decisions, they still prefer increasing sequences; however, in the health area, they prefer decreasing sequences, as they expect to experience health problems with the passage of time.

The **date-delay effect** implies that future outcomes are discounted at higher rates when time is described as an extent of time (e.g., six months), than when it is expressed as a calendar date (e.g., October 17). This anomaly was discover by Read (Read et al., 2005).

The **interval effect** consists in the fact that the discount rate will be higher the closer the rewards are in time. For example, a decision-maker may be indifferent between receiving $100 in 6 months or $150 in 12 months (the interval is 6 months) but would wait to receive $200 in 18 months rather than $100 in 6 months (the interval is now 12 months).

In choices with uncertainty, some anomalies also arise thus contradicting the axioms of the Expected Utility (EU) model. Traditionally, the analysis of decisions in the contexts of intertemporal choice and choice with uncertainty has been carried out separately. However, recent papers (Cruz Rambaud and Sánchez Pérez, 2018) have analyzed the parallelism between the DU and EU models. Therefore, it is necessary to consider them in this study as a part of the research on intertemporal choice anomalies.

Loewenstein and Prelec (Loewenstein and Prelec, 1992) and Prelec and Loewenstein (Prelec and Loewenstein, 1991) were among the first scholars to observe that some effects in intertemporal choice are similar to those presented in choices with uncertainty, although their behaviour is different. For example, the amount of the reward affects differently the degree of discount depending on whether the reward is delayed or probabilistic. Thus, in the case of delay discounting, larger rewards are discounted less abruptly than smaller ones (Thaler, 1981; Green et al., 1997; Kirby, 1997) whilst, in the case of probability discounting, the opposite occurs; larger rewards are discounted more abruptly than smaller ones (Green et al., 1999).

The anomalies in the expected utility model, comparable to intertemporal choice effects, are explained now.

The **"peanuts" effect** occurs when increasing the magnitude of the outcome by a constant factor shifts preferences from the larger, less likely reward to the smaller but more likely reward (Cruz Rambaud and Sánchez Pérez, 2018; Chapman and Weber, 2006). In this case, someone might prefer to receive $2 with a 50% probability to $1 for sure but might also prefer $100 for sure to $200 with a 50% probability. In other words, decision-makers are more risk-averse as the magnitude increases, so they are more willing to take risks for small rewards. The "peanuts" effect is the reversal of the magnitude effect for probabilistic reward.

The **common ratio effect** is the effect parallel to the delay effect in choices with uncertainty. In this case, the reduction of probabilities for both options by a common ratio results in a shift in preferences from smaller and more likely to larger and less likely outcomes (Chapman and Weber, 2006; Baucells and Heukamp, 2012). That is to say, a person may prefer $100 with a 50% probability to $200 with a 25% probability of obtaining, but if the probabilities are reduced by a ratio of 10, the option of obtaining $200 with a 2.5% probability is preferred to $100 with a 5%

Table 1
Comparing the main anomalies. **Source:** Own elaboration.

Delayed Discounting	Expected Discounting
Delay effect/Common difference effect	Common ratio effect
Magnitude effect	Peanuts effect
Sign Effect	Reflection effect
Delay/Speed up Asymmetry	—
Sequence effect	—
Date-Delay effect	—
Interval effect	—

Table 2
The process of systematic review. **Source:** Own elaboration.

KEYWORDS	WOS	SCOPUS
"Intertemporal Choice" OR "Delay Discount*"	1925	1700
"Anomal*" OR "Effect*"	767	660
"Loss-Gain Asymmetry" OR "Delay/Speed-Up Asymmetry" OR "Sign Effect" OR "Sequence Effect" OR "Time Consistency" OR "Magnitude Effect" OR "Framing Effect" OR "Interval Effect" OR "Delay Effect" OR "Present-Bias Effect" OR "Common Difference Effect" OR "Interval Length Effect"	82	91
Article	80	77
English language	74	74
Total articles	148	
Duplicates	−53	
Not considered in the analysis	−17	
Articles 2021	+2	
Total articles analyzed	80	

probability. Therefore, the lower the probabilities of obtaining a reward, the higher the risk-taking tendency of decision-makers.

The **reflex effect** is analogous to the sign effect in choices under uncertainty. Individuals show risk aversion in the case of gains, but in the case of losses they become risk seekers (Prelec and Loewenstein, 1991).

Table 1 shows a comparison between the effects in intertemporal and uncertainty choices.

However, for the sake of clarity, a review of the main anomalies present in the EU model will not be included in this paper.

3. Methodology

In this paper, the so-called "Systematic Literature Review" has been applied to the analysis of the main anomalies in intertemporal choice. This technique determines the current state of knowledge in a specific field (Tarifa-Fernandez and De Burgos-Jiménez, 2017; Tranfield et al., 2003), thus allowing the identification of the areas of research, main findings, research directions and gaps.

The search for the most relevant articles was carried out using two of the main bibliographic databases, the Web of Science (WoS) and Scopus, because of the high impact of their publications, being the two most important international academic databases covering interdisciplinary publications. This affords significant strength to our analysis and facilitates comparison between different scientific fields (Archambault et al., 2006).

The keywords chosen for the search were grouped into three categories: the first identifies the field of study with the concept of "intertemporal choice" or "delay discounting"; the second category restricts the previous search to articles dealing exclusively with the anomalies or effects in intertemporal choice ("anomalies" and "effect"); and the last category limits the search to the effects which are the object of this analysis by locating the use of the terms: "gain-loss asymmetry", "delay-speed up asymmetry", "sign effect", "sequence effect", "time consistency", "magnitude effect", "framing effect", "interval effect", "delay effect", "present-bias effect", "common difference effect" and "interval length effect". These keywords were chosen to achieve the greatest possible coverage on this topic. The articles included in the analysis were extracted from the aforementioned databases prior to December 2020. However, given their relevance in the analysis, two articles published in 2021 were added to the study.

Table 2 shows the criteria followed in the search for articles, which was conducted at the beginning of January 2021.

The first search resulted in 3,625 articles: 1,925 from WoS and 1,700 from Scopus. This search was limited to 1,427 with the terms "Anomal*" or "effect*", and to 173 articles with the inclusion of the anomalies described in Table 2. Additionally, the search was restricted to articles written in English, which meant a total of 148. Moreover, 53 duplicate articles were found in the two databases, and 17 were removed for not meeting the objectives of this work. Finally, two works published in 2021, available in the 2020 databases, were included. In summary, a total of 80 articles were analyzed.

4. Descriptive results

As indicated in Section 3, the total number of analyzed articles was 80, of which 44 were published in the last 5 years (55%). Table 3 shows the articles published by periods of 5 years and the effects investigated in each of them. It can be seen that the most studied anomalies have been the magnitude effect, which has been analyzed in 47 works; the delay effect, which appears in 41 papers; and the sign effect, in 30 works. The less investigated areas are the sequence effect, researched in 10 articles, the delay/speed-up asymmetry and date-delay effect in 7, and the interval effect in only 3 articles, which were published in the last 5 years.

Table 4 shows the countries and areas in which the anomalies in intertemporal choice have been most investigated. The countries with a high number of publications are USA, with 32, and Japan and Spain with 9 studies each. Whereas USA and Japan stand out for their empirical contribution, in Spain most of the studies are theoretical. Regarding the areas of study, Economics and Psychology are those most involved in the research of these effects. Specifically, USA is prominent in both areas, Spain in Economics and Japan in Psychology. Other areas in which these effects have been dealt with, but to a lesser extent, are Medicine, Neuroscience and Political Science.

Table 5 shows the articles per effect, framing (delayed or expected discounting) and type of study (theoretical, empirical or both). All effects have been studied within both framings, that is to say, under delayed and expected discounting, except for the date-delay effect. However, it is worth observing that the most relevant scenario is delayed discounting, which is the focus of this study. Although all effects have been theoretically and empirically analyzed, further research is needed on the date-delay effect, the delay/speed-up asymmetry, the sequence effect, and especially the interval effect.

Table 3
Number of articles per year and effect. **Source:** Own elaboration.

Period	Articles	Magnitude Effect	Interval Effect	Delay Effect	Sign Effect	Delay/Speed-Up Asymmetry	Date-Delay Effect	Sequence Effect
1997-2004	5	2	0	2	2	1	0	1
2005-2009	10	7	0	7	6	2	1	4
2010-2014	21	12	0	11	8	2	3	0
2015-2020	44	26	3	22	13	2	3	5
Total	**80**	**47**	**3**	**42**	**29**	**7**	**7**	**10**

Table 4
Number of articles per country, type of study and area. **Source:** Own elaboration.

Country	Number of Articles	Type of Study			Area of Study			
		Theo.	Emp.	Econ.	Medical	Psycho	Neuro.	Political Science
Australia	6	1	6	3		3		
Austria	1	1		1				
Canada	2	2		1		1		
China	6		6	3		2	1	
USA	32	11	24	9	6	13	3	1
United Kingdom	7	5	5	4	1	2		
France	1	1		1				
Germany	5	2	5	1		3	1	
Italy	5		5	2		3		
Japan	9	1	9	3		5	1	
Luxembourg	1		1			1		
Netherlands	2		2	1		1		
New Zealand	2		2			2		
Norway	1	1	1	1				
Portugal	1	1	1	1				
Spain	9	7	4	7	1	1		
Total	**90**	**33**	**71**	**38**	**8**	**37**	**6**	**1**

Table 5
Number of articles per effect, framing and area. **Source:** Own elaboration.

Effects	Articles	Framing		Type of Study	
Date-Delay Effect	**7**	Delay discounting	7	Theoretical/ Empirical	3
				Empirical	4
Delay Effect	**42**	Delay discounting	33	Theoretical/ Empirical	1
				Empirical	20
				Theoretical	12
		Expected discounting	9	Theoretical/ Empirical	1
				Theoretical	4
				Empirical	4
Delay/Speed Up Asymmetry	**7**	Delay discounting	6	Theoretical	3
				Empirical	3
		Expected discounting	1	Theoretical	1
Interval Effect	**3**	Delay discounting	2	Theoretical/ Empirical	1
				Empirical	1
		Both models	1	Theoretical	1
Magnitude Effect	**47**	Delay discounting	37	Theoretical/ Empirical	4
				Theoretical	11
				Empirical	22
		Expected discounting	10	Theoretical/ Empirical	1
				Theoretical	5
				Empirical	4
Sequence Effect	**10**	Delay discounting	9	Theoretical/ Empirical	2
				Theoretical	4
				Empirical	3
		Expected discounting	1	Empirical	1
Sign Effect	**29**	Delay discounting	25	Theoretical	5
				Empirical	20
		Expected discounting	4	Theoretical	1
				Empirical	3

Table 6 shows the different names given to the anomalies in their corresponding studies. Only the date-delay effect and the delay/speed-up asymmetry have kept the same name in all the analyzed papers. Whereas the other anomalies have received different names, and even in some cases differences in the same article, which can make research quite confusing. This justifies the need to unify the nomenclature of these effects in all the areas of study.

Table 6
Different names of the effects. **Source:** Own elaboration.

Effect	Articles	Names	
Date-Delay Effect	**7**	Date-delay effect	7
Delay Effect	**42**	Common difference effect	7
		Declining impatience	2
		Delay discounting	1
		Delay effect	14
		Dynamic inconsistency effect	2
		Effect of self-control	1
		Hyperbolic discounting	6
		Impatience	1
		Impulsivity	2
		Present bias	1
		Short/long-term asymmetry	1
		Time delay	1
		Time effect	1
		Time inconsistency	1
		Preference reversals	1
Delay/Speed-Up Asymmetry	**7**	Delay/speed-up asymmetry	7
Interval Effect	**3**	Interval effect	2
		Interval length effect	1
Magnitude Effect	**47**	Magnitude effect	43
		Absolute magnitude effect	3
		Size effect	1
Sequence Effect	**10**	Sequence effect	8
		Negative time preference	1
		Preference for improving sequences	1
Sign Effect	**30**	Sign effect	23
		Gain-loss asymmetry	4
		Instant endowment	1
		Gain-loss	2

5. Discussion

In this section, the main contributions of the selected articles are classified by differentiating between effects, and theoretical and empirical works. A summary table of all articles consulted can be found in Appendix Table AI.

5.1. The magnitude effect

The effect of impatience decreasing with the amount has been shown in both humans and animals such as pigeons and rats, by reflecting certain similarities in their decision-making (Grace et al., 2012; Vanderveldt et al., 2016). However, De Petrillo et al. (De Petrillo et al., 2015) demonstrated the opposite pattern in capuchin monkeys, i.e. a

reverse magnitude effect.

Regarding the influence of religious and cultural factors on decision-making, Paglieri et al. (Paglieri et al., 2013) revealed a higher discount rate for Italian Catholics than for Dutch Calvinists, and intermediate rates for atheist groups. They concluded that the magnitude effect is specifically modulated by religious upbringing rather than by any generic cultural difference.

Furthermore, when using different elicitation methods, such as matching, choice, sequences and penalty tasks (Guyse and Simon, 2011; Meyer, 2015; Faralla et al., 2017), the magnitude effect appeared consistently. This anomaly has also been demonstrated in studies on different types of decision: money (Chapman and Winquist, 1998), tips (Green et al., 2003), health (Chapman and Weber, 2006), sweets (Faralla et al., 2021), academic tasks (Olsen et al., 2018), and others. However, this effect was absent when it came from decisions concerning human mortality (Guyse et al., 2020). Likewise, the magnitude effect was present in both social and private individual decisions on health and money. Therefore, it was shown that the decision mechanisms were the same, although the underlying psychological process was different (Lazaro et al., 2002).

Additionally, some works have shown that drug addicts exhibit the magnitude effect in a similar way as those not having any addiction (Klapproth, 2012). However, Oberlin (Oberlin et al., 2015) revealed that this effect was detected in social drinkers, but not in alcoholics not under treatment where small rewards were involved. Among people with ADHD disorder, the magnitude effect was demonstrated, with them being more impulsive in their intertemporal decisions than those without this disorder (Paloyelis et al., 2010; Jackson and Mackillop, 2016).

Moreover, Ballard et al. (Ballard et al., 2017) studied the influence of self-control on the magnitude effect, by providing evidence that the visceral (for example, hunger) and cognitive factors which reduce self-control, also reduced the magnitude effect. Other studies showed a positive relationship between this anomaly and unhealthy behaviours (Muñoz Torrecillas et al., 2018). In other words, unhealthy habits are associated with increasing impatience, especially in naive people (people who are unaware of their self-control problems).

In the field of neuroscience, Ballard et al. (Ballard et al., 2018) showed that the magnitude effect is related to cognitive control mechanisms in the dorsal lateral prefrontal cortex (dlPFC). Additionally, Wagner et al. (Wagner et al., 2020) found that this effect was attenuated by haloperidol, and Gershman and Bhui (Gershman and Bhui, 2020) demonstrated that the optimal allocation of mental effort can give rise to the magnitude effect in intertemporal choice.

Considering different decision frames, Wang et al. (Wang et al., 2015) showed that when considering subjective[1], instead of objective time perception, the magnitude effect disappeared. Likewise, Johnson et al. (Johnson et al., 2015) discovered that opportunity costs may replace the magnitude effect for consumable commodities. For their part, Lu et al. (Lu et al., 2020) confirmed that this effect does not influence the preference pattern in loan repayment sequences but, in a preference reversal framework, the presence of the magnitude effect in losses was not demonstrated (Holt et al., 2008). Finally, Kinari et al. (Kinari et al., 2009) confirmed that interval and magnitude effects are at least partially due to subjects' choices being influenced by the differential in the size of the reward.

With respect to the expected discounting scenario, the peanut effect has been demonstrated, i.e., increasing impatience with the amount (Sun and Li, 2010). Moreover, this effect and the magnitude effect (intertemporal choice) seem to be correlated (Chapman and Weber, 2006). In particular, Luckman et al. (Luckman et al., 2017) found that, despite showing indifference to risk or delay in isolation, when forced to choose one of them, participants preferred delayed to risky rewards. Likewise, this shift in indifference was further reinforced as the amount of reward was increased.

When considering theoretical works, Ortendahl (Ortendahl and Fries, 2005; Ortendahl, 2006) argued that health programmes could benefit from including the psychological factor of discounting. Framing health messages in terms of large, important outcomes might diminish the implicit discount rate used.

With regard to research on the magnitude effect, on the one hand, there are several studies which offer mathematical support to the existing literature. Al-Nowaihi and Dhami (Al-Nowaihi and Dhami, 2009) defended an explanation based on the property of incremental elasticity (Loewenstein and Prelec, 1992), by creating a theoretical framework to obtain this type of utility function. Cruz Rambaud et al. (Cruz Rambaud et al., 2019) also proposed an index which led on from the hyperbolic factor of Rohde (Rohde, 2010), the so-called ME-index, to determine whether a discount function was able to explain the magnitude effect.

On the other hand, a number of discounting models have been proposed to explain the magnitude effect. Streich and Levy (Streich and Levy, 2007) claimed the use of the quasi-hyperbolic function whilst Noor (Noor, 2011) proposed the magnitude effect model (MED), which generalizes the separable discounting model, making the discount factor dependent on the amount of the reward. Moreover, Read et al. (Read et al., 2013) developed the DRIFT model, a heuristic description of how framing influences intertemporal choice. Later, Baucells and Bellezza (Baucells and Bellezza, 2017) proposed a descriptive model, called the anticipation-event-recall (AER) model, in order to explain the magnitude effect and the delay/speed-up asymmetry. This was a utility model which incorporated the psychological elements of conceptual consumption, adaptation during anticipation and magnitude. Afterwards, Cruz Rambaud et al. (Cruz Rambaud et al., 2018) proposed an alternative model, called the q-exponential discount function deformed by amount, which was able to describe the magnitude and delay effects jointly. Finally, Drouhin (Drouhin, 2020) defined an additive and non-stationary discounted utility function within a continuous cycle of savings and consumption.

From a psychological perspective, Killeen (Killeen, 2009) proposed a discount function which explains the magnitude effect, making the marginal discount rate time-sensitive and discounting utility rather than monetary value. The additive utility model was unique in that it proposed a disutility to waiting which was added to the utility of the goods.

Alternatively, Stevens (Similarity, 2016) tested discounting against attribute-based models, which use similarity judgments to make choices. His results showed that similarity judgments accounted for the magnitude effect. Therefore, attribute-based models such as similarity models provide an alternative to discounting models. This may offer several insights into the process of decision-making in the context of intertemporal choice. Analogously, Cheng and González-Vallejo (Cheng and González-Vallejo, 2016) analyzed two attribute-wise models: the trade-off model (Scholten et al., 2014) and the proportional difference model (González-Vallejo, 2002); and an alternative hyperbolic model based on Rachlin (Rachlin, 2006). They noted that the attribute-wise models were better to describe intertemporal choices.

Finally, there are models which incorporate probability in order to explain the magnitude effect in intertemporal choice. Walther (Walther, 2010) described the magnitude effect within a common framework of intertemporal state-dependent expected utility. Moreover, Xia (Xia, 2011) provided an expected utility model, with uncertainty, risk aversion and preference for precautionary saving, which simultaneously explained three anomalies (magnitude, delay and sign effects). Additionally, Baucells and Heukamp (Baucells and Heukamp, 2012) proposed a general model able to reconcile the DU and the EU models, as well as to explain the anomalies arising in intertemporal choices and in choices under uncertainty. For their part, Dai and Busemeyer (Dai and

[1] Subjective time perception occurs because individuals do not perceive e.g., 3 years as three times longer than a 1-year time horizon (objective time), but rather as only 1.3 times longer than 1 year.

Busemeyer, 2014) concluded that the DFT model was the most appropriate to explain the magnitude effect. Analogously, Holden and Quiggin (Holden and Quiggin, 2017) provided the Zooming model, which was based on the idea of limited awareness and reference-dependent utility in order to explain the magnitude effect. Likewise, Shoji and Kenehiro (Shoji and Kanehiro, 2012) showed that rational choice depends on human psychological factors, such as reward myopia (preference for the earliest reward) and different risk tolerances. The combination of both factors resulted in different optimal choices. Finally, Ariani and Sonderegger (Adriani and Sonderegger, 2020) carried out a simple cost-benefit analysis to derive optimal similarity judgments, thus explaining the magnitude effect in the delayed and probabilistic discounting scenarios.

5.2. The delay effect

The delay effect has been analyzed in both humans and animals, and the conclusions are similar to those from the magnitude effect (Vanderveldt et al., 2016). Furthermore, this anomaly has been confirmed in several incomes: money (Chapman and Winquist, 1998), drugs (Johnson et al., 2015), health (Khwaja et al., 2007), academic tasks (Olsen et al., 2018), and others. Nevertheless, the delay effect failed to appear in decisions about respiratory health (Berry et al., 2017), air quality (Berry et al., 2017) and human mortality (Guyse et al., 2020), possibly because of the long-term implications of these. In addition, it was found that people with a higher impatience are associated with higher level of debt, and the delay effect was positively related to borrowing (Ikeda and Il, 2015). Moreover, these conclusions were similar to those reached by analysis of the magnitude effect regarding social and private decisions in the domain of health and money (Lazaro et al., 2002).

Regarding the different decision frames, Wang (Wang et al., 2015) demonstrated the absence of the delay effect when considering subjective time perception, which was similar to the results obtained for the magnitude effect. Likewise, Tiezzi (Tiezzi and Xiao, 2016) empirically studied how tax information influenced citizens' decisions. They concluded that, when the explicit information was provided on the intertemporal trade-offs taxation, this effect practically disappeared, but was stronger when no such information was given. Finally, Takeuchi and Tsubuku (Takeuchi and Tsubuku, 2018) showed that when it came from intertemporal choices about goods with a limited time of enjoyment, the reverse delay effect arose, i.e., discount rates increased over time.

In addition, the delay effect has been shown among smokers and drug addicts in a pattern similar to those without any addiction (Khwaja et al., 2007; Johnson et al., 2015), and the same for people with ADHD disorder (Paloyelis et al., 2010; Jackson and Mackillop, 2016). However, some studies showed a positive relationship between this anomaly and unhealthy behaviours (Muñoz Torrecillas et al., 2018; Kang and Ikeda, 2016), such as smoking (Kang M and Ikeda, 2014), and a high body mass index (Ikeda et al., 2010). Moreover, this effect is shaped by the individual's religious and cultural tendencies (Paglieri et al., 2013). All these results are analogous to those shown for the magnitude effect.

Some studies analyzed the delay effect in intertemporal choice and in choice with uncertainty, showing instead the opposite conclusion to the so-called common ratio effect, where the discount rate was increasing with probability (Chapman and Weber, 2006, Sun and Li, 2010). Liu and Xie (Liu et al., 2014) examined this anomaly on environmental risks by demonstrating that the more distant in time the occurrence of an environmental risk, lower is the intensity with which subjects perceive it as a severe threat.

In terms of preference reversal, it has been shown that people are more patient in receiving a later, larger reward when a common delay is added (Shen et al., 2019). However, when decisions are made in losses, the opposite pattern has been shown. People tend to discount larger losses to a greater extent. However, when a common delay is added, this preference shifts towards smaller losses (Holt et al., 2008).

With regard to theoretical works, Ortendahl (Ortendahl and Fries, 2005; Ortendahl, 2006) highlighted the importance of the delay effect in designing health programmes suggesting that stating positive benefits to health could offset the negative reaction to long delays.

With respect to the papers relying on the properties of discount functions to explain the delay effect, some researchers have focused on the distinction between the interval effect, the delay effect and subadditivity (Kinari et al., 2009; Cruz Rambaud and Ortiz Fernandez, 2020). On the one hand, Kinari et al. (Kinari et al., 2009) confirmed that the delay effect was a more general concept than the interval effect. And, on the other hand, Cruz Rambaud and Ortiz Fernández (Cruz Rambaud and Ortiz Fernandez, 2020) found that, from a stationary point of view, the interval effect was a more general concept than the delay effect whilst, from a dynamic perspective, both effects were independent.

Focusing on discounting models, Wathieu (Wathieu, 1997) proposed a model of discounted utility under habit formation which means that utility in each period is determined by the difference between the received outcome and the expected outcome at that point in time. For their part, Streich and Levy (Streich and Levy, 2007) defended the quasi-hyperbolic function as an explanation for the delay effect, whilst Han and Takahashi (Han and Takahashi, 2012) provided the q-exponential model as an alternative, based on the idea that the delay effect is due to psychophysical effects of time perception. Han and Takahashi (Han and Takahashi, 2012) also confirmed that subjective time was perceived as shorter in the distant future in comparison to the near future. Moreover, other authors proposed models which explained the delay and magnitude effects jointly, such as the q-exponential discount function affected by the amount (Cruz Rambaud et al., 2018), Drouhin (Drouhin, 2020)'s additive and non-stationary discounted utility function, Killeen (Killeen, 2009)'s additive-utility model of delay discounting and the DRIFT model (Read et al., 2013) (see Section 5.1). Later, Cruz Rambaud and Ortiz Fernández (Cruz Rambaud and Ortiz Fernandez, 2020) presented a dynamic discount model, called asymmetric exponential discounting, which explained the delay effect and subadditivity.

From a psychological perspective, Scherbaum et al. (Scherbaum et al., 2012) rely on self-control and contextual framing factors to account for intertemporal decision outcomes. These authors constructed a dynamic connectionist model of intertemporal choice based on computational modelling and the dynamic properties of decision processes.

In decisions with uncertainty, there is the expected utility models proposed by Walther (Walther, 2010), Xia (Xia, 2011) and Baucells et al. (Baucells and Heukamp, 2012) which explained the delay effect and others which are clarified in their corresponding sections. Analogously, Holden and Quiggin (Holden and Quiggin, 2017) proposed the Zooming model which jointly explains the magnitude and delay effects based on the point reference. Finally, Adriani and Sonderegger (Adriani and Sonderegger, 2020) accounted for the time inconsistency and the interval and magnitude effects in the delayed and probabilistic discounting scenarios through a simple cost-benefit analysis (see Section 5.1).

5.3. The sign effect

The sign effect is one of the strongest and most analyzed effects in the existing literature, along with the magnitude and delay effects. The main contributions on this anomaly are hereafter identified.

The presence of the sign effect was detected (similarly to the magnitude effect) by using the different elicitation methods (Guyse and Simon, 2011; Breuer and Soypak, 2015). However, it seemed that the framing effect (elicitation method) appeared stronger for negative results.

Regarding the choice domains, the sign effect was revealed on money (Chapman and Winquist, 1998), drugs (Johnson et al., 2015), health (Khwaja et al., 2007), sweets (Faralla et al., 2021), career issues (Hesketh, 2000), and others. By contrast, and in line with the delay

effect, this anomaly did not appear for decisions on respiratory health (Berry et al., 2017), air quality (Berry et al., 2017) and human mortality (Guyse et al., 2020). In addition, it was found that people with higher impatience were associated with a higher level of debt, and the sign effect was related negatively to borrowing (Ikeda and Il, 2015).

In addition, people with or without drug and alcohol habits showed the same sign effect, as in the case of the magnitude and delay effects. However, the sign effect presented a negative relationship with smoking (Kang M and Ikeda, 2014) and body weight (Ikeda et al., 2010). In other words, bad habits could reduce the differences in discounting between losses and gains.

Unlike the date-delay, magnitude and delay effects, the sign effect did not disappear when considering subjective time (Wang et al., 2015). Molouki et al. (Molouki et al., 2019), for their part, demonstrated that the sign effect emerged more strongly and consistently when discounting future events than for past ones. Likewise, the relationship between subadditivity and the delay/speed-up effect has been found by McAlvanah (McAlvanah, 2010).

From a neurological point of view, Tanaka (Tanaka et al., 2014) compared the brain activity of individuals who showed the sign effect and those who did not present this anomaly in their decision-making. Participants with the sign effect demonstrated a greater insular response to the magnitude of the loss than to the magnitude of the gain, and a greater linear response to the delay of the loss than to the delay of the gain. Another study (Qu et al., 2013) provided some evidence on the sign effect and concluded that this effect could be encoded in FRN (feedback-related negativity) at the initial stage of evaluating the results.

When considering theoretical works, some research showed that framing health messages as losses rather than gains might lower the implicit discount rate used (Ortendahl and Fries, 2005; Ortendahl, 2006), increasing the effectiveness of health campaigns.

As for explanations of the sign effect, based on the properties of the utility function, the work by Al-Nowaihi and Dhami (Al-Nowaihi and Dhami, 2009) allowed for the creation of utility functions including the property of incremental elasticity (Loewenstein and Prelec, 1992) and therefore explained both the magnitude and sign effects. Similarly, Abdellaoui et al. (Abdellaoui et al., 2010) presented a parameter-free method to measure the discounted utility model. Moreover, they found concave utility for gains and slightly convex utility for losses, which supported Loewenstein and Prelec's hypothesis.

With respect to the studies on models accounting for the sign effect, on the one hand, some authors, such as Killeen (Killeen, 2009) and Han and Takahashi (Han and Takahashi, 2012), proposed new discounting functions, whereas others postulated in favour of a particular model. For example, Streich and Levy (Streich and Levy, 2007) considered the quasi-hyperbolic discounting function as an existing model fitting explanation for the sign effect, and Stevens (Similarity, 2016) defended the attribute-based models against the discounting models to account for the sign effect.

With respect to subjective time, Han and Takahashi (Han and Takahashi, 2012) discovered that it was perceived as shorter in losses than gains. However, Xu et al. (Xu et al., 2020) did not find evidence for this premise, possibly due to the large difference of timescales used in the two studies.

When considering uncertainty as an aspect of the intertemporal decision, there is the intertemporal state-dependent expected utility model of Walther (Walther, 2010), which explained the sign effect. According to this theory, the loss-gain asymmetry emerges if the subject is either 'relative risk-averse' or 'relative disappointment-averse' (or both). Another expected utility model is that proposed by Xia (Xia, 2011), which also accounted for the magnitude, delay and sign effects. Finally, the research of Shoji and Kanehiro (Shoji and Kanehiro, 2012) confirmed that psychological factors of myopia and risk tolerance affected individuals' rational choices.

5.4. The sequence effect

After considering the articles selected for this paper, it is evident that the sequence effect has not received enough attention from researchers. The main conclusions on this anomaly will be presented now.

From an empirical point of view, the decreasing sequence effect has been demonstrated in choices among loans for the purchase of a car. In this scenario, individuals preferred to make higher repayments at the beginning of the loan duration, leaving the lower repayments to the end (Lu et al., 2020; Cruz Rambaud et al., 2019). By contrast, in choices concerning wages and with participants being aware of present value maximization, improving sequences of incomes are shown to cover their future spending needs, to provide motivation and to be an indication of success and status (Garcia et al., 2020 Dec 1). In addition to monetary outcomes, the sequence effect has been analyzed in human mortality decisions to assist in the development of health policy, showing a preference for uniform outcomes over time (Guyse et al., 2020).

Another study related to decisions about life, but in terms of probability, was provided by Van der Pol and Ruggeri (van der Pol and Ruggeri, 2008). These scholars examined the sequence effect resulting from the risk attitudes of respondents throughout their lives. They found that respondents tended to be more risk-seeking if they has previously experienced a period of ill health. The sequence effect was seen to be more pronounced for individuals exhibiting negative time preferences than for those exhibiting positive time preferences.

From a neurological perspective, Jenkins and Hsu (Jenkins and Hsu, 2017) analyzed the decision mechanisms underlying the sequence effect. They demonstrated that sequence framing could increase the rôle of imagination in decision-making without increasing the exertion of willpower.

As far as theoretical works are concerned, there is a similarity to the previous sections. The work of Ortendahl (Ortendahl and Fries, 2005; Ortendahl, 2006) showed that the impact of a health programme is greater if messages are expressed as a series, rather than as individual outcomes.

As for the mathematical explanations provided for this effect, some researchers advocated the use of the quasi-hyperbolic discounting model (Streich and Levy, 2007), and others the use of the q-exponential discount model (Cruz Rambaud et al., 2019). Still others proposed alternative models of valuing individuals' preferences (Garcia et al., 2020 Dec 1).

5.5. The date-delay effect

Unlike the effects previously analyzed, the date-delay effect has not been widely studied. The main contributions about this anomaly are here discussed.

The research has mainly focused on monetary choices rather than entering into other areas such as food, health, education, health care, or education. As has been amply demonstrated, individuals exhibit different behaviours when faced with the choice of gains and losses (sign effect). However, considering the date-delay effect, it was shown that in both gains (lottery or investment) and losses individuals were willing to pay more for delaying the outcome when the time was expressed as an extent of time than when it was expressed as a date (LeBoeuf, 2006). Likewise, this effect appeared in both real and hypothetical results, although the date-delay effect was substantially greater when the chosen reward was real (Read et al., 2005). This was also confirmed when using different types of questionnaire, such as choice-based and matching based (Read et al., 2005; Breuer and Soypak, 2015). Elsewhere, the effect was also observed regardless of how time was described, i.e., whether it was described in months or weeks (Read et al., 2005). Likewise, looking at the amounts and times analyzed in previous experiments, it was observed that the amounts varied from $20 to $2,000, i.e., small amounts were used. Similarly, the time periods were short, ranging from 1 day to 30 months.

When considering the influence of substance abuse on decision-making, it was shown that the date-delay effect appeared in both addicted and healthy individuals. However, distinguishing between these groups, the effect was found to be smaller in healthy individuals (Klapproth, 2012).

As to the possible causes of this effect, Zauberman et al. (Zauberman et al., 2009) proposed the time-perception-based theory as an explanation. They demonstrated empirically that people's subjective time perception was more contracted when time was expressed as calendar dates than when it was described as a period of delay. Thus, time horizon sensitivity appears to be an explanatory factor for the date-delay effect. In relation to this theory, Wang et al. (Wang et al., 2015) showed that when subjective time perception was considered, the date-delay, magnitude and delay effects did not take place.

Moreover, Scherbaum et al. (Scherbaum et al., 2012) proposed a dynamic connectionist model which took into account the distinction between delay periods and calendar dates in terms of discount. For their part, Dshemuchadse et al. (Dshemuchadse et al., 2013) and Schoemann et al. (Schoemann et al., 2019) considered that the date-delay effect was only the general consequence of more deliberative processing caused by higher cognitive demands due to the more complex format of calendar dates. Thus, the methodological configuration had a crucial influence on the results of the experiment.

5.6. The delay/speed-up asymmetry

Although intertemporal choice includes both delay and receipt of rewards, deferred decisions have received greater attention. The main findings in the study of this anomaly are now considered.

Regarding empirical studies, the delay/speed-up effect was demonstrated in decisions involving both health and money, regardless of whether these were social or private. It was shown that the decision mechanisms were the same (Lazaro et al., 2002). Moreover, differences between delay and speed-up frames have been shown to be less significant in intertemporal choice than in intertemporal matching tasks (Breuer and Soypak, 2015). This means that time-inconsistent behaviour could be less frequent in choice tasks than matching tasks.

In addition, the relationship between subadditivity and the delay/speed-up effect has been found by McAlvanah (McAlvanah, 2010). Specifically, it was shown that, for gains, subadditivity was stronger when considering delaying a later rather than an earlier outcome, and weakest when anticipating an outcome from a later situation. However, for losses, subadditivity was weaker when delaying a loss to a later date, and stronger when anticipating a delayed loss to an earlier date.

From a theoretical point of view, we find mathematical explanations for the delay/speed-up asymmetry. Firstly, Lazaro et al. (Lazaro et al., 2002) confirmed the explanation that the hyperbolic model was more convincing than that offered for the quasi-hyperbolic and exponential models. By contrast, Streich and Levy (Streich and Levy, 2007) supported the use of the quasi-hyperbolic discount model as accounting for this effect, along with the other anomalies.

With a more psychological perspective, Killeen (Killeen, 2009) proposed an additive utility model which predicted the most important anomalies in intertemporal choice, including the delay/speed-up asymmetry, whereas Baucells and Bellezza (Baucells and Bellezza, 2017) provided the AER model, which explained the magnitude effect and the delay/speed-up asymmetry.

Among the explanations which consider uncertainty as an aspect of intertemporal decision, the work of Walther (Walther, 2010) accounted for the delay-speed up asymmetry, and affirmed that this anomaly emerged if the relative risk aversion was constant and positive, and disappeared if the subject was risk-neutral.

5.7. The interval effect

Finally, the interval effect is now analysed. It is the least studied anomaly, possibly due to the fact that traditionally this has been confused with the delay effect. Three articles have been found.

Considering the empirical work, the interval effect has only been analyzed once (Kinari et al., 2009)through experiment. It was demonstrated on hypothetical monetary gains, using short time horizons (days and weeks), and using a choice-based questionnaire.

From a theoretical point of view, the interval effect has been studied together with the delay effect and subadditivity (Kinari et al., 2009; Cruz Rambaud and Ortiz Fernández, 2021). In particular, two opposite approaches were found. On the one hand, Kinari et al. (Kinari et al., 2009) affirmed that the interval effect was a concept less generalised than the delay effect, and the former was a sufficient condition for subadditivity. However, the interval effect could not be explained by the Weber-Fechner law. On the other hand, Cruz Rambaud and Ortiz Fernández (Cruz Rambaud and Ortiz Fernández, 2021) demonstrated mathematically that, from a stationary perspective, the interval effect was a more general concept than the delay effect. However, these effects were independent from a dynamic perspective.

Lastly, Adriani and Sonderegger (Adriani and Sonderegger, 2020) carried out a simple cost-benefit analysis to derive optimal similarity judgments, in order to explain the anomalies, including the interval effect, from the EU and DU models. And, they addressed the following question: When should we expect a decision-maker to distinguish between different time periods or different rewards? Their key premise was that cognitive resources are costly and should be deployed only where they really matter.

6. Further research lines

This systematic review of the literature provides an insight into the main contributions made by different papers over the last two decades in the field of intertemporal choice. Based on these findings, the authors of this paper identify research gaps and propose future lines of research, both from a theoretical and an empirical point of view.

6.1. Theoretical perspective

With regard to theoretical mathematical papers, those which study the discount function's properties to explain the different anomalies have analyzed subadditivity jointly with the sign, delay, and interval effects. Therefore, it would be useful to expand the analysis of this property to other areas, such as the magnitude effect, the sequence effect and the delay/speed-up asymmetry.

Similarly, there are many proposals for discounting models which attempt to explain these anomalies, especially the delay and magnitude effects. Some studies incorporate factors and parameters explaining individuals' behaviour concerning the discount functions. Specifically, an interesting line of research would be to demonstrate these anomalies through the deformation of time in delayed decisions (Cruz-Rambaud and Sanchez-Perez, 2018; Cruz Rambaud and Ventre, 2017). In effect, taking into account that the general expression of a discount function is $F(t) = \exp\{-g(t)\}$, where $g(t)$ is a deformation of time, a subjective view of time shows its relevance when defining the function which describes the preferences between dated rewards. The exponential discounting itself ($F(t) = \exp\{-kt\}$, $k>0$) implicitly considers a proportional distortion of time. In general, it can be stated that there is a one-to-one correspondence between discount functions and time deformations (Cruz Rambaud et al., 2018; Cruz Rambaud et al., 2018) from which it can be concluded that basically they are the same concept: $F(t)$ and $-\ln F(t)$, respectively. Other proposals focus on the properties of the utility function, such as Killeen (Killeen, 2009), which was able to explain most of the anomalies (the magnitude, delay and sign effects, as well as the delay/speed-up asymmetry).

It is therefore considered necessary to continue working along these lines in order to obtain a model which explains all possible effects. Moreover, it would be particularly useful to propose a model which

accounts for the interval effect. It is also important to complement this research with empirical work capable of validating the discount functions obtained. This involves the comparison of new modelling approaches (MED, DRIFT, AER, etc.) to see which of them most reliably represents people's behaviour.

Another interesting line of research could be the design of an index able to measure each of these effects, such as the one proposed by Cruz Rambaud et al. (Cruz Rambaud et al., 2019) for the magnitude effect.

From a more psychological perspective, there are attribute-based models, and specifically those which use similarity judgements. This is an emerging line of research focused on comparing these with traditional discounting models, in order to discover which ones better explain intertemporal choice anomalies, or whether some are more appropriate for certain anomalies than others.

Finally, there are discount models which try to account for intertemporal choices by incorporating risk or probability factors. In general, there is no doubt about the similarity between DU and EU models, that is to say, between decisions involving intertemporal and uncertain choices. Similarly, from a psychological point of view, time has been interpreted in a probabilistic way (Keren and Roelofsma, 1995), or risks have been converted into delays in risky choices (Rachlin et al., 1991). However, other scholars, such as Prelec and Loewenstein (Prelec and Loewenstein, 1991), Quiggin and Horowitz (Quiggin and Horowitz, 2012) and Baucells et al. (Baucells et al., 2006) have stressed the analogies between the anomalies in DU and EU models, as both paradoxes exhibit the same psychological properties of multidimensional prospect valuation. Despite these similarities, both models have been independently studied by using different methodologies, based on the idea that delayed and risky rewards do not require the same treatment.

Recently, there have been several attempts to unify DU and EU models, for example the Discounted Expected Utility (DEU) (Andreoni et al., 2010; Schneider, 2016). This is the case of Cruz Rambaud and Sánchez Pérez (Cruz Rambaud and Sánchez Pérez, 2018) (see lemmas 1 and 2; corollaries 1 and 2; and observations 1 and 2) who demonstrated that, under conditions of regularity and continuity of the discount function involved in the intertemporal choice, an increase in time must be compensated for by increasing probability in order to preserve the value of the reward offered. Definitively, this shows the trade-off between time and probability in a model which combines delayed and risk rewards.

Regarding the reviews of this literature, the authors consider it helpful for them to be more specific, focusing on the different research areas of intertemporal choice. First, it would be interesting to unify the explanatory models proposed so far and find similarities between them, thus helping in the search for a unified model. Secondly, given the large number of experiments carried out over the last 30 years and that the characteristics of the participants (demographics, health and consumption habits, etc.), of the questionnaires (type of questionnaire, type of rewards, scenarios, amounts, deadlines, etc.), the way in which the experiments are conducted and even the statistical analysis carried out which are known to be determinants of individuals' impulsivity, it would be worthwhile to know which characteristics favour certain behaviours over others, thus combining the experience of previous researchers. And, finally, it would be useful to subdivide these reviews according to the anomalies under consideration, in order to give a more precise insight.

6.2. Empirical perspective

First, although most of the anomalies have been extensively analyzed, the study of the interval effect is still at an early stage of research. Given the relevance of this with respect to the delay and magnitude effects, researchers could pay more attention to this anomaly and incorporate it in their experiments.

The investigation of anomalies has mainly been carried out on humans, although some research, especially in the field of psychology, has also been conducted on animals. Due to the complexity of studies on animals, the number of papers included in this literature review is small. The magnitude and delay effects have been the most studied anomalies in both monkeys and pigeons, showing a similar trend to that shown in humans. Therefore, it would be valuable for researchers in this field to analyse the similarities in terms of decision-making between humans and animals.

An important question in empirical research is the influence of demographic, cultural, religious and social factors on individuals' decision-making. It is possible that characteristics such as gender, age, culture, etc. might affect the appearance of anomalies, and whether differences in the effects which these have on groups thus defined. In fact, it has been shown that the type of religion could affect how the delay and magnitude effects appear. Therefore, it would be worth examining whether the intensity of this factor, as a determinant of choices, could determine the occurrence of the other anomalies. In addition, political ideology could influence these effects, something which has not so far been analyzed. If confirmed, these results could be used to design political campaigns which attract the largest possible number of voters.

The magnitude, delay, sign, and date-delay effects were demonstrated for different groups of people, such as those with drug and tobacco addiction problems, and with ADHD. However, there are other effects which have not been studied for any of these groups, such as the interval effect, the sequence effect, and the delay/speed-up asymmetry. Therefore, further research is needed in this direction.

Regarding the impact of addictive (alcohol, drugs, or tobacco) or psychological (ADHD) problems on the appearance of anomalies, it has been shown that people with alcohol problems present a greater magnitude effect than those without such problems. Additional research could reveal whether this tendency also holds for other effects, and whether other addictive behaviours, such as drugs or tobacco, and even psychological disorders, have a similar effect. Dietary habits and body mass have similarly been demonstrated to affect the occurrence of the sign and delay effects. Extending this research to other effects would improve understanding of the influence of self-control on decisions. The importance of self-control lies in the fact that it is considered by some authors to explain the anomalies in intertemporal choice.

In terms of the type of outcome on which individuals make decisions, monetary decisions have traditionally been the area of study. However, this has gradually been extended to non-monetary and more realistic rewards in line with the new challenges which face current society.

For decisions concerning tipping, the magnitude and sign effects have been explored but not the other anomalies, so this analysis could be extended to the delay, sequence, and delay/speed-up asymmetry. Similarly, for decisions on academic tasks, it would be interesting to broaden the research to other anomalies, in addition to the delay and magnitude effects, which have already been tested. These decisions may vary according to culture, age or gender, so it would be worthwhile to include these variables in the study.

In the area of health policy, more research is clearly needed. Citizens' preferences for different government policies have previously been analyzed in terms of potential life savings and losses, as well as the economic terms of such policies. This research was carried out considering only the delay and magnitude effects and delay/speed-up asymmetry. Therefore, further analysis to the sign, sequence, interval and date-delay effects would be of great interest to policy makers.

For health and air quality decisions, it is necessary to broaden the study by considering effects other than the sign and the delay. Currently, COVID-19 has given rise to many health-related questions, such as: would you rather socialize now and contract the virus in a few days, or stay at home alone and be healthy? To raise awareness about COVID-19, as well as other conditions such as cancer or cardiovascular diseases, numerous campaigns have been developed, with different rates of success. The study of intertemporal choice and its anomalies can be key to the design of health campaigns which aim to reduce bad habits and

Table AI
Summary of anomalies studied per paper. **Source:** Own elaboration

Refs.	Paper	Magnitude effect	Delay effect	Sign effect	Delay/Speed Up Asymmetry	Date-delay effect	Sequence effect	Interval effect
(Abdellaoui et al., 2010)	Abdellaoui et al, 2010			X				
(Adriani and Sonderegger, 2020)	Adriani and Sonderegger, 2020	X	X					X
(Al-Nowaihi and Dhami, 2009)	al-Nowaihi and Dhami, 2009	X		X				
(Ballard et al., 2017)	Ballard et al, 2017	X						
(Ballard et al., 2018)	Ballard et al, 2018	X						
(Baucells and Bellezza, 2017)	Baucells and Bellezza, 2017	X			X			
(Baucells and Heukamp, 2012)	Baucells and Heukamp, 2012	X	X					
(Berry et al., 2017)	Berry et al, 2017		X	X				
(Breuer and Soypak, 2015)	Breuer and Soypak, 2015			X	X	X		
(Chapman and Weber, 2006)	Chapman and Weber, 2006	X	X					
(Chapman and Winquist, 1998)	Chapman and Winquist, 1998	X		X				
(Cheng and González-Vallejo, 2016)	Cheng and González-Vallejo, 2016	X						
(Cruz Rambaud and Ortiz Fernandez, 2020)	Cruz Rambaud and Ortiz Fernández, 2020		X					
(Cruz Rambaud and Ortiz Fernández, 2021)	Cruz Rambaud and Ortiz Fernández, 2021		X					X
(Cruz Rambaud et al., 2018)	Cruz Rambaud et al, 2018	X	X					
(Cruz Rambaud et al., 2019)	Cruz Rambaud et al, 2019	X						
(Cruz Rambaud et al., 2019)	Cruz Rambaud et al, 2019						X	
(Dai and Busemeyer, 2014)	Dai and Busemeyer, 2014	X	X					
(De Petrillo et al., 2015)	De Petrillo et al, 2015	X						
(Drouhin, 2020)	Drouhin, 2020	X	X					
(Dshemuchadse et al., 2013)	Dshemuchadse et al, 2013					X		
(Faralla et al., 2017)	Faralla et al, 2017	X						
(Faralla et al., 2021)	Faralla et al, 2021	X		X				
(Garcia et al., 2020 Dec 1)	Garcia et al, 2020						X	
(Gershman and Bhui, 2020)	Gershman and Bhui, 2020	X						
(Grace et al., 2012)	Grace et al, 2012	X						
(Green et al., 2003)	Green et al, 2003	X						
(Guyse and Simon, 2011)	Guyse and Simon, 2011	X		X				
(Guyse et al., 2020)	Guyse et al, 2020		X	X			X	
(Han and Takahashi, 2012)	Han and Takahashi, 2012		X	X				
(Hesketh, 2000)	Hesketh, 2000			X				
(Holden and Quiggin, 2017)	Holden and Quiggin, 2017	X	X					
(Holt et al., 2008)	Holt et al, 2008	X	X					
(Ikeda and Il, 2015)	Ikeda and Kang, 2015		X	X				
(Ikeda et al., 2010)	Ikeda et al, 2010		X	X				
(Jackson and Mackillop, 2016)	Jackson and Mackillop, 2016		X					
(Jenkins and Hsu, 2017)	Jenkins and Hsu, 2017						X	
(Johnson et al., 2015)	Johnson et al, 2015	X	X					
(Johnson et al., 2015)	Johnson, et al, 2015			X				
(Kang M and Ikeda, 2014)	Kang and Ikeda, 2014		X	X				
(Kang and Ikeda, 2016)	Kang and Ikeda, 2016		X					
(Khwaja et al., 2007)	Khwaja et al, 2007		X	X				
(Killeen, 2009)	Killeen, 2009	X	X	X	X			
(Kinari et al., 2009)	Kinari et al, 2009	X	X					X
(Klapproth, 2012)	Klapproth, 2012	X				X		
(Lazaro et al., 2002)	Lazaro et al, 2002	X	X		X			
(Liu et al., 2014)	Liu et al, 2014		X					
(Lu et al., 2020)	Lu et al, 2020	X					X	
(Luckman et al., 2017)	Luckman et al, 2017	X						
(McAlvanah, 2010)	McAlvanah, 2010			X	X			
(Meyer, 2015)	Meyer, 2015	X						
(Molouki et al., 2019)	Molouki et al, 2019			X				
(Muñoz Torrecillas et al., 2018)	Munoz Torrecillas et al, 2018	X	X					
(Noor, 2011)	Noor, 2011	X						
(Oberlin et al., 2015)	Oberlin et al, 2015	X						
(Olsen et al., 2018)	Olsen et al, 2018	X	X					
(Ortendahl and Fries, 2005)	Ortendahl, 2005	X	X	X			X	
(Ortendahl, 2006)	Ortendahl, 2006	X	X	X			X	
(Paglieri et al., 2013)	Paglieri et al, 2013	X	X					
(Paloyelis et al., 2010)	Paloyelis et al, 2010	X	X					
(Qu et al., 2013)	Qu et al, 2013			X				
(Read et al., 2005)	Read et al, 2005					X		
(Read et al., 2013)	Read et al, 2013	X	X					
(Scherbaum et al., 2012)	Scherbaum et al, 2012		X			X		
(Schoemann et al., 2019)	Schoemann, 2019					X		
(Shen et al., 2019)	Shen et al, 2019		X					
(Shoji and Kanehiro, 2012)	Shoji and Kanehiro, 2012	X		X				
(Similarity, 2016)	Stevens, 2016	X		X				
(Streich and Levy, 2007)	Streich and Levy, 2007	X	X	X	X		X	

(*continued on next page*)

Table AI (*continued*)

Refs.	Paper	Magnitude effect	Delay effect	Sign effect	Delay/Speed Up Asymmetry	Date-delay effect	Sequence effect	Interval effect
(Sun and Li, 2010)	Sun and Li, 2010	X	X					
(Takeuchi and Tsubuku, 2018)	Takeuchi and Tsubuku, 2018		X					
(Tanaka et al., 2014)	Tanaka et al, 2014			X				
(Tiezzi and Xiao, 2016)	Tiezzi and Xiao, 2016		X					
(van der Pol and Ruggeri, 2008)	van der Pol and Ruggeri, 2008						X	
(Vanderveldt et al., 2016)	Vanderveldt et al, 2016	X	X					
(Wagner et al., 2020)	Wagner et al, 2020	X						
(Walther, 2010)	Walther, 2010	X	X	X	X			
(Wang et al., 2015)	Wang et al, 2015	X	X	X		X		
(Wathieu, 1997)	Wathieu, 1997		X				X	
(Xia, 2011)	Xia, 2011	X	X	X				
(Xu et al., 2020)	Xu et al, 2020			X				

encourage good practice among citizens from different population strata. In this way, the likelihood of suffering from certain diseases could be reduced.

Regarding the field of Business and Management, no study has been found which analyses intertemporal decision-making in the areas of HR, Marketing, Production, etc. Therefore, it would be relevant to analyse the preferences of stakeholders concerning the decisions taken by management, with the aim of helping the company to ensure that its actions are adopted in the best possible way, and thus create value for shareholders. Other areas of study are needed to see whether workers prefer to receive incentives monthly or all together in one lump sum, whether customers or suppliers prefer to pay in several instalments or in one lump sum, whether they prefer to pay a larger amount later or prefer an immediate lesser payment, whether these preferences hold when the amount of the payment involves larger or smaller amounts and so on. In addition, it could be extended to investment decisions involving corporate social responsibility.

Finally, it has been observed that decision-making can be significantly affected if taxation is taken into account. This was the case of the delay effect. Research could be extended to other effects such as magnitude, sequence, interval and date-delay effects, and to identify possible differences between gender and even age groups.

With respect to decision frames, it was found that when subjective time perception instead of objective time is considered, the delay, magnitude and date-delay effects disappeared. Therefore, it would be worthwhile to replicate these studies for the delay/speed-up asymmetry, and the sequence and interval effects. In addition, it was discovered that when decisions are made on goods available for a limited time, individuals' preferences may be reversed. This is the case of the delay effect. It would therefore be useful to determine what would happen with the other effects.

Finally, in the field of Neuroscience, future lines of research need to focus on broadening the analysis of the anomalies in order to know which areas of the brain are affected by the presence of these effects and how imagination and willpower are affected. It would be useful to analyse the preferences of individuals with striatal and insular brain activities along with individual biological (ethnicity, gender, age, obesity and genetic polymorphisms) and social (culture, income, work, social status and marital status, etc.) attributes. Another possible line of research is to understand the neural behaviour in the intertemporal choices of animals.

7. Conclusion

This paper has described a systematic review of literature on the main intertemporal choice effects (delay effect, magnitude effect, sign effect, sequence effect, delay/speed-up asymmetry, sequence effect and interval effect). From the analysis of the most important contributions in this field, it has been possible to identify anomalies, and those areas which require further investigation. It is worth noting that the date-delay, interval, and sequence effects have received comparatively less attention. In addition, there is a growing number of studies focusing on more realistic intertemporal decisions such as those related to climate change or borrowing, yet there is a lack of study in the domain of business, specifically from a managerial point of view. From a theoretical perspective, there is a trend towards the unification of the EU and DU models as an explanation for the different anomalies.

This analysis has also identified a particular problem in this field, viz the wide variety of names given by different authors to these effects, especially in the case of the delay effect. This causes difficulties for any profound analysis of these anomalies. Therefore, it is necessary to achieve consistency when referring to these effects, because only in this way can a complete analysis be made in each area of study. In this paper, the following denominations have been used to standardise: delay effect, magnitude effect, sign effect, sequence effect, delay/speed-up asymmetry, sequence effect and interval effect.

Regarding the limitations of this paper, the variety of names given to all the anomalies meant that articles which did not include keywords for the search were not considered. Another constraint was that early studies of these anomalies were not found in the databases chosen, as these only included articles from the 1990s onwards. However, the authors of this paper have included those which are most relevant.

Ethics approval and consent to participate

"Not applicable" in this section.

Consent for publication

"Not applicable" in this section.

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Authors' contributions

POF convened the working group, contributed to the consultation document, collated feedback, wrote the draft manuscript, and critically revised and approved the final manuscript. SCR participated in the working group, contributed to the consultation document, and critically revised and approved the final manuscript. IMPO participated in the working group, contributed to the consultation document, and critically revised and approved the final manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

"The authors declare that they have no competing interests" in this

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Data availability

No data was used for the research described in the article.

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Appendix

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