Intertemporal Correlation Aversion – A Model-Free Measurement*

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Abstract

Decisions with risky consequences at multiple points in time are driven not only by risk attitudes and time preferences, but also by attitudes towards intertemporal correlation, i.e. correlation between outcomes at different points in time. This paper proposes a model-free method to measure degrees of intertemporal correlation aversion. We disentangle attitudes towards positive and negative intertemporal correlation, which can differ if expected intertemporal utility is violated. In an experiment, subjects on average exhibited correlation aversion both for lotteries with positive correlation and for lotteries with negative correlation. That is, they disliked positive correlations and liked negative correlations. At the individual level, we found heterogeneity, and remarkably many subjects being insensitive to intertemporal correlations. Moreover, for most subjects expected intertemporal utility was violated, because attitudes towards positive and negative correlation differed.

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1 Introduction

Most decisions have consequences that are both delayed and risky. Moreover, such consequences typically involve not only a single, but multiple points in time. Savings decisions, for instance, require people to think about how much they would like to consume at multiple points during a period of time, with future needs and returns on savings being risky. Health behavior is another example of decision making that involves risky outcomes at multiple future points in time. Decisions to live a healthier life by exercising more or going on a diet, involve investments in the near future with prolonged, but risky, health benefits in the further future.

Risk attitudes and intertemporal preferences are key determinants of behavior with delayed and risky consequences. An additional key determinant of behavior when there are *multiple* delayed and risky consequences, is the attitude towards intertemporal correlations, i.e. the degree to which people like or dislike correlations between outcomes received at multiple points in time (Bommier, 2007). Attitudes towards intertemporal correlation are closely related to intertemporal elasticities of substitution. Hence, they play a central role in savings and investment behavior during the life cycle (Bommier and Rochet, 2006) and in the development of asset prices over time (Hansen and Singleton, 1983).

Intertemporal correlations are particularly important for lifetime decisions. Such decisions cannot be determined by risk attitudes at single timepoints only. The widely used discounted expected utility model, however, implicitly assumes that decision makers ignore intertemporal correlations. Consequently, little is known about people's attitudes towards such correlation. This paper introduces and implements a model-free method to measure such attitudes.

Most literature on intertemporal and risky choice has focussed exclusively on either the time or the risk dimension of outcomes. Recently, however, we have witnessed an increasing number of studies that combine the insights from both strands of literature (e.g. Abdellaoui et al. 2019, Abdellaoui et al. 2011, Baucells and Heukamp 2012, Epper and Fehr-Duda 2020, DeJarnette et al. 2019, Dillenberger et al. 2019, Öncüler and Onay

2008). Studies combining risk and time consider (1) single risky outcomes to be received at a single point in time, or (2) sequences of risky outcomes to be received at several points in time. The former setting is useful when merely studying discounting or changes in risk attitudes over time. The latter setting is more often the relevant one in applications. This paper concerns the latter setting. Thus, we examine decisions over risky outcomes at multiple points in time.

Decision makers who want to determine the value of a risky outcome sequence, have to aggregate the outcomes of the sequence over the risk and the time dimension. They may do so sequentially, by aggregating first over one dimension and then over the other. Then the order in which they aggregate over these dimensions is closely related to their attitudes towards intertemporal correlation, as illustrated by the following example. Consider lottery L that gives a 50% chance to receive €10 and a 50% chance to receive €5. Assume it is received twice, at times s and $t > s$. In case of perfectly positive correlation (POS) the decision maker has a 50% chance of receiving the outcome sequence $(s : 10, t : 10)$ and a 50% chance of receiving $(s : 5, t : 5)$. In case of perfectly negative correlation (NEG) the decision maker has a 50% chance of receiving the outcome sequence $(s : 10, t : 5)$ and a 50% chance of receiving the outcome sequence $(s : 5, t : 10)$.

Decision makers who first aggregate over risk at each point in time separately, will first determine the certainty equivalents of the lotteries at each point in time separately, i.e. ignoring the outcomes to be received at other points in time, and then determine the present value of the resulting sequence of certainty equivalents. As NEG gives the same lotteries as POS, the certainty equivalents for NEG will be equal to those for POS. Hence, NEG will give the same sequence of certainty equivalents as POS, and will therefore have the same present value as well, implying indifference between POS and NEG. However, decision makers who first aggregate over time, will first determine the present value of each possible outcome sequence and then the certainty equivalent of the resulting lottery over present values. As the present values differ between POS and NEG, the certainty equivalents may differ as well. Thus, while first aggregating over risk and then over time makes one ignore intertemporal correlations, first aggregating over time and then over risk makes one explicitly take these correlations into account (Epper and Fehr-Duda, 2015).

Many economic applications assume discounted expected utility. This model assumes that outcomes are separable over states of nature as well as over points in time. It essentially implies that outcomes can be aggregated over the two dimensions separately and that the order of aggregation does not matter (Berger and Emmerling, 2020). It therefore implies that people ignore, or are insensitive to intertemporal correlations. It thereby also imposes restrictions on the degree of risk aversion concerning lifetime value of consumption, because positive intertemporal correlation implies a riskier lifetime value of consumption than negative intertemporal correlation. Alternative models with different assumptions about the order of aggregation and the related intertemporal correlation attitudes, were developed some decades ago (Kreps and Porteus 1978, Epstein and Zin 1989, and Chew and Epstein 1990) and also recently (Bommier et al. 2017, Lichtendahl et al. 2012, and Bastianello and Faro 2022). Such models can enhance predictions of savings behavior and asset prices (Bommier 2007, Bommier et al. 2017, Hall 1988, and Hansen and Singleton 1983). In fact, correlation aversion is a general phenomenon that does not only play a role in intertemporal choice, but also in other multi-attribute settings[1] (Richard 1975, Epstein and Tanny 1980, Bommier 2007, Crainich et al. 2020, Denuit et al. 2010, Eeckhoudt et al. 2007, Tsetlin and Winkler 2009).

Surprisingly, whereas models that incorporate intertemporal correlation aversion have been around for a considerable time, there have been only few experimental studies on people's attitudes towards intertemporal correlation (Andreoni and Sprenger 2012, Cheung 2015, Lanier et al. 2022, Miao and Zhong 2015, Epper and Fehr-Duda 2015). Only two of these papers investigate whether people like or dislike such correlations. Andersen et al. (2018) and Ebert and van de Kuilen (2019) used choices between perfectly negatively and perfectly positively correlated risks and found a preference for the former. Ebert and van de Kuilen (2019) did not measure degrees of correlation aversion, but Andersen et al.

[1] Correlation aversion is related to residual risk aversion as defined by Dillenberger et al. (2019). A preference for negative over positive intertemporal correlation, together with an independence assumption over states of nature, implies residual risk aversion.

(2018) did so by using a parametric specification of intertemporal utility.

This paper introduces and implements a *model-free* method to measure subjects' *degrees* of intertemporal correlation aversion. Thus, we can measure not only whether or not, but also the extent to which, decision makers are intertemporal correlation averse. This allows for a comparison of intertemporal correlation aversion between decision makers and for an assessment of its sensitivity to specific aspects of the decision setting without relying on parametric assumptions. To illustrate this point, most estimations in Andersen et al. (2018) are based on expected utility, and some on rank-dependent utility (Quiggin, 1982). Violations of these models distort their results.

Our paper is the first to decompose intertemporal correlation attitudes into attitudes towards positive and negative correlation, which we show to be particularly relevant in case of deviations from an expected utility framework. Positive correlation-aversion implies a preference for independent over positively correlated lotteries ($IND \succ POS$), suggesting correlation aversion. Consistently with Epstein and Tanny (1980), negative correlation-aversion is defined by a preference for negatively correlated lotteries over independent ones ($NEG \succ IND$), which, indeed, again suggests correlation aversion in the sense that a lower degree of correlation (-1 for NEG) is preferred to a higher degree of correlation (0 for IND). Our method elicits present certainty equivalents (PCEs) of positively- and negatively-correlated and independent intertemporal risks. A higher degree of positive correlation-aversion implies a larger difference, in PCEs, between independent and positively correlated risks. Similarly, a higher degree of negative correlation-aversion implies a larger difference, in PCEs, between negatively correlated and independent risks.

We show that positive and negative correlation-aversion go hand in hand under expected intertemporal utility. This model assumes that decision makers can first aggregate over time by computing the intertemporal utility of each possible outcome sequence, and then aggregate over risk by expected utility, where intertemporal utility need not be time-separable. If expected utility is violated, correlation attitudes can differ between lotteries with positive and negative correlation. One possibility is that a preference for negatively over positively correlated lotteries is then driven by positive correlation-aversion and negative correlation-neutrality or negative correlation-aversion and positive correlation-neutrality. Another possibility is that this preference is driven by a combination of correlation aversion and correlation seeking. Hence, disentangling attitudes towards positive and negative correlation will enhance our understanding of the drivers of correlation aversion and allow for a more accurate measurement of correlation aversion. Our experiment finds that for most subjects, attitudes towards positive and negative correlation indeed differed, revealing a violation of expected intertemporal utility.

Our experimental design differs from the ones of Ebert and van de Kuilen (2019) and Andersen et al. (2018), as we do not require our subjects to make direct choices between types of intertemporal correlation. Thereby, we do not explicitly ask them to compare different types of intertemporal correlation and make this comparison less salient. This allows us to assess the robustness of intertemporal correlation aversion. In a different setting, Fox and Tversky (1995), for instance, found much more ambiguity aversion in the usual within-subjects design where subjects compared the ambiguous with the risky situation, than in their between-subjects design where this comparison was not possible. Their findings showed that an explicit comparison between two situations may, due to contrast effects, lead to overestimations of effects. It led them to argue against universal ambiguity aversion, something confirmed in later empirical studies (Trautmann and van de Kuilen 2015). The differences between choice and valuation (often "matching"; Hardisty, Thompson, Krantz, and Weber 2013), and between within- versus between-subject designs (Greenwald 1976), have been widely debated.

The results of our experiment show that on average subjects were positive as well as negative correlation-averse. A preference for negative over positive correlation is thereby driven by disliking positive as well as liking negative intertemporal correlation. This gives evidence against aggregating first over risk and then over time (because then correlations are ignored) and is consistent with the results of Öncüler and Onay (2008), who found that decision makers first process the time dimension and then the risk dimension when evaluating lotteries that give a single nonzero outcome at a single point in time. We also confirm the results of Lampe and Weber (2022), who, using parametric estimations of prospect theory functions, found that decision makers first aggregate over the time dimension when evaluating lotteries that give risky outcomes at multiple points in time.

Remarkably, we found that for the majority of subjects, attitudes towards positive and negative correlation differed. For these subjects, expected intertemporal utility is not suitable, even if intertemporal utility is non-separable. We also found considerable heterogeneity in attitudes towards intertemporal correlation. A substantial fraction of 21-31% of our subjects were correlation-seeking and 29-46% were correlation-neutral.

We did not find the degrees of correlation aversion to be affected by framing or the timing of resolution of uncertainty, suggesting robustness of intertemporal correlation attitudes. While framing was not found to affect the degrees of correlation aversion, as measured by relative differences in PCEs, we did find an impact on the reported PCEs themselves. This framing effect was mainly driven by its impact on risk aversion, as we will discuss in the results section. Interestingly, we did not find an effect of the timing of resolution of uncertainty on PCEs.

2 Intertemporal correlation

This paper considers binary lotteries that are received twice, i.e. at two points in time. *Lottery* $X_p x$ gives outcome $X > 0$ with probability p and outcome $x > 0$ with probability $1 - p$, where we assume $X > x$. Outcomes are monetary. Imagine a decision maker who receives this lottery twice, once at time s ("soon") and once at time $t > s$. If the two lotteries are independent, one of the possible *outcome sequences* that the decision maker may receive is $(s : x, t : X)$, i.e. x is received at timepoint s and X at timepoint t.[2] The outcome sequences that can be generated by the two lotteries depend on the correlation between the lotteries at the two points in time. We consider three situations: POS, where the outcomes of the lotteries are positively correlated over time, NEG, where the outcomes are negatively correlated, and IND where the lotteries are independent and, thus, uncorrelated. To simplify the analysis, and allow for the most extreme cases of

[2]Throughout we assume a default neutral outcome 0 ("life as usual") at all unspecified timepoints.

	POS		NEG		IND			
	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.25
s	X	x	X	x	X	X	x	x
t	X	x	x	X	X	x	X	x

Table 1: Three types of intertemporal correlation

correlation, we will assume $p = 0.5$ henceforth.

The *intertemporal lottery* $(X_{0.5}x)^{POS}_{\{s,t\}}$, or POS for short, gives outcome sequence $(s : X, t : X)$ or $(s : x, t : x)$, each with probability 0.5. The intertemporal lottery $(X_{0.5}x)^{NEG}_{\{s,t\}}$, or NEG, gives $(s : X, t : x)$ or $(s : x, t : X)$, each with probability 0.5. Finally, $(X_{0.5}x)^{IND}_{\{s,t\}}$, or IND, gives $(s : X, t : X)$, $(s : X, t : x)$, $(s : x, t : X)$, or $(s : x, t : x)$, each with probability 0.25. Table 1 summarizes.

We consider preferences $\succcurlyeq$ over intertemporal lotteries, and assume weak ordering (completeness and transitivity) with $\succ, \sim, \prec$, and $\preccurlyeq$ as usual. The preference domain also contains outcomes. These are assumed to be received with certainty at present. The present coincides with timepoint $s = 0$, and outcome x is identified with the sequence $(0 : x, t : 0)$. We assume monotonicity, i.e. strictly increasing an outcome (also in any intertemporal lottery) is always strictly preferred. Sequences of outcomes $(s : x, t : y)$ are equated with degenerate lotteries yielding them with certainty. We assume that for all intertemporal lotteries L considered, there exists a *present certainty equivalent*, denoted $PCE(L)$.

Consistently with Epstein and Tanny (1980), we say that intertemporal correlation is increasing from NEG to IND and from IND to POS. A decision maker is *positive (intertemporal) correlation-averse* if she prefers no correlation to positive correlation, i.e. $IND \succ POS$ for all $X > x > 0$ and $s < t$. Similarly, a decision maker is *negative (intertemporal) correlation-averse* if she prefers negative correlation to no correlation, i.e. she *likes* negative correlation: $NEG \succ IND$ for all $X > x > 0$ and $s < t$. Positive and negative correlation-aversion thereby both imply a preference for lower degrees of intertemporal correlation. A decision maker is *positive* and/or *negative correlation-seeking* if the aforementioned preferences are always the reverse, and *positive* and/or *negative correlation-neutral* if the aforementioned preferences are always an indifference. A decision maker is *(intertemporal) correlation averse* if $NEG \succ POS$ for all $X > x > 0$ and $s < t$. Correlation seeking and neutrality are defined similarly as before.

We propose to measure the *degree of positive correlation-aversion* by computing the difference in present certainty equivalents between the independent and positively correlated lotteries, relative to the independent lottery:

$$\Delta^{\%}_{POS} = \frac{PCE\,(IND) - PCE\,(POS)}{PCE\,(IND)}.$$

Similarly, we propose to measure the *degree of negative correlation-aversion* by computing the difference in present certainty equivalents between negatively correlated and independent lotteries, relative to the independent lottery:

$$\Delta^{\%}_{NEG} = \frac{PCE\,(NEG) - PCE\,(IND)}{PCE\,(IND)}.$$

Positive and negative correlation-aversion jointly imply correlation aversion. Yet, a decision maker may be correlation averse while being positive or negative correlation-seeking. Hence, positive and negative correlation-aversion need not go hand in hand. The following example shows that a decision maker may be indifferent between positive and negative intertemporal correlation while strictly preferring no correlation (IND) to both positive and negative intertemporal correlation.

Example 2.1

Consider a decision maker who evaluates intertemporal lotteries by first computing the discounted utilities of all possible outcome sequences, with discount function δ and utility function v, and then computing the rank-dependent utility of these discounted utilities with probability weighting function w. This decision maker applies the *rank-dependent discounted utility model* (Abdellaoui et al. 2022). We assume impatience, $(s : X, t : x) \succcurlyeq$

$(s:x, t:X)$, so that $0 < \delta(s) < 1$ for all s. We then have

$$\begin{aligned}
RDDU(POS) &= w(0.5)\left(\delta(s)v(X) + \delta(t)v(X)\right) + (1 - w(0.5))\left(\delta(s)v(x) + \delta(t)v(x)\right) \\
RDDU(NEG) &= w(0.5)\left(\delta(s)v(X) + \delta(t)v(x)\right) + (1 - w(0.5))\left(\delta(s)v(x) + \delta(t)v(X)\right) \\
RDDU(IND) &= w(0.25) \times \left(\delta(s)v(X) + \delta(t)v(X)\right) \\
&+ (w(0.5) - w(0.25)) \times \left(\delta(s)v(X) + \delta(t)v(x)\right) \\
&+ (w(0.75) - w(0.5)) \times \left(\delta(s)v(x) + \delta(t)v(X)\right) \\
&+ (1 - w(0.75))) \times \left(\delta(s)v(x) + \delta(t)v(x)\right) \\
&= w(0.5)\delta(s)v(X) + (1 - w(0.5))\,\delta(s)v(x) \\
&+ (w(0.75) - w(0.5) + w(0.25))\,\delta(t)v(X) \\
&+ (1 - w(0.75) + w(0.5) - w(0.25))\,\delta(t)v(x) \\
&= w(0.5)\delta(s)v(X) + (1 - w(0.5))\,\delta(s)v(x) + w(0.5)\delta(t)v(X) + (1 - w(0.5))\,\delta(t)v(x) \\
&+ (w(0.75) - 2w(0.5) + w(0.25))\,\delta(t)v(X) \\
&+ (-w(0.75) + 2w(0.5) - w(0.25))\,\delta(t)v(x) \\
&= RDDU(POS) + (w(0.75) - 2w(0.5) + w(0.25))\,\delta(t)\left(v(X) - v(x)\right)
\end{aligned}$$

If, $w(p) = p$ for all p then we have the *discounted expected utility model (DEU)*. DEU implies insensitivity towards intertemporal correlation: $POS \sim IND \sim NEG$. When w is non-linear, correlation attitudes depend on the shape of w. As $v(X) > v(x)$, we have $IND \succcurlyeq POS$ if and only if $w(0.75) - 2w(0.5) + w(0.25) \geq 0$. We know that $0.5\left(w(0.75) + w(0.25)\right) > w(0.5)$ if w is strictly convex. Similarly, $0.5\left(w(0.75) + w(0.25)\right) < w(0.5)$ if w is strictly concave. Thus, if w is strictly convex we have positive correlation-aversion, i.e. $IND \succ POS$. Yet, if w is strictly concave we have positive correlation-seeking.

Similarly, we have

$$RDDU(IND) = RDDU(NEG) + (w(0.75) + w(0.25) - 1)\,\delta(t)\left(v(X) - v(x)\right)$$

Hence we have $NEG \succcurlyeq IND$ if and only if $1 - w(0.75) - w(0.25) \geq 0$. It follows that $NEG \succ IND$ if w is strictly convex. Similarly, $NEG \prec IND$ if w is strictly concave.

Finally, $NEG \succcurlyeq POS$ if and only if $1 - w(0.5) \geq w(0.5)$, i.e. $w(0.5) \leq 0.5$. Hence, in the $RDDU$ model, attitudes toward intertemporal correlation depend on the shape of the probability weighting function. If w is strictly convex for all probabilities, we have $NEG \succ IND \succ POS$, and if w is strictly concave for all probabilities, we have $NEG \prec IND \prec POS$. Yet, w can be convex for some probabilities and concave for others. When allowing for such probability weighting functions, one can readily devise functions w that imply $NEG \succcurlyeq POS \succ IND$, $IND \succ NEG \succcurlyeq POS$, $IND \prec NEG \preccurlyeq POS$, or $NEG \preccurlyeq POS \prec IND$. Therefore, positive and negative correlation-aversion need not go hand in hand. In particular, the subjective value of IND need not be between those of POS and NEG. $\square$

While positive and negative correlation-aversion need not go hand in hand, many models in the literature are what we will call expected intertemporal utility models, which assume positive and negative correlation-aversion to be equivalent. Consider a decision maker whose preferences over outcome sequences with at most two non-zero outcomes can be represented by a continuously differentiable *intertemporal utility* function $U(s : x_s, t : x_t)$, which need not be additively separable. Single outcomes that are received immediately are evaluated by $u(x) = U(0 : x, t : 0)$. Given our assumption of a default 0 outcome at all times not specified, we have $U(0 : x, s : 0) = U(0 : x, t : 0)$ for all s, t. The *expected intertemporal utility model* assumes that preferences $\succcurlyeq$ over intertemporal lotteries can be represented by expected intertemporal utility:

$$E\left[U(s : x_s, t : x_t)\right].$$

Expected intertemporal utility assumes that decision makers aggregate first over time using a flexible intertemporal utility function, and then over risk using expected utility. It thereby does not allow for non-linear probability weighting. Moreover, the outcome realised at time s cannot serve as a reference point for the evaluation of the lottery at time t.

The following theorem states that positive correlation-aversion implies negative correlation-aversion and vice versa for expected intertemporal utility. Andersen et al. (2018) consider a special case of this model.

Theorem 2.2 *Under expected intertemporal utility, positive correlation-aversion (neutrality/seeking) holds if and only if negative correlation-aversion (neutrality/seeking) does.*

Under expected intertemporal utility, the degrees of positive and negative correlation-aversion approach each other when X approaches x, as is shown in the following theorem. Moreover, for two individuals who have the same present certainty equivalent of the independent lottery, the difference in degrees of positive and negative correlation-aversion between the two individuals are determined by the first-order derivative of the utility function u and by the second-order derivative of the intertemporal utility function U with respect to x_s and x_t.

Theorem 2.3 *Under expected intertemporal utility with continuously differentiable intertemporal utility U, we have for all $s < t$ and all outcomes $X > x > 0$*

$$\lim_{X\to x} \Delta^{\%}_{POS} = \lim_{X\to x} \Delta^{\%}_{NEG} = \frac{U_{x_s x_t}(s:x, t:x)}{u'\left(PCE\left(IND\right)\right) \times PCE\left(IND\right)} \times Var(X_{0.5}x),$$

where

$$U_{x_s x_t}(s:x, t:x) = \frac{\partial^2 U(s:x, t:x)}{\partial x_s \partial x_t},$$

and $Var(X_{0.5}x)$ denotes the variance of lottery $X_{0.5}x$.

3 Experimental Design

We implemented our measures of positive and negative correlation-aversion in an experiment. Our experiment considers two lotteries, which are received twice, at two points in time, and which can be positively or negatively correlated, or independent. The first lottery gives either €5 or €10, both with 50% probability. The second lottery gives €30 with 25% probability and nothing otherwise (Table 2). We measure positive correlation aversion using both lotteries and negative correlation aversion using the first lottery. For the second lottery NEG gives a larger expected value in the second period than POS and

IND, because it gives €30 with 25% probability at time s and with 75% probability at time t. It can thereby be used to check whether subjects understood the tasks and took probabilities into account, as we expect a stronger preference for NEG over IND due to the difference in expected value reinforcing negative correlation aversion.

We consider three time frames (Table 3). The lottery is received today and in 4 weeks, in 1 week and in 5 weeks, or in 1 week and in 24 weeks. Two time frames have an equal delay of four weeks between both lotteries, and differ in terms of the timing of the first lottery – today or in one week. We expected that a larger delay between the two lotteries could result in a reduced sensitivity to correlation through an increased likelihood of the lotteries being perceived as separate. To test this intuition, our third time frame has a much larger delay between the two lotteries. For each lottery we consider POS, NEG, and IND (Figure 1). For each time frame we also consider a risk-free case CER, which gives the expected value of the lottery (€7.5) at both points in time for sure. This allows for a separation of correlation attitudes, risk attitudes, and time preferences.

p	x	X
0.5	5	10
0.25	0	30

Table 2: Lotteries

t	T
today	4 weeks
1 week	5 weeks
1 week	24 weeks

Table 3: Time frames

For every intertemporal lottery, we elicited subjects' present certainty equivalents through choice lists. These PCEs are denoted by PCE_{POS}, PCE_{NEG}, PCE_{IND}, and PCE_{CER}. For the €5-€10 lottery the first choice in the choice list concerned a choice between the intertemporal lottery and €1 today, and the last choice compared the intertemporal lottery to €20 today. For the €0-€30 lottery the first value was €2 today and the last one was €40 today. In both cases the choice lists consisted of 20 rows. The PCEs resulting from the switching points in the choice lists, allow us to calculate model-free degrees of positive and negative correlation-aversion, $\Delta^{\%}_{POS}$ and $\Delta^{\%}_{NEG}$. For the analysis of the results of our

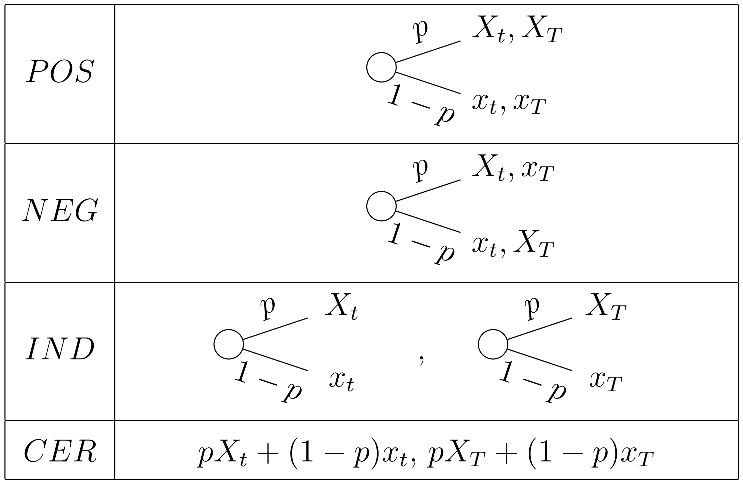


Figure 1: Intertemporal correlations

experiment we also use model-free measures of risk aversion and time preference. As the measure of risk aversion, we compute the strength of preference for CER over IND for each lottery and time frame as follows:

$$RA = \frac{PCE_{CER} - PCE_{IND}}{PCE_{IND}}.$$

The more risk averse, the larger RA. For every pair of time frames i and j ($i < j$), we computed

$$TP(i,j) = \frac{PCE_{CER_j} - PCE_{CER_i}}{PCE_{CER_i}}$$

as a measure of time-preference: the less one discounts between time frame i and time frame j, the larger $TP(i,j)$.

At the start of the experiment, subjects first filled out a practice choice list for a lottery which gives €5 with 75% probability and €10 otherwise. For this practice question we implemented positive correlation. After this practice question every subject filled out 21 choice lists: 2 (lotteries) × 3 (time frames) × 3 (POS, NEG, IND) + 3 (CER for 3 time frames). The choice lists were grouped by time frames, the order of which was randomized. Within each time frame the order of the CER, POS, NEG, and IND questions was randomized. Within each of POS, NEG, and IND the order of the lotteries was randomized. We chose this randomization to be able to correct for order effects without confusing our subjects. At the end of the experiment subjects were asked for their gender, year of birth, nationality, and field of study.

3.1 Framing

We randomly allocated subjects to one of four treatments, which differed in terms of framing and timing of resolution of uncertainty, to assess the robustness of our measurements. We constructed two types of framing, the risk-first and the time-first framing. The risk-first framing encourages subjects to ignore intertemporal correlations, whereas the time-first framing encourages them *not* to ignore these correlations. For *POS* and the €5-€10 lottery in the 0-4 weeks time frame, these two types of framing are as follows:

> *Risk-first condition*
>
> Option A gives you an amount of money twice: once today and once in 4 weeks.
> The amounts are uncertain:
>
> - Today you get €5 with 50% probability and €10 with 50% probability
> - In 4 weeks you get €5 with 50% probability and €10 with 50% probability
>
> The amount you get in 4 weeks is the <u>same</u> as the amount you get today.
> [*after this text there was a tree with two branches corresponding to the outcome sequences, as illustrated in Figure 1*]

Time-first condition

Option A gives you an amount of money twice: once today and once in 4 weeks. The amounts are uncertain:

- with 50% probability you get €5 today and €5 in 4 weeks
- with 50% probability you get €10 today and €10 in 4 weeks

[*after this text there was a tree with two branches corresponding to the outcome sequences, as illustrated in Figure 1*]

For NEG the risk-first condition had the same framing as for POS, except for the last sentence, which for NEG was: "The amount you get in 4 weeks equals the amount you do not get today." The time-first condition for NEG would simply state the relevant outcome sequences, as for POS. The trees depicted in the figures did not differ between framings for both POS and NEG. For IND the risk-first condition also had the same framing as for POS and NEG, except for the last sentence: "The amount you get in 4 weeks is independent from the amount you get today." The graphs in the risk-first condition showed two trees next to each other, as in Figure 1. For the time-first condition the four possible outcome sequences were spelled out, resulting in one tree with four branches. Hence, for IND the trees depicted in the figures differed between framings, while for POS and NEG these did not differ between framings. Figures 1 and 2 in the Online Appendix are screenshots that illustrate the two framings for IND. The CER framing was the same for the risk-first and time-first framing.

3.2 Resolution of uncertainty

We considered both early and gradual resolution of uncertainty, between subjects. For half of the subjects the uncertainty was resolved at the end of the experimental session (the immediate-resolution condition). For the other half the uncertainty was resolved when they received the amounts on their bank accounts (the gradual-resolution condition).

Imagine a subject in the gradual-resolution condition. For the NEG and POS questions all uncertainty is resolved at the first payment, as the first payment tells the subject what she will receive as second payment. For the IND condition, however, she has to wait for the second payment for the uncertainty about the second payment to be resolved. Thus, for a subject with a preference for early resolution of uncertainty, the NEG and POS lotteries will be more attractive compared to the IND lotteries in the gradual-resolution than in the immediate-resolution condition.

3.3 Payments

For every subject one decision was randomly chosen to be paid for real by banktransfer. All paid decisions were randomly selected by a bingo machine and all risks involved in the experiment were resolved by one or two four-sided dice. On average our subjects earned €18.80 in total. When subjects finished answering all questions, those in the gradual-resolution group were asked to leave the room. They would eventually receive an email with a link to a recorded video of how the risk was resolved. The immediate resolution group was informed of their payoffs in the experiment room. For all subjects the same question was paid out, and the ones choosing the intertemporal lottery would all receive the same payments. The payoffs in the immediate and gradual resolution groups were independent.

4 Results

A total of 256 students[3] participated in our experiment: 64 in each treatment. They were recruited Subjects were allowed to switch back and forth between the options in the choice lists. Subjects who exhibited a wrong switch or multiple switches in at least 10 out of the 21 questions (5 subjects in total), were dropped from the sample[4]. For the remaining subjects,

[3]Subjects were recruited from the subject pool of the ESE-econlab at Erasmus University Rotterdam.

[4]Switching multiple times is a violation of monotonicity. Subjects could also switch in the wrong direction, by choosing the lottery when the immediate sure amount is large, and switching to the immediate sure amount when this amount gets smaller. Twenty-three subjects exhibited a wrong or multiple switches

the present certainty equivalent for the questions where they switched wrongly or multiple times, was set to missing. We also set the PCE to missing in case the subject reported a PCE below the lowest possible immediate amount to be received with the lottery in the 0-4 weeks time frame[5]. The PCE of a question where a subject never switched was set to the value it would have had if the subject would switch if one additional row were added.[6] Of the 251 remaining subjects, 45% were female and the vast majority were students with an economics or business background. This section reports the results for the €5-€10 lottery, which allow for an analysis of positive as well as negative correlation-aversion. The results for the €0-€30 lottery are in the Appendix.

Figure 2 summarizes the average PCEs across all treatments (see also Table 1 in the Online Appendix). This figure suggests that on average our subjects were positive as well as negative correlation-averse, because PCEs are increasing from POS to IND and from IND to NEG. Moreover, subjects seem to be risk averse because PCEs are smaller for IND than for CER. Finally, Figure 2 also suggests that our subjects discounted the future as PCEs are smaller for later time frames. The remainder of this section will confirm these patterns using statistical analyses. We will use Wilcoxon signed-rank tests for within-subjects comparisons, and Mann-Whitney U tests for between-subjects comparisons. All reported p-values are two-sided.

in at least one question, nine of them in only one question.

[5]Ten subjects had such a PCE in at least one of the questions.

[6]Fourty subjects always chose the lottery in at least one of the questions and twenty-three subjects always chose the immediate sure outcome in at least one of the questions.

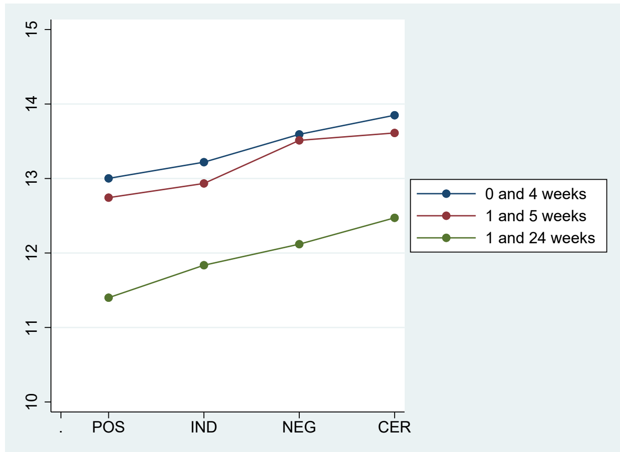


Figure 2: Present certainty equivalents (means) for €5-€10 lottery

4.1 Discounting and risk aversion

Before analyzing correlation attitudes, we first want to check whether our subjects exhibited the usual risk attitudes and time preferences. The results confirm that on average our subjects indeed were risk averse and discounted the future. For both lotteries and all time frames the risk aversion indices RA are positive (all $p < 0.001$). All time preference indices $TP(i, j)$ are negative ($p = 0.055$ for a comparison between the 0-4 weeks and 1-5 weeks time frames and $p < 0.001$ for the other two comparisons), confirming that subjects discounted the future, though only marginally in the near future.

Subjects who are risk averse and discount the future, should report PCEs that are lower than the undiscounted expected total payoff of €15 (lower than €30 for the NEG versions of the €0-€30 lottery). For both lotteries and all time frames this was indeed the case ($p < 0.001$ for all except for a few[7] with $p < 0.05$). Subjects who discount the future, should also report larger PCEs for the 0-4 weeks than the 1-5 weeks time frame and larger PCEs for 1-5 weeks than for 1-24 weeks. The PCEs do not differ between the 0-4 weeks and the 1-5 weeks frame (except for CER with $p = 0.043$, consistent with subjects discounting the future). The differences between the 0-4 weeks and the 1-24 weeks time frame and

[7]For some of the questions involving IND or POS for the €0-€30 lottery we found $p < 0.05$.

between the 1-5 weeks and the 1-24 weeks time frame all confirm that subjects discounted the future ($p < 0.01$ for all, except for one with $p = 0.021$). This stronger discounting for the far than for the near future is inconsistent with present-bias, but consistent with the constant-sensitivity discount function of Ebert and Prelec (2007).

4.2 Correlation aversion

The average PCEs in Figure 2 suggest that, overall, subjects were positive as well as negative correlation-averse, because they prefer IND to POS and NEG to IND. The degrees of correlation aversion confirm this. The measure $\Delta^{\%}_{POS}$ captures the strength of preference for IND over POS, $\Delta^{\%}_{NEG}$ the strength of preference for NEG over IND, and $\Delta^{\%}_{NEG}+\Delta^{\%}_{POS}$ the strength of preference for NEG over POS. Each of these variables should be larger than zero in case of correlation aversion. Table 4 summarizes the averages of the degrees of correlation aversion and confirms that our subjects were correlation averse[8].

For one of the time frames (1-5 weeks), the degree of positive correlation-aversion is not significantly different from zero. Interestingly, the average degrees of correlation aversion in Table 4 suggest that the preference for negative over positive correlation is more strongly driven by negative than by positive correlation-aversion, because the average degrees of correlation aversion are smaller for positive than for negative correlation. In absolute terms, all degrees of correlation aversion are smaller than the average degrees of risk aversion, which equal 0.092, 0.266, and 0.258 for the three time frames, respectively.

[8]Table 2 in the Online Appendix reports these numbers separately for each treatment.

	€5 or €10		
	$\Delta^{\%}_{POS}$	$\Delta^{\%}_{NEG}$	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$
0 and 4 weeks	-0.007 ($p = 0.040$)$^{\diamond}$	0.063 ($p = 0.007$)	0.056 ($p < 0.001$)
1 and 5 weeks	-0.021 ($p = 0.622$)	0.091 ($p < 0.001$)	0.069 ($p < 0.001$)
1 and 24 weeks	0.008 ($p = 0.008$)	0.071 ($p = 0.018$)	0.080 ($p < 0.001$)

Note: Mean degrees of correlation aversion, with between parentheses the p-value of a Wilcoxon signed-rank test to test whether the difference deviates from zero.

$^{\diamond}$ Note that for all cases, even those where the mean is negative, the Wilcoxon signed-rank tests suggest the median is positive.

Table 4: Degrees of correlation aversion

(a) Positive correlation

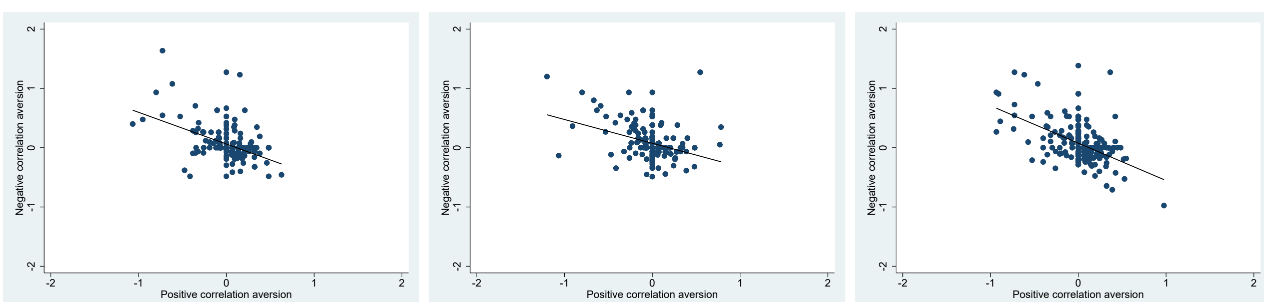
(b) Negative correlation

Figure 3: Attitudes towards positive and negative correlation for the €5-€10 lottery

We are not only interested in the average correlation-attitudes of our subjects, but also in the heterogeneity of these attitudes. Figure 3 gives the percentages of subjects who were positive and negative correlation-averse, neutral, or seeking for each time frame. This figure shows a high degree of heterogeneity between subjects. Regarding positive correlation-aversion ($\Delta^{\%}_{POS} > 0$), only 31-38% behaved as such, while 40-43% were positive correlation-neutral ($\Delta^{\%}_{POS} = 0$) and 21-27% were positive correlation-seeking ($\Delta^{\%}_{POS} < 0$). Regarding negative correlation, the proportions are similar, with 31-39% negative correlation-averse ($\Delta^{\%}_{NEG} > 0$), 31-46% correlation-neutral ($\Delta^{\%}_{NEG} = 0$), and 21-31% negative correlation-seeking ($\Delta^{\%}_{NEG} < 0$). For the €0-€30 lottery we saw a little more aversion and less neutrality towards positive correlation: 42-46% were positive correlation-averse, 29-36% were positive correlation-neutral, and 21-26% were positive correlation-seeking.

The heterogeneity in correlation-attitudes is also visible in Figure 4, which illustrates the distributions of *degrees* of positive and negative correlation-aversion for the three time frames[9]. Section 9.3 in the Appendix discusses that part of this heterogeneity may be driven by gender differences, with women being slightly more negative correlation-averse than men.

Figure 4 also shows a negative correlation between degrees of positive and negative correlation-aversion for every time frame (Spearman's correlation between -0.44 and -0.34, $p < 0.001$ for all three time frames). These degrees of positive and negative correlation aversion were negatively and positively correlated with degrees of risk aversion for each time frame ($p < 0.001$ for all time frames).



(a) €5-€10, 0 and 4 weeks (b) €5-€10, 1 and 5 weeks (c) €5-€10, 1 and 24 weeks

Figure 4: Degrees of positive and negative correlation aversion

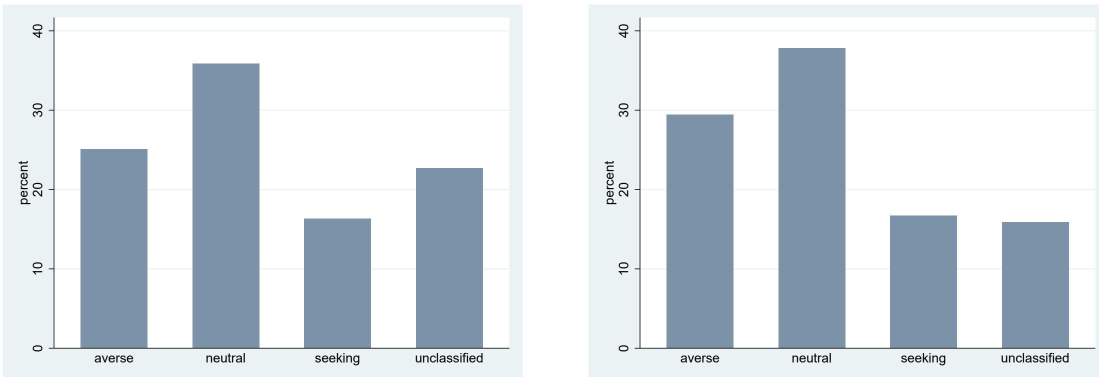
[9]Figure 4 excludes two observations with absolute degrees of correlation seeking or aversion exceeding 2.

Expected intertemporal utility predicts similar attitudes towards positive and negative correlation. For every time frame we tested whether the attitude towards positive correlation (averse, neutral, or seeking) differed from the attitude towards negative correlation and found no significant difference on average. However, only between 32% and 42% of all subjects had the same attitude towards positive and negative correlation. A binomial test showed that the probability that a subject's attitude towards positive and negative correlation differed, was larger than 50% for each time frame ($p < 0.004$ for all). Thus, for each time frame a majority of our subjects violated expected intertemporal utility.

4.3 Consistency across time frames

Next, we will analyse how consistent subjects were across time frames. We found no significant differences in degrees of negative and positive correlation-aversion between time frames. Nevertheless, on average our subjects were positive correlation averse ($\Delta^{\%}_{POS} > 0$) in only 1.03 of the three time frames, negative correlation-averse ($\Delta^{\%}_{NEG} > 0$) in 1.05 of the three time frames and correlation averse ($\Delta^{\%}_{NEG} + \Delta^{\%}_{POS} > 0$) in 1.24 of the three time frames. In Ebert and van de Kuilen (2019) subjects were correlation averse in 1.92 out of 3 choices. Unlike us, however, they did not allow for correlation neutrality, which may explain why they found a larger fraction of correlation aversion.

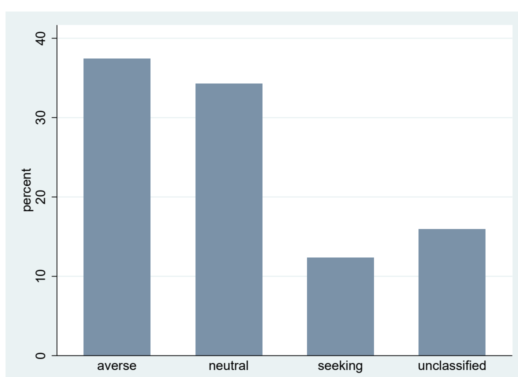
To further assess the consistency in correlation-attitudes, we classify each subject into one of four types of correlation attitudes, both for positive and for negative correlation. A subject is classified as positive correlation-averse (neutral, seeking) if $\Delta^{\%}_{POS} > (=, <)\ 0$ in at least two of the three time frames. By using a threshold of two out of three (instead three out of three) time frames, we account for the possibility that decision makers make mistakes. A subject is classified as negative correlation-averse (neutral, seeking) if $\Delta^{\%}_{NEG} > (=, <)\ 0$ in at least two of the three time frames. A subject is classified as correlation averse (neutral, seeking) for a lottery if $\Delta^{\%}_{NEG} + \Delta^{\%}_{POS} > (=, <)\ 0$ in at least two of the three time frames. In all other cases the subject is left 'unclassified'. Figures 5 and 6 show the classifications of subjects. We see a similar heterogeneity as before: while on average subjects were positive as well as negative correlation averse, a substantial fraction of 34-38% was correlation neutral and 12-17% were correlation seeking.



(a) Positive correlation (b) Negative correlation

Note: Subjects are classified as positive correlation-averse (neutral, seeking) if $\Delta^{\%}_{POS} > (=, <)\ 0$ in at least two of the three time frames. The remaining subjects are unclassified. Similarly, subjects are classified as negative correlation-averse (neutral, seeking) if $\Delta^{\%}_{NEG} > (=, <)\ 0$ in at least two of the three time frames. The remaining subjects are unclassified.

Figure 5: Attitudes towards positive and negative correlation for €5-€10 lottery



Note: Subjects are classified as correlation averse (neutral, seeking) if $\Delta^{\%}_{NEG} + \Delta^{\%}_{POS} > (=, <)\ 0$ in at least two of the three time frames. The remaining subjects are unclassified.

Figure 6: Attitudes towards correlation for €5-€10 lottery

Interestingly, Figures 5 and 6 show that there is stronger evidence for correlation aversion when comparing NEG and POS (Figure 6) than when comparing each of them to IND separately (Figure 5). In particular, the subjects classified as positive correlation-averse in Figure 5 cannot be a subset of the subjects classified as negative correlation-averse in Figure 5. This gives further evidence that positive and negative correlation-aversion do not go hand in hand. Table 5 gives a more detailed overview of how attitudes towards positive and negative correlation were related. First of all, many subjects (52%) are exhibiting neutrality towards positive or negative correlation (or both). Only 12 subjects (5%) were classified as positive as well as negative correlation-averse. A total of 104 subjects (41%) were positive as well as negative correlation-neutral or averse. Interestingly, 48 subjects (19%) were positive correlation-averse and negative correlation-seeking or positive correlation-seeking and negative correlation-averse. Thus, our results give evidence that attitudes towards positive correlation may well differ from attitudes towards negative correlation.

		negative correlation			
		averse	neutral	seeking	unclassified
positive correlation	averse	12	19	22	10
	neutral	18	55	6	11
	seeking	26	3	8	4
	unclassified	18	18	6	15

Note: Numbers are number of subjects classified as averse, seeking, neutral, or unclassified.

Table 5: Attitudes towards positive correlation and negative correlation for €5-€10 lottery

4.4 Framing and resolution of uncertainty

The PCEs and three types of degrees of correlation aversion did not differ between immediate and gradual resolution of uncertainty, except for the PCE for the €5-€10 POS lottery in the 1-24 weeks time frame being smaller for immediate than gradual resolution of uncertainty (p=0.038). Fisher exact tests also showed no association between timing of resolution of uncertainty and classification of subjects into types. We conclude that the timing of resolution of uncertainty had no significant impact in our experiment.

PCEs in the time-first treatment were significantly larger than in the risk-first treatment for POS, IND, and NEG in the 0-4 weeks time frame, but none of the other time frames (see Table 7 in Appendix). Moreover, there are no significant differences in the three types of degrees of correlation aversion between the two treatments (see Table 8 in Appendix).

Fisher exact tests also showed no clear difference between framings in terms of classification of subjects (attitude towards positive and negative correlation). Only the classification of subjects in terms of attitude towards positive correlation for the €5-€10 lottery was different between the time-first and risk-first framings, with 17 more subjects classified as positive correlation averse (and 5 more as positive correlation-seeking) in the time-first than in the risk-first framing (p=0.046). This effect disappears, however, when we classify subjects according to their preferences between NEG and POS.

All in all, we conclude that our framing conditions have a significant impact on PCEs, but not on degrees of correlation aversion. To further analyze the framing effect on PCEs, we analyzed the impact of framing on our measures of risk aversion and time preference. We found that risk aversion RA was significantly larger in the risk-first than in the time-first framing in all time-frames ($p < 0.013$ for all)[10]. Time preferences $TP(i,j)$ did not differ between framings. Thus, it appears that the framing effect on PCEs must be driven at least partly by a framing effect on risk aversion.

[10]For the €0-€30 lottery risk aversion did not differ significantly between framings.

5 Discussion

The subjects in our experiment were correlation averse on average, confirming the findings of Ebert and van de Kuilen (2019) and Andersen et al. (2018). Thus, the intertemporal correlation aversion found by these two studies extends to a setting that does not ask subjects explicitly to choose between negative and positive correlation. Nevertheless, we also found considerable heterogeneity in attitudes at the individual level. A substantial fraction of subjects were classified as insensitive to intertemporal correlations and a non-negligible fraction of subjects were positive and/or negative correlation-seeking.

We are the first to disentangle attitudes towards positive and negative intertemporal correlation. These attitudes may differ if people deviate from the expected intertemporal utility model. Deviations from this model are to be expected given the widely documented violations of expected utility. Our results confirm this expectation. Our subjects are positive as well as negative correlation-averse on average. Yet, the attitudes towards positive and negative correlation differed for between 58% and 68% of our subjects. A majority of our subjects thereby violated the expected intertemporal utility model[11].

Several studies in the literature suggest that attitudes towards correlation could be quite sensitive to framing. Ellis and Piccione (2017) introduced a model that allows for decision makers to misperceive the correlations between the returns of the assets in their portfolios. Eyster and Weizsäcker (2016) show that people tend to neglect correlations between assets in a portfolio-allocation setting. Though their setting does not involve a time-dimension, their results suggest that correlations are not always well-understood, and this indirectly suggests that people may be sensitive to framing concerning intertemporal correlations. We compared two types of framing with a theoretical underpinning. The risk-first framing was constructed to encourage subjects to ignore intertemporal correlations

[11]A related study that considered POS, NEG, and IND in a setting with the two dimensions being social and risk instead of time and risk (Rohde and Rohde, 2015), found that IND was preferred to both POS and NEG. It therefore seems important not to assume a priori that IND will be considered between POS and NEG in terms of preferences.

by first aggregating over risk and then over time. The time-first framing was constructed to encourage people to first aggregate over time and then over risk. While we expected the time-first framing to generate larger degrees of correlation aversion, we found no such framing effect. Thus, we found no systematic difference in correlation attitudes between the two framings.

While our framings did not affect correlation-attitudes, they did affect risk attitudes. The time-first treatment resulted in higher present certainty equivalents than the risk-first treatment for several lotteries and time-frames. For the €5-€10 lottery this was found only for the 0-4 weeks time frame. For the €0-€30 lottery this was found only for negative correlation, yet both for the 0-4 and the 1-5 weeks time frame. We also found that risk aversion was significantly larger in the risk-first than in the time-first framing for the €5-€10 lottery in all time-frames. Time preferences did not differ between framings.

Our finding that the time-first framing prompted people to give higher PCEs, is consistent with the findings of Öncüler and Onay (2008) and Ahlbrecht and Weber (1997) for single delayed risky outcomes. Öncüler and Onay (2008) considered preferences over single outcomes to be received at a single point in time with a particular probability. They compared three different ways of obtaining present certainty equivalents for these intertemporal lotteries. In their direct path they elicited the PCE directly. In their risk-time path they first elicited the future certainty equivalent and then asked for the present value of this future certainty equivalent, thereby explicitely first considering the risk dimension and then the time dimension. In their time-risk path they first elicited the present values and then the certainty equivalent of the resulting lottery over present values. Their risk-time and time-risk paths thereby correspond to our risk-first and time-first framings, respectively. They found that the elicited PCEs were higher in the direct and the time-risk paths than in the risk-time path.

Ahlbrecht and Weber (1997) also considered preferences over single delayed risky outcomes and found similar framing effects. Subjects were asked for the present certainty equivalent of the lottery directly, or in two steps by first asking for the future certainty equivalent and then the present value of this future certainty equivalent. For losses they found that the present certainty equivalent was higher than the present value of the future certainty equivalent. For gains their evidence pointed in the same direction, though less significantly. These results, however, were found for matching tasks where people were asked for their certainty equivalents and present values. The choice tasks did not find any difference between the present certainty equivalent and the present values of the future certainty equivalent. Öncüler and Onay (2008) also used matching tasks.

One possible driver of the framing effect we found may be time-varying risk attitudes. If one is more risk averse for later than for sooner payments, the risk-first framing generates more risk aversion and lower PCEs, as we found. Abdellaoui et al. (2011) and Noussair and Wu (2006) found, to the contrary, more risk tolerance for later payments.

In general, degrees of intertemporal correlation aversion may depend on the timing of resolution of uncertainty (Stanca, 2022), but we did not find evidence for that. Interestingly, we also found no influence of the timing of resolution on the present certainty equivalents. Thus, we do not find a preference for early resolution of uncertainty. This finding is in line with Nielsen (2020) who found no aversion to gradual resolution of uncertainty. For further literature we refer to Nielsen. An important difference between the existing studies on the timing of resolution of uncertainty and ours, is that they let their subjects explicitly choose between early and late resolution of uncertainty (Masatlioglu et al. 2017 and Abdellaoui et al. 2022), while we varied the timing of resolution of uncertainty between subjects. A question for future research is to study whether our results would be different if the timing of resolution were varied within subjects and made more salient.

Several limitation of our study provide additional suggestions for further research. We considered only three time frames. One avenue for future research is to thoroughly assess how degrees of correlation aversion depend on time frames. This will require systematically varying the timing of the first lottery and the time between the two lotteries. Another avenue for future research concerns the lotteries presented to decision makers. To keep matters simple, we restricted our study to two-outcome lotteries involving monetary gains only. It remains to be studied which attitudes decision makers have to intertemporal correlations involving more complex lotteries with more outcomes and/or losses, including non-monetary outcomes. Several authors recommended using direct consumption rather than money to avoid fungibility problems (Cohen et al. 2020). Our 1-24 weeks time frame makes fungibility less plausible than the other two time frames, but yielded similar results, suggesting that fungibility was not problematic in our experiment. Yet, further research is needed to study the robustness of our results when using different outcomes. One can think of replacing the monetary outcomes by a single non-monetary type of outcome. Another extension would be to see how correlation attitudes are affected when different types of outcomes are received at different points in time. In many applications, outcomes even have multiple attributes. When considering multi-attribute outcomes, an extra layer of dimensions is added over which decision makers have to aggregate. It remains to be studied, both experimentally and theoretically, how they aggregate over these dimensions. A final extension of our study, would be to consider a framework where decision makers receive lotteries at more than two points in time. This will not only require additional experiments, but also an extension of the theoretical framework.

6 Conclusion

This paper distinguished between positive and negative correlations, and proposed a model-free measurement of intertemporal correlation aversion. Our results showed that on average subjects were averse to intertemporal correlation, both for positive and negative correlations, but there was considerable heterogeneity at the individual level. Within subjects, positive and negative correlation-aversion did not go hand-in hand. They differed for between 58% and 68% of subjects, i.e. for the majority. This gives a clear violation of expected intertemporal utility. We also found that a substantial fraction of subjects were correlation neutral or seeking.

Subjects valued lotteries with different intertemporal correlations without being asked to directly choose between two types of correlation, avoiding contrast effects. One of our framings was constructed to encourage subjects to consider intertemporal correlations, while the other encouraged ignoring these. These framings were effective in impacting evaluations, but did not affect degrees of correlation aversion. Neither did immediate versus gradual resolution of uncertainty. We have shown that the distinction between positive and negative correlation is relevant for correlation preferences in new ways that classical models cannot accommodate, calling for further behavioral generalizations.

7 Acknowledgments

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9 Appendix

9.1 Proofs of Theorems

Proof of Theorem 2.2

We first simplify notation by fixing s and t and writing

$$U(x_s, x_t) = U(s : x_s, t : x_t).$$

Then we have

$$\begin{aligned}
u\left(PCE\left(IND\right)\right) &= 0.25U(x,x) + 0.25U(x,X) + 0.25U(X,x) + 0.25U(X,X), \\
u\left(PCE\left(POS\right)\right) &= 0.5U(x,x) + 0.5U(X,X), \quad \text{and} \\
u\left(PCE\left(NEG\right)\right) &= 0.5U(x,X) + 0.5U(X,x).
\end{aligned}$$

It follows that

$$\begin{aligned}
u\left(PCE\left(NEG\right)\right) &- u\left(PCE\left(IND\right)\right) \\
&= -0.25U(x,x) + 0.25U(x,X) + 0.25U(X,x) - 0.25U(X,X) \\
&= u\left(PCE\left(IND\right)\right) - u\left(PCE\left(POS\right)\right).
\end{aligned}$$

Thus, $NEG \succcurlyeq IND$ if and only if $IND \succcurlyeq POS$.

Proof of Theorem 2.3

By taking Taylor series approximations it follows that for X close to x we have

$$\begin{aligned}
u\left(PCE\left(IND\right)\right) &- u\left(PCE\left(POS\right)\right) \\
&= -0.25U(x,x)+0.25U(x,X)+0.25U(X,x)-0.25U(X,X) \\
&= 0.25\left[U(x,X)-U(x,x)\right]-0.25\left[U(X,X)-U(X,x)\right] \\
&\approx 0.25\frac{\partial U(x,x)}{\partial x_t}\left(X-x\right)-0.25\frac{\partial U(X,x)}{\partial x_t}\left(X-x\right) \\
&= 0.25(X-x)\left(\frac{\partial U(x,x)}{\partial x_t}-\frac{\partial U(X,x)}{\partial x_t}\right) \\
&\approx 0.25(X-x)\times-\frac{\partial^2 U(x,x)}{\partial x_s \partial x_t}(X-x) \\
&= -0.25\ \frac{\partial^2 U(x,x)}{\partial x_s \partial x_t}(X-x)^2 \\
&= -\frac{\partial^2 U(x,x)}{\partial x_s \partial x_t}Var(X_{0.5}x).
\end{aligned}$$

We also see that as X gets close to x, $PCE\left(POS\right)$ gets close to $PCE\left(IND\right)$. Then, by taking a Taylor series approximation of u around $PCE\left(POS\right)$ we have the following for X close to x:

$$\begin{aligned}
&u\left(PCE\left(POS\right)\right)\approx \\
&u\left(PCE\left(IND\right)\right)+u'\left(PCE\left(IND\right)\right)\left(PCE\left(POS\right)-PCE\left(IND\right)\right),
\end{aligned}$$

which implies

$$PCE\left(IND\right)-PCE\left(POS\right)\approx\frac{u\left(PCE\left(IND\right)\right)-u\left(PCE\left(POS\right)\right)}{u'\left(PCE\left(IND\right)\right)}.$$

From the proof of Theorem 2.2 it then follows that

$$\lim_{X\to x}\Delta^{\%}_{POS}=\lim_{X\to x}\Delta^{\%}_{NEG}.$$

9.2 Results for the €0-€30 lottery

This Appendix summarizes the results for the €0-€30 lottery. Figure 7 gives the average PCEs across all treatments. As predicted, subjects indeed gave NEG a substantially larger value than POS, IND, and CER for this lottery. Table 6 summarizes the averages of the degrees of correlation aversion and confirms correlation aversion on average. Figure 8 gives the number of subjects who were positive correlation-averse, neutral, or seeking.

For each lottery we also tested whether the degrees of negative and positive correlation aversion differ between time frames. We found no significant differences, except for the degree of negative correlation-aversion for the €0-€30 lottery being larger in the 1-5 weeks time frame than in the 0-4 weeks and 1-24 weeks time frames (p=0.05 and p=0.005).

Subjects were positive correlation-averse in 1.28 of the three time frames for the €0-€30 lottery. Figure 9 illustrates the classification of subjects' attitudes towards positive correlation.

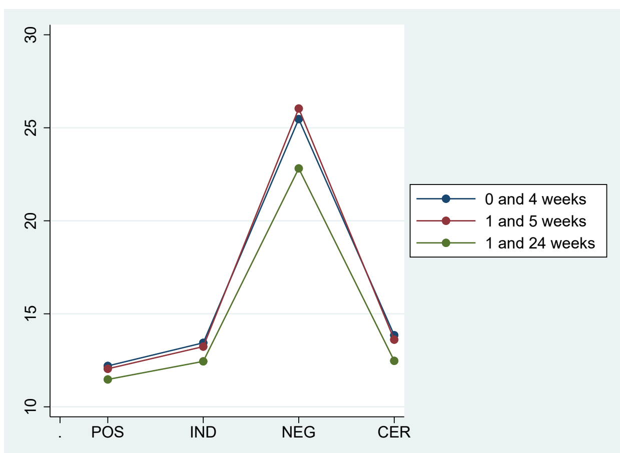


Figure 7: Present certainty equivalents (means) for €0-€30 lottery

	€0 or €30		
	$\Delta^{\%}_{POS}$	$\Delta^{\%}_{NEG}$	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$
0 and 4 weeks	0.045 $(p < 0.001)$	1.39 $(p < 0.001)$	1.39 $(p < 0.001)$
1 and 5 weeks	-0.074 $(p = 0.002)^{\diamond}$	1.86 $(p < 0.001)$	1.81 $(p < 0.001)$
1 and 24 weeks	-0.127 $(p < 0.001)^{\diamond}$	1.67 $(p < 0.001)$	1.54 $(p < 0.001)$

Note: Mean degrees of correlation aversion, with between parentheses the p-value of a Wilcoxon signed-rank test to test whether the difference deviates from zero. For comparison, the average degrees of risk aversion for the three time frames were 0.403, 0.467, and 0.469, respectively.

$^{\diamond}$ Note that for all cases, even those where the mean is negative, the Wilcoxon signed-rank test suggests the median is positive.

Table 6: Degrees of correlation aversion

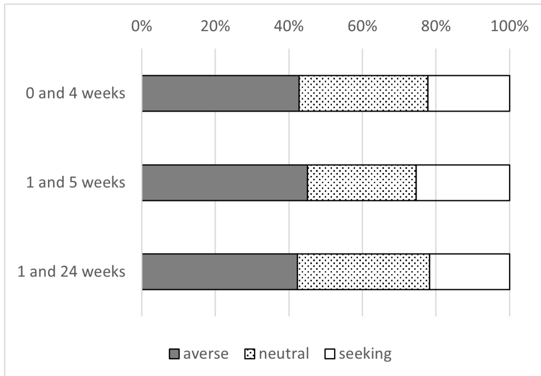
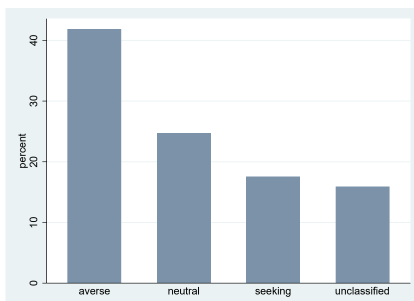


Figure 8: Attitudes towards positive correlation for €0-€30 lottery



Note: Subjects are classified as positive correlation-averse (neutral, seeking) if $\Delta^{\%}_{POS} > (=, <)\ 0$ in at least two of the three time frames. The remaining subjects are unclassified.

Figure 9: Attitudes towards positive correlation for €0-€30 lottery

		Risk-first vs. Time-first	
		€5 or €10	*€0 or €30*
0 and 4 weeks	POS	$< (p = 0.013)^{*}$	$\geq (p = 0.107)$
	IND	$< (p = 0.009)^{**}$	$\geq (p = 0.687)$
	NEG	$< (p = 0.025)^{*}$	$< (p = 0.004)^{**}$
	CER	$\geq (p = 0.319)$	
1 and 5 weeks	POS	$\leq (p = 0.250)$	$\geq (p = 0.702)$
	IND	$\leq (p = 0.129)$	$\leq (p = 0.963)$
	NEG	$\leq (p = 0.392)$	$< (p = 0.000)^{**}$
	CER	$\geq (p = 0.126)$	
1 and 24 weeks	POS	$\geq (p = 0.488)$	$\geq (p = 0.509)$
	IND	$\leq (p = 0.606)$	$\geq (p = 0.559)$
	NEG	$\geq (p = 0.697)$	$\leq (p = 0.473)$
	CER	$\geq (p = 0.135)$	

Note: ‘$\leq$’ (‘$\geq$’) means that the PCE is at least as large for the time-first (risk-first) as for the risk-first (time-first) treatment. The signs ‘$<$’ and ‘$>$’ are used when the difference is significant according to a Mann-Whitney U test with a p-value less than 0.01 (denoted by **) or less than 0.05 (denoted by *). CER is the same for both lotteries, and is therefore reported only for the €5-€10 lottery for each time-frame.

Table 7: Comparison of PCEs between Risk-first and Time-first framing

		Risk-first vs. Time-first	
		€5 or €10	*€0 or €30*
0 and 4 weeks	$\Delta^{\%}_{POS}$	$\leq$ ($p = 0.694$)	$\leq$ ($p = 0.189$)
	$\Delta^{\%}_{NEG}$	$\geq$ ($p = 0.153$)	$<$ ($p = 0.028$)*
	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$	$\geq$ ($p = 0.081$)	$<$ ($p = 0.003$)**
1 and 5 weeks	$\Delta^{\%}_{POS}$	$\geq$ ($p = 0.989$)	$\leq$ ($p = 0.593$)
	$\Delta^{\%}_{NEG}$	$\geq$ ($p = 0.161$)	$<$ ($p = 0.011$)*
	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$	$\geq$ ($p = 0.123$)	$<$ ($p = 0.009$)**
1 and 24 weeks	$\Delta^{\%}_{POS}$	$\leq$ ($p = 0.083$)	$\geq$ ($p = 0.854$)
	$\Delta^{\%}_{NEG}$	$\geq$ ($p = 0.125$)	$\leq$ ($p = 0.131$)
	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$	$\leq$ ($p = 0.862$)	$\leq$ ($p = 0.162$)

Note: '$\leq$' ('$\geq$') means that the strength of correlation aversion is at least as large for the time-first (risk-first) as for the risk-first (time-first) treatment. The signs '$<$' and '$>$' are used when the difference is significant according to a Mann-Whitney U test with a p-value less than 0.01 (denoted by **) or less than 0.05 (denoted by *).

Table 8: Comparison of degrees of correlation aversion between Risk-first and Time-first framing

Table 7 shows that for the €0-€30 lottery NEG had a higher PCE in the time-first than in the risk-first treatment for the 0-4 weeks and the 1-5 weeks time frame. Table 8 shows that for the €0-€30 lottery the degree of negative correlation-aversion is larger in the time-first than in the risk-first treatment for the 0-4 weeks and the 1-5 weeks time frame. Yet, these are also the lotteries where a preference for NEG over IND is not driven merely by negative correlation-aversion, but also by a larger expected value in NEG than in IND.

Finally, for each time frame we tested whether the degrees of positive correlation-aversion differ between the two lotteries. We found that it is smaller for the €5-€10 than for the €0-€30 lottery for all time frames (p=0.002, p=0.005, and p=0.033 for 0-4 weeks, 1-5 weeks, and 1-24 weeks, respectively). Note that a similar test would not be informative for negative correlation-aversion, as the preference for NEG over IND should be stronger in the €0-€30 lottery by construction due to the larger expected value, irrespective of the degree of negative correlation-seeking. Thus, the degree of positive correlation-aversion differs between lotteries with equal expected value. This can be driven by the difference in outcomes as well as by the difference in probabilities between the lotteries.

9.3 Gender differences in correlation aversion

Many studies find that women are more risk averse than men. Our measurements of *degrees* or correlation aversion allow us to analyze whether such gender differences also exist for intertemporal correlation aversion. First of all, our measures of risk aversion, RA, were significantly larger for women than for men ($p < 0.01$ for all, except for the €5-€10 lottery in the 0-4 weeks time frame with $p = 0.024$ and in the 1-5 weeks time frame with $p = 0.057$ and the €0-€30 lottery in the 1-5 weeks time frame with $p = 0.014$). Thus, women were more risk averse than men in our experiment, confirming the usual findings in the literature. We found no gender differences for the time-preferences $TP(i, j)$. For several combinations of lottery and time frame we found that men had a larger PCE than women (see Table 9), which is consistent with women being more risk averse while having similar time preferences. This effect seemed to be more pronounced for the €0-€30 lottery.

Women were more correlation averse than men in the 0-4 and 1-5 weeks time frames for the €5-€10 lottery, which seems to be mostly driven by a difference in attitude towards negative correlation (see Table 10). Thus, while we find only few gender differences in terms of correlations attitudes, the few significant differences point into the direction of women being more negative correlation-averse than men. A Fisher exact test on the classification of subjects confirms that women were more often classified as negative correlation-averse for the €5-€10 lottery (p=0.032).

		Men vs. Women	
		€5 or €10	*€0 or €30*
0 and 4 weeks	POS	$> (p = 0.007)^{**}$	$> (p = 0.043)^{*}$
	IND	$> (p = 0.021)^{*}$	$> (p = 0.011)^{*}$
	NEG	$\leq (p = 0.503)$	$\geq (p = 0.595)$
	CER	$\leq (p = 0.191)$	
1 and 5 weeks	POS	$\geq (p = 0.137)$	$> (p = 0.018)^{*}$
	IND	$\geq (p = 0.440)$	$> (p = 0.025)^{*}$
	NEG	$\leq (p = 0.201)$	$\geq (p = 0.685)$
	CER	$< (p = 0.046)^{*}$	
1 and 24 weeks	POS	$\geq (p = 0.193)$	$> (p = 0.009)^{**}$
	IND	$\geq (p = 0.388)$	$> (p = 0.015)^{*}$
	NEG	$\leq (p = 0.601)$	$\leq (p = 0.307)$
	CER	$< (p = 0.028)^{*}$	

Note: '$\leq$' ('$\geq$') means that the PCE is at least as large for women (men) as for men (women). The signs '$<$' and '$>$' are used when the difference is significant according to a Mann-Whitney U test with a p-value less than 0.01 (denoted by **) or less than 0.05 (denoted by *). CER is the same for both lotteries, and is therefore reported only for the €5-€10 lottery for each time-frame.

Table 9: Comparison of PCEs between men and women.

		Men vs. Women	
		€5 or €10	*€0 or €30*
0 and 4 weeks	$\Delta^{\%}_{POS}$	$\leq$ ($p = 0.983$)	$\geq$ ($p = 0.955$)
	$\Delta^{\%}_{NEG}$	$<$ ($p = 0.027$)*	$\leq$ ($p = 0.781$)
	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$	$<$ ($p = 0.037$)*	$\leq$ ($p = 0.845$)
1 and 5 weeks	$\Delta^{\%}_{POS}$	$\leq$ ($p = 0.825$)	$\leq$ ($p = 0.252$)
	$\Delta^{\%}_{NEG}$	$\leq$ ($p = 0.304$)	$\leq$ ($p = 0.413$)
	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$	$<$ ($p = 0.027$)*	$\leq$ ($p = 0.138$)
1 and 24 weeks	$\Delta^{\%}_{POS}$	$\geq$ ($p = 0.935$)	$\leq$ ($p = 0.857$)
	$\Delta^{\%}_{NEG}$	$\leq$ ($p = 0.346$)	$\leq$ ($p = 0.081$)
	$\Delta^{\%}_{NEG} + \Delta^{\%}_{POS}$	$\leq$ ($p = 0.244$)	$<$ ($p = 0.038$)*

Note: ‘$\leq$’ (‘$\geq$’) means that the strength of correlation aversion is at least as large for women (men) as for men (women). The signs ‘$<$’ and ‘$>$’ are used when the difference is significant according to a Mann-Whitney U test with a p-value less than 0.01 (denoted by **) or less than 0.05 (denoted by *).

Table 10: Comparison of strength of correlation aversion between men and women