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Risk Attitudes and Digit Ratio (2D:4D): Evidence from Prospect Theory

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Abstract

Prenatal androgens have organizational effects on brain and endocrine system development, which may have a partial impact on economic decisions. Numerous studies investigated the relationship between prenatal testosterone and financial risk taking, yet results remain inconclusive. We suspect that this is due to difficulty in capturing risk preferences with expected utility based tasks. Prospect theory, on the other hand, suggests that risk preferences differ between gains, losses and mixed prospects, as well as for different probability levels. This study investigates the relationship between financial risk taking and 2D:4D, a putative marker of prenatal testosterone exposure, in the framework of prospect theory. We conducted our study with 350 participants from Caucasian and Asian ethnicities. We do not observe any significant relationship between 2D:4D and risk taking in neither of these domains and ethnicities.

Keywords: Risk, Prospect Theory, Prenatal Testosterone, Digit Ratio

Introduction

Prenatal testosterone exposure (PTE) has organizational effects on the brain and endocrine system development of the fetus and thereby it may have a systematic influence on subsequent behavior (see Manning, 2002, for a review). This relationship has attracted the interest of economists, who studied its role in various contexts including social preferences (Buser, 2012; Brañas-Garza et al., 2013), financial trading (Coates et al., 2009), competitive bidding (Pearson and Schipper, 2012) or manegarial activities (Guiso and Rustichini, 2018). Although studies investigating the association between risk aversion and 2D:4D have the largest proportion in this literature, the results are not conclusive. While several studies showed that higher PTE yields lower risk aversion, many others reported null results.

This study investigates the relationship between financial risk taking and PTE in the framework of prospect theory. According to prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Wakker, 2010a), risk preferences may differ between gains, losses and mixed prospects, as well as for different probability levels. In his recent study, Hermann (2017) showed that higher PTE correlates with lower degrees of loss aversion. This might suggest that the inconclusive results in the literature may be due to the domain-dependent nature of risk preferences. Evolutionary perspective confirms this argument as survival decisions such as foraging or reproduction involve risk taking both in gain and loss domains. As a result, prospect theory is now shaping foraging models as well (McDermott et al., 2008). We find no significant relationship between PTE and risk-aversion in neither domains. This null result is consistent both for Caucasian and Asian samples in our study.

Background

2D:4D and Prenatal Testosterone Exposure

Unlike circulating testosterone, direct measure of PTE through saliva or blood samples is not possible as the exposure takes place during the first trimester of the pregnancy. This is why, the ratio between the lengths of the index and ring fingers (2D:4D or digit ratio) is employed as an indirect somatic marker of PTE (Goy and McEwen, 1980). A smaller 2D:4D is associated with higher PTE and men in general have lower ratios than women (Lutchmaya et al., 2004; Hönekopp and Watson, 2010).

The negative relationship between 2D:4D and PTE has been confirmed with various methods. Direct evidence from the amniotic fluid during pregnancy, Lutchmaya et al. (2004) and Ventura et al. (2013) showed a significant relationship between prenatal testosterone-estradiol ratio in utero and 2D:4D of infants and newborns. Male fetuses with Klinefelter's Syndrome are shown to have lower prenatal testosterone, therefore higher 2D:4D ratios (Manning et al., 2013). Fetuses with Congenital Adrenal Hyperplasia are exposed to higher levels of testosterone in utero, which yields lower 2D:4D ratios (Brown et al., 2002). Rodents that had been administered testosterone in utero ended up having lower 2D:4D ratios than rodents in a control group (Zheng and Cohn, 2011). van Anders et al. (2006) show that females with male twins have lower 2D:4D than the ones with female twins. Yet, it should be noted that there are also disputes about the connection between 2D:4D and prenatal androgen exposure (McIntyre, 2006).

2D:4D and Risk Aversion

A number of studies suggested correlations between 2D:4D and economic behavior such as social preferences (Buser, 2012; Brañas-Garza et al., 2013; Galizzi and Nieboer, 2015), profitability in financial trading (Coates et al., 2009), reaction to payment scheme changes (Friedl et al., 2018), manegarial traits (Guiso and Rustichini, 2018) and overconfidence (Neyse et al., 2016; Dalton and Ghosal, 2018). In the context of risk taking, several studies reported positive correlations between 2D:4D (lower PTE) and risk aversion, although a larger proportion reported null findings (See Table 1 for an overview of the literature). Despite significant results in the literature, frequently obtained null-results, Type I errors due to small sample sizes and varying gender specific findings suggest that the relationship between 2D:4D and risk taking is difficult to capture.[1] Further heterogeneities, such as ethnicities in the samples or the hands used for the 2D:4D analysis, makes the interpretation of the results even more challenging.

Brañas-Garza et al. (2018) tested the relationship with the largest sample in the literature to this date (N=702). Their results show a positive correlation between 2D:4D and revealed risk aversion in the incentivized Eckel and Grossman task (Eckel and Grossman, 2008). They, however, do not obtain a significant result with the self reported risk attitude question. This contradiction within the same study mimics diverse findings in

[1] See Parslow et al. (2018) for an extensive review of 2D:4D and risk taking literature.

the literature. One may suggests that a potential reason behind inconsistent findings might be the variations in the risk eliciation methods. However, replicability issue is common even among studies that employ the same tasks.

Table 1: Literature on 2D:4D and risk taking

Study	Task	N	Hands	Ethnicities	Result
Brañas-Garza et al. (2018)					
Measure I	EG ($)	702	Both	Mix	(-)
Measure II	Survey	702	Both	Mix	NS
Lima de Miranda et al. (2018)	EG ($)	150	Both	Caucasian	NS
Alonso et al. (2018)	HL ($)	497	Right	Mix	NS
Parslow et al. (2018)	MPL ($)	330	Both	Mix	NS
Chicaiza-Becerra and Garcia-Molina (2017)	EG ($)	123	Both	Ladino	NS (R) / (-)(L)
Barel (2017)	Survey	204	Both	Caucasian	NS
Bönte et al. (2016)	Survey	432	Right	Caucasuan	NS
Schipper (2012)	HL ($)	208	Right	Mix	NS
Drichoutis and Nayga (2015)	HL ($)	157	Right	Caucasian	NS
Aycinena et al. (2014)	HL ($)	219	Both	Ladino	NS
Stenstrom et al. (2011)	Survey	413	Right	Caucasian	NS (W) / (-)(M)
Garbarino et al. (2011)	MPL ($)	152	Mean	Caucasian	(-)
Brañas-Garza and Rustichini (2011)	HL	188	Right	Caucasian	(-)
Ronay and Von Hippel (2010)	BART ($)	52	Mean	Caucasian	(-)(M)
Sapienza et al. (2009)	HL ($)	183	Mean	Mix	NS
Apicella et al. (2008)	GP ($)	89	Both	Mix	NS
Dreber and Hoffman (2007)	GP ($)	152	Both	Caucasian	(-)

Tasks that used monetary incentives are shown with $. Right hands are shown with R and left with L.
Men are shown with M and women with W. NS represents non-significant results.
(-) and (+) presents the direction of the relationship between 2D:4D and risk-seeking in the tasks.
Task abbrevations are EG: Eckel and Grossman; HL: Holt and Laury; Survey: Self Reported; GP: Gneezy and Potters

Similar to Brañas-Garza et al. (2018), Lima de Miranda et al. (2018) and Chicaiza-Becerra and Garcia-Molina (2017) used the incentivized Eckel and Grossman task. Yet, they did not observe any significant relationship between risk aversion and 2D:4D.[2] The recent study of Parslow et al. (2018) which uses an extended and incentivized version of the task reports also null results from a large sample of women. In the case of self reported risk elicitation, Stenstrom et al. (2011) showed a positive correlation between

[2]Note that, despite the fact that right hand 2D:4D is the most common measure in the literature, Chicaiza-Becerra and Garcia-Molina (2017) observe a significant positive correlation between 2D:4D and risk aversion only from left hands.

financial risk-aversion and 2D:4D in men, while Brañas-Garza et al. (2018) did not observe a significant association. Holt and Laury method (Holt and Laury, 2002) generates a similar discrepancy. Studies using the Holt and Laury task with real monetary incentives (Sapienza et al., 2009; Schipper, 2012; Aycinena et al., 2014; Drichoutis and Nayga, 2015; Alonso et al., 2018) do not report any significant correlations, while Brañas-Garza and Rustichini (2011) reports that males with higher 2D:4D were more risk averse under unicentivized version of it.[3] Finally, the Gneezy and Potters method (Gneezy and Potters, 1997) also produced conflicting results: High 2D:4D is associated with higher risk aversion in Dreber and Hoffman (2007) while Apicella et al. (2008) could not show any significant relationship.

2D:4D and Prospect Theory

One potential reason behind contradicting results in the literature may be the fact that previously used methods are unable to capture the complexity of risky decisions. Most of the above mentioned risk elicitation methods rely on expected utility theory and have been designed to elicit only one parameter measuring the degree of relative risk aversion. Risk preferences, however, are known to be far more complex than modeled in expected utility theory. A large number of violations of expected utility motivated the development of various alternative theories which are usually descriptively more accurate than expected utility. Nowadays, prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Wakker, 2010a) is the most prominent descriptive alternative to expected utility. Based on extensive empirical evidence, prospect theory proposes that (i) behavior differs in the gain and loss domains (reflection effect), (ii) individuals are more risk averse over prospects involving both gains and losses than in either pure outcome domain (loss aversion), and (iii) people tend to be relatively insensitive to variations of probabilities, leading to subjective probability distortions. The elicitation of risk preferences in previous 2D:4D studies could not address this complexity of risky decisions as in most cases only gains and/or 50% probabilities were involved.

Recent findings of Hermann (2017) may indeed suggest that the association between 2D:4D and risk aversion may alter between gain and loss domains. Using an incentivized

[3] The fact that 2D:4D has no impact on the risk preferences elicited with the HL method is in some sense consistent with the meta study of Filippin and Crosetto (2016) which shows that under this method no significant gender differences can be observed.

Gächter et al. (2007) method, he observed that right hand 2D:4D ratios of participants were positively correlated with their elicited loss aversion levels.

The literature on the evolutionary basis of risk preferences also supports prospect theory. According to risk-sensitive foraging theory, making complex trade-off calculations is vital for animals and hunter-gatherers (see Kacelnik and El Mouden, 2013; Houston et al., 1993 for reviews). Since their survival is constantly threatened by various factors such as predators, competitors, natural conditions or starvation, their risk calculations are not only in the gain domain (McDermott et al., 2008). Further research also showed that decision biases such as loss aversion, are observed even in animals (Chen et al., 2006; Lakshminarayanan et al., 2011).

The goal of the present paper is to comprehensively study the impact of 2D:4D on the different facets of risk attitudes. We employ the method of Vieider et al. (2015), in which certainty equivalents for only gains, only losses, and for mixed gain-loss lotteries are elicited while systematically varying the probabilities. This procedure allows us to analyze whether 2D:4D is associated with (i) risk preferences in the domain of gains, (ii) risk preferences in the domain of losses, (iii) the degree of loss aversion, and (iv) probabilistic insensitivity. While our study is motivated by prospect theory, its statistical analyses are based on model-free tests. By just comparing certainty equivalents, our analysis is entirely non-parametric and valid for any theory which is based on standard definitions of risk aversion.

In order to control for possible effects of ethnicity on 2D:4D patterns (see Manning, 2002), we ran our experiment with two ethnic samples, a Caucasian sample from Germany and an Asian sample from Vietnam. We chose these two ethnicities to ensure that our results are comparable with previous studies. On the one hand, a large proportion of the literature report findings from Caucasian samples. In the mixed samples, on the other hand, the largest non-Caucasian ethnic groups were Asians.

Theoretical Background

To formalize decision-making under risk we consider a set of monetary outcomes X. A lottery P assigns a real number $P(x)$ to each $x \in X$ such that $P(x) \geq 0 \quad \forall x \in X$ and $\sum_{x \in X} P(x) = 1$. $\mathcal{P}$ denotes the set of all lotteries. We consider a binary preference relation $\succeq$ defined on $\mathcal{P}$ where $\succ$ indicates strict preference and $\sim$ indifference.

The certainty equivalent of a lottery P, denoted by $CE(P) \in X$, is defined by $CE(P) \sim P$. A decision maker is risk averse if $CE(P) \leq E(P) \quad \forall P \in \mathcal{P}$, where E designates the expectation operator. Moreover, decision maker A is more risk averse than decision maker B if $CE_A(P) \leq CE_B(P) \quad \forall P \in \mathcal{P}$ (Pratt, 1964). Consequently, if lower 2D:4D leads to less risk aversion, 2D:4D and certainty equivalents should be negatively correlated. This is the basic hypothesis for the analyses in the present paper.

In expected utility theory (von Neumann and Morgenstern, 1944), preferences of the decision maker are represented by

$$EU(P) = \sum_{x \in X} u(x)P(x), \tag{1}$$

where u is a monotonically increasing utility function. In expected utility theory the degree of risk aversion depends solely on the curvature of u, i.e., (a higher degree of) risk aversion is equivalent to a (more) concave u. Empirical applications often rely on the specification $u(x) = x^\alpha$ where $\alpha > 0$ is the degree of relative risk aversion. The method of Holt and Laury (2002) which is employed in the majority of 2D:4D studies on risk aversion has been specifically designed to elicit the parameter α.

Starting with the famous paradoxes of Allais (1953), a large body of evidence has shown that subjects often violate expected utility when choosing between risky lotteries. This research has revealed that risk attitudes are far more complex than modeled in expected utility theory and has motivated the development of alternative theories with superior descriptive performance. Prospect theory has nowadays become the most prominent of these alternatives (Dhami, 2016; Starmer, 2000a; Wakker, 2010b). In prospect theory, outcomes are evaluated relative to a reference point, with positive deviations from the reference point coded as gains and negative deviations as losses. Our CE's are explicitly designed in such a way as to fix the reference point to zero—a more detailed discussion of this design feature is provided in L'Haridon and Vieider (2018). The experiment is based solely on lotteries with two outcomes. We denote these outcomes by x and y such that $|x| > |y| \geq 0$. Now if x and y are either both gains or both losses the utility of lottery P with $P(x) := p$ in prospect theory is given by

$$PT(P) = w(p)v(x) + [1 - w(p)]v(y). \tag{2}$$

Compared to expected utility, the evaluation of lotteries in prospect theory differs by two aspects:

(i) Outcomes in prospect theory are evaluated by a value function v which satisfies diminishing sensitivity and loss aversion. Diminishing sensitivity means that the marginal value is decreasing if one moves further away from the reference point (i.e., zero) implying a concave (convex) value function in the gain (loss) domain. This assumption accommodates the reflection effect of Kahneman and Tversky (1979) which summarizes empirical evidence that people are typically risk averse (seeking) for gains (losses). Loss aversion indicates that a given loss has a higher impact on the attractiveness of a lottery than a gain of equal size and is captured by a value function which is steeper for losses than for gains. Numerous studies have provided an empirical basis for loss aversion on the behavioral level (Ganzach and Karsahi, 1995; Kahneman et al., 1990), the psychophysiological level (Hochman and Yechiam, 2011; Sokol-Hessner et al., 2009), the brain level (De Martino et al., 2010; Tom et al., 2007) and in self-reported feelings (McGraw et al., 2010).

(ii) Probabilities in prospect theory are transformed by a weighting function $w : [0, 1] \rightarrow [0, 1]$ which is strictly increasing and satisfies $w(0) = 0$ and $w(1) = 1$. Originally, this value function was proposed to capture the tendency of people to overweight small and underweight large probabilities. Nowadays, there is ample evidence (Abdellaoui et al., 2011; Tversky and Fox, 1995; Wu and Gonzalez, 1996) that the weighting function is inverse-S shaped for most subjects, which implies, besides the overweighting (underweighting) of small (large) probabilities, a relative insensitivity towards probability changes for medium sized probabilities.

A central empirical finding in the context of prospect theory is the fourfold pattern of risk attitudes: People are risk averse for high probability gains and low probability losses while they are risk seeking for low probability gains and high probability losses (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). Evidence in favor of this pattern has been reported in several experimental studies (Cohen et al., 1987; Harbaugh et al., 2010; Tversky and Kahneman, 1992; Wehrung et al., 1989). Prospect theory directly implies the fourfold pattern if the influence of probability weighting is large relative to the curvature of the value function, e.g., if the value function is linear.

As mentioned in the introduction, our study is motivated by prospect theory. Therefore, we analyze pure gain, pure loss and mixed lotteries while systematically varying probabilities. However, our analysis does not rely on prospect theory or on any other theory and is entirely non-parametric. We just consider the certainty equivalent of a lottery P and compare it to its expected value ($E(P)$). According to Pratt (1964), a subject is risk averse if $CE(P) < E(P)$, risk neutral if $CE(P) = E(P)$ and risk loving if $CE(P) > E(P)$. In the case of risk neutrality we thus have

$$CE(P) = px + (1-p)y. \tag{3}$$

Solving this equation for p yields

$$\frac{CE(P) - y}{x - y} = p. \tag{4}$$

In the following we will call $(CE_i - y_i)/(x_i - y_i)$ the normalized certainty equivalent of lottery i denoted by π_i. The normalized certainty equivalent π_i equals p in the case of risk neutrality whereas it is less than (exceeds) p in the case of risk aversion (seeking). For illustrative purposes, the analyses of the present paper will rely on normalized certainty equivalents instead of regular certainty equivalents.[4] This has the advantage of making our measures directly comparable across outcomes, which is its great advantage in our setup. We can then further control for the effect of probabilities in our regression to detect variations in probabilistic sensitivity.

If we assume prospect theory with a linear value function, the normalized certainty equivalent equals the transformed probability, i.e. we get

$$\pi_i = w(p) \tag{5}$$

This equation shows that while the analysis of normalized certainty equivalents does not rely on prospect theory it allows a straightforward interpretation in terms of probability weights.

For our analysis based on normalized certainty equivalents we do not need to assume that risk attitudes do not change as stakes increase, since one can simply insert the outcome dimension into the regression to test this hypothesis. By regressing the index on the probability of winning or losing in the given prospect, one can then detect

[4] Since a higher regular certainty equivalent implies a higher normalized certainty equivalent, this procedure does not involve any assumptions or restrictions.

probabilistic insensitivity, which will be captured by a regression coefficient smaller than unity, i.e. probability weights that change less than proportionally with the probability of winning or losing the prize.

In order to measure loss aversion without altering the reference point, we aimed at fixing the certainty equivalents to zero for mixed prospects (see L'Haridon and Vieider (2018) for details). In these cases, participants had to state a loss $y < 0$ that makes them indifferent between playing a 50/50 lottery involving a certain gain $x > 0$ and the stated loss y, or receiving zero for sure. Obviously, a higher degree of risk aversion corresponds to a lower absolute value of y. Instead of analyzing y directly we consider the *Gain-Loss Ratio* (GLR)given by

$$GLR = \frac{x}{-y}. \tag{6}$$

As x is fixed, a higher GLR is equivalent to a higher degree of risk aversion. Again, our analysis relying on GLR is entirely non-parametric and does not rely on prospect theory. However, the GLR has a clear interpretation in this theory. For mixed gain-loss prospect prospect theory can be defined as as follows:

$$PT(P) = w(p)v(x) + \lambda w(1-p)v(y), \tag{7}$$

where $x > 0 > y$ and λ is the index of loss aversion where values of $\lambda > 1$ indicate loss aversion. In our design with 50/50 lotteries and a certainty equivalent of zero a linear value function yields $GLR = \lambda$. Therefore, GLR allows for a non-parametric analysis of risk aversion for mixed prospects and can be interpreted as index of loss aversion in the context of prospect theory.

Materials and Methods

Participants

The experimental sessions were run in Germany and Vietnam. In both samples sex ratios were balanced. The German sample consists 199 students from Kiel University, who were recruited with the hroot software (Bock et al., 2014). Students were randomly assigned to seats in a classroom. At the beginning of the experiment, participants were given general instructions about the experimental procedure, which were followed by the decision task. Subsequently, they were asked to fill out a short questionnaire. After the experiment, participants were invited one by one to a separate room for receiving their payments and scanning of their both hands. Due to missing information we used the data of 191 of the students.

In Vietnam, we ran the experiment with 243 students and the gender distribution was balanced. The students were recruited at the Economics University of Ho-Chi-Minh city using flyers. The hands of students were photocopied after the experiment. In our 2D:4D analysis, we used the data of 162 students due to quality issues in the copies and missing 2D:4D data from a part of the sample.

Experimental Design

We used the risk elicitation task of Vieider et al. (2015) in both countries. In this task, participants decide between binary monetary lotteries and different sure monetary payments. In the gain domain, participants typically prefer the lottery for low sure payments, but switch as the sure payment rises. This behavior is reversed in the loss domain. The point where participants switch from the lottery to the sure payment is called the certainty equivalent. At the certainty equivalent a participant is just indifferent between the lottery and the sure payment. In the loss domain, outcomes were realized by subtraction from an initial endowment. There were a total of 28 decision tasks including 14 for gains, 13 for losses and 1 for mixed outcomes (i.e., gains and losses). In total, participants 881 decisions in these 28 lottery tasks. For mixed lotteries, we aimed at fixing the certainty equivalent to zero. Therefore, we asked participants here to state a loss that makes them indifferent between playing a 50/50 lottery involving a certain price and the stated loss, or receiving zero for sure.

In Vietnam, the orders of the experiment were counter-balanced. We found no order effects in our data, and using a fixed order was found to reduce the cognitive burden for our subjects. We thus decided to present the task in a fixed order in Germany, where participants were presented gains first, then losses and mixed prospects in order.

The experiments were run with pen and paper in both countries. As a standard procedure, one choice was randomly selected to be paid. The possible payments for this task ranged from €4 to €44 in purchasing power parity, including a fixed participation payment of €4. On average, participants spent 30 minutes to complete the lottery tasks. The whole procedure including hand scanning and the follow-up questionnaire, took about 1 hour.

2D:4D

In Germany, both hands were scanned with a high-resolution scanner (Epson V370 Photo). In Vietnam, the hands were photocopied, and the 2D:4D ratios were measured from a subsequent scan of these photocopies.To determine 2D:4D, we measured the lengths of the index and ring digits on both hands from basal crease to the finger tip using GIMP image editting software. As the right hand 2D:4D shows greater sex differences (see Hönekopp and Watson, 2010) a large body of the literature on 2D:4D use only right hand ratios in their analysis. The current study focuses on the right hand 2D:4D as well. However, the complete analysis of both hands can be found in the appendix.

Table 2: Mean of 2D:4Ds by sex and country

	left hand 2D:4D			right hand 2D:4D		
	Germany	Vietnam	difference	Germany	Vietnam	difference
male	0.960	0.937	$p < 0.001$	0.955	0.950	$p = 0.209$
	(0.028)	(0.035)	$d = 0.710$	(0.027)	(0.031)	$d = 0.194$
female	0.962	0.963	$p = 0.822$	0.965	0.974	$p = 0.083$
	(0.033)	(0.036)	$d = 0.033$	(0.039)	(0.039)	$d = 0.258$
difference	$p = 0.623$	$p < 0.001$		$p = 0.046$	$p < 0.001$	
effect size	$d = 0.071$	$d = 0.722$		$d = 0.291$	$d = 0.688$	

Table 2 shows the average 2D:4D by sex and country, separately for the left and the right hands. Standard deviations are given in parantheses. The means are tested against each other using t-tests. Effect sizes (Cohen's d) are also reported in the table. Men have significant lower right hand 2D:4D than women both in Germany and Vietnam ($p = 0.046$, $d = 0.291$ and $p < 0.01$, $d = 0.688$ respectively). Men have significantly lower left 2D:4D than women in Vietnamese sample too ($p < 0.001$). In the German sample though, left hand ratios are quite similar with men having a 0.002 lower ratio than women on average. These differences are in line with the literature and the meta study of Hönekopp and Watson (2010). Both left and right hand ratios of Vietnamese men are lower than German men. The difference is statistically significant for the left hand ($p < 0.001$, $d = 0.710$) but not for the right ($p = 0.059$, $d = 0.325$). Women in Vietnamese sample have slightly higher ratios than the ones in the German sample, although differences are not strong ($p = 0.822$, $d = 0.033$ for the left and $p = 0.083$, $d = 0.258$ for the right).

Results

Descriptive analysis of risk preferences

We start with a descriptive analysis of risk preferences elicited across the different decision domains. Figure 1 and 2 show normalized certainty equivalents π_i by probability of winning or losing. We only show our indices for changing probabilities of obtaining a fixed outcome of €20 or else nothing. While equivalent indices for different outcome sizes are easily constructed, the latter add nothing to our analysis, and all conclusions drawn in this section remain stable to including such measures.

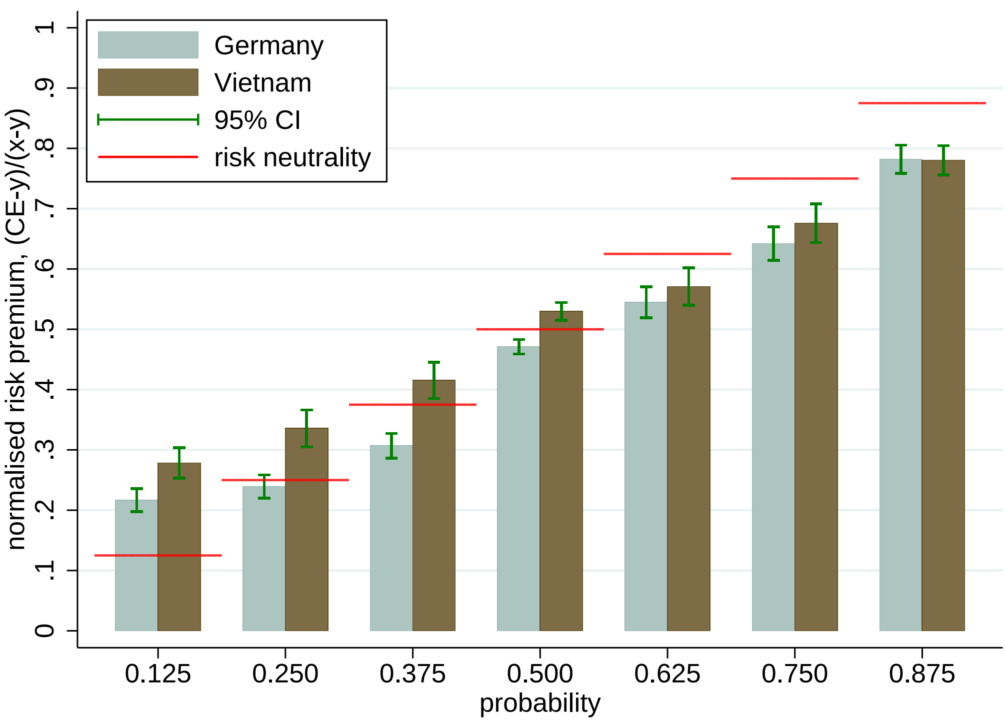

Figure 1: Risk preferences in the gain domain by probability and country.

We start from the results for gains, shown in Figure 1. For the smallest probability of $p = 0.125$, π_i is significantly higher than the objective probability of winning the prize, indicating risk seeking behavior. This changes as probabilities increase. Already at $p = 0.375$, subjects in Germany are significantly risk averse on average, and risk aversion increases further with probabilities. For subjects in Vietnam, we observe a similar tendency, except that they become risk averse only at the much larger probability of $p = 0.625$. The pattern of risk aversion increasing in probability is consistent with probabilistic insensitivity (see Section 2). The Vietnamese students are more risk taking on average than the German students ($z = -4.020, p < 0.001, N = 364$, Mann-Whitney test on average normalized certainty equivalents for gains). This result corresponds closely to previous comparative studies, which found risk aversion to increase in GDP per capita for gains (Rieger et al., 2014; L'Haridon and Vieider, 2018).

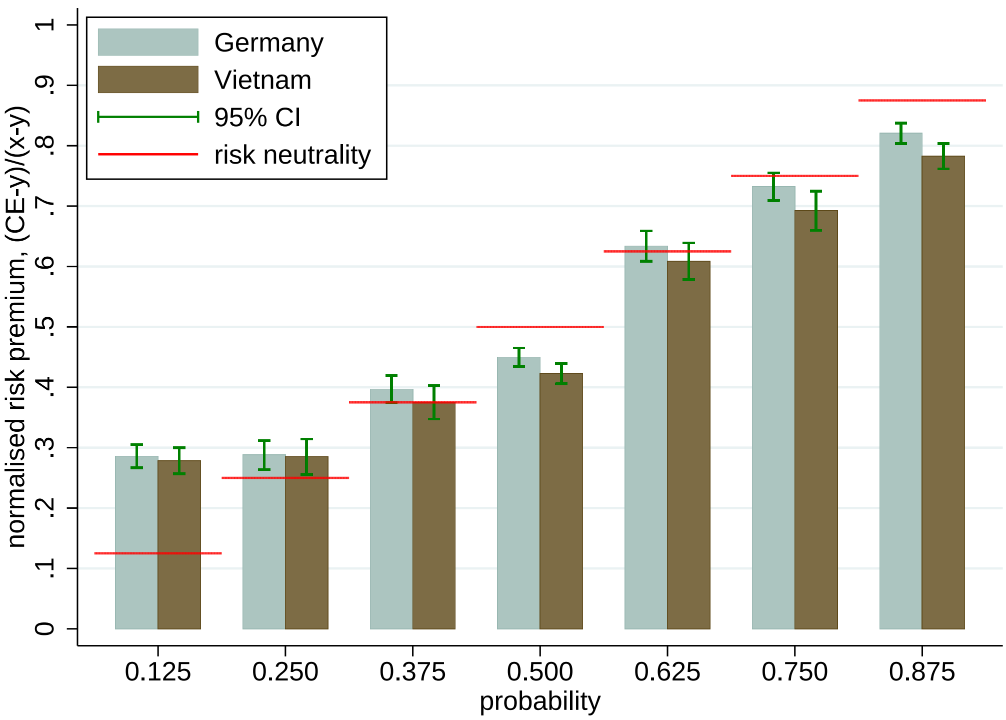

Figure 2: Risk preferences in the loss domain by probability and country.

An equivalent graph for losses is shown in Figure 2. We can now think of these values as insurance premia, since they are the absolute amounts that the subjects are willing to forgo to avoid playing a given prospect. The interpretation is thus reversed relative to gains, with values higher than the probability indicating risk aversion, and lower values indicating risk seeking. For the lowest probability, we now find risk aversion in both countries. As the probability increases, this risk aversion decreases and gives way to risk seeking for the highest probability level. As implied by prospect theory, this trend thus mirrors the one found for gains. While Germany and Vietnam exhibit very similar patterns of risk preferences for low probabilities, our Vietnamese subjects are more risk seeking than our German subjects for large probabilities. On average, our Vietnamese subjects are thus again more risk seeking than our German subjects ($z = 2.490, p = 0.012, N = 363$, Mann-Whitney test on average π_i for losses). This again corresponds to patterns found using the same tasks by Vieider et al. (2012) and L'Haridon and Vieider (2018), but it contradicts a correlation with GDP per capita in the opposite direction found by Rieger et al. (2014) using hypothetical willingness to accept for lotteries.[5]

Finally, we analyze the mixed prospect, where we find no significant difference between Germany and Vietnam in terms of risk aversion ($z = -1.081, p = 0.280, N = 364$). On average, we find the acceptable loss is slightly smaller than half the gain. This matches the popular adage that losses loom about twice as large as gains, and our results in terms of the GLR are remarkably consistent with the median loss aversion estimate of 2.25 reported by Tversky and Kahneman (1992). It also means that we find considerably more risk aversion over mixed prospects than for either gains or losses, where we found risk preferences close to risk neutrality for the same probability (although with some differences across countries and decision domains, as discussed above). This is again quite typical, as loss aversion is thought to account for most of risk aversion over small stakes (Köbberling and Wakker, 2005; Rabin, 2000).

2D:4D and risk preferences

We can now regress our measures of risk preferences on the independent variables of interest. We present the regression analyses by decision domains and countries. Table 3 shows the results for gains and losses. All regressions are random effects OLS regressions, with standard errors clustered at the subject level. This allows us to enter the probability level as an independent variable capturing within-subject variance in risk preferences. The differing number of subjects across regressions is due to some unreadable hand scans, as outlined above. RDR x female and RDR x probability are the interaction variables. The first four columns present the regressions for Germany and the latter four for Vietnam. Models I, II and V, VI are the regressions of the loss domain and the models III, IV and VII, VIII are of the gain domain. Note that our analyses include participants who

[5] Rieger et al. (2014) used WTP for gains, but WTA for losses. This changes the references point, and may explain the opposing effects found across outcome domains.

completed corresponding lotteries entirely and consistently. The missing observations are due to multiple switches in the lotteries or lotteries without responses. [6]

Table 3: Regression analysis for gains and losses in both countries

Dep. var: π_i	Germany				Vietnam			
	Losses		Gains		Losses		Gains	
	I	II	III	IV	V	VI	VII	VIII
probability	0.764***	0.764***	0.779***	0.779***	0.708***	0.707***	0.668***	0.668***
	(0.020)	(0.020)	(0.023)	(0.023)	(0.025)	(0.025)	(0.028)	(0.028)
RDR	0.003	0.005	0.001	0.017	-0.010	-0.022	0.006	0.011
	(0.012)	(0.015)	(0.018)	(0.018)	(0.014)	(0.019)	(0.019)	(0.026)
RDR x female	-0.011	-0.011	-0.007	-0.007	0.020	0.020	-0.004	-0.004
	(0.014)	(0.014)	(0.020)	(0.020)	(0.017)	(0.017)	(0.023)	(0.023)
RDR x probability	–	-0.004	–	-0.031	–	0.025	–	-0.011
	–	(0.026)	–	(0.023)	–	(0.026)	–	(0.027)
female	-0.007	-0.007	-0.007	-0.009	0.007	0.007	-0.095***	-0.095***
	(0.013)	(0.013)	(0.020)	(0.018)	(0.018)	(0.018)	(0.024)	(0.024)
constant	0.122***	0.122***	0.080***	0.081***	0.117***	0.112***	0.240***	0.240***
	(0.014)	(0.014)	(0.015)	(0.015)	(0.017)	(0.017)	(0.024)	(0.024)
Observations	2431	2431	2562	2562	2093	2093	2268	2268
Subjects (clusters)	187	187	183	183	161	161	162	162
R^2 within	0.48	0.48	0.54	0.54	0.42	0.42	0.45	0.45
R^2 between	0.01	0.01	0.01	0.01	0.01	0.01	0.09	0.09

Standard errors in parentheses; * , ** , *** indicate significance at the 10, 5 and 1 % level respectively; π_i is the normalised certainty equivalent; RDR is the right 2D:4D; 2D:4Ds are entered as z-scores; female is a dummy variable with 1 for women.

The coefficient of the probability variable is always significantly lower than 1, indicating the probabilistic insensitivity —a coefficient lower than 1 indicates that the π_i indicex varies less than proportionately with the probability of winning the constant prize. The coefficient is generally lower for Vietnam, indicating lower probabilistic sensitivity in Vietnam.

We do not observe any significant effect of 2D:4D in either country or either domains. We also find no significant effect of the 2D:4D either for males (indicated by the 2D:4D variable, which indicates a main effect for males only) or for females (as captured by the interaction effect). The interaction between the 2D:4D and the probability coefficient is insignificant and shows that probabilistic insensitivity is not related to 2D:4Ds. We do not observe any gender effects in risk taking in Germany. For Vietnam, we find a strong gender effect, going in the expected direction of women being more risk averse than men.

Table 4 shows the regressions of our measure of risk aversion in the mixed gain-loss domain on the usual independent variables. A larger GLR indicates increased risk aversion. Since we do not have repeated observations, we now use OLS regressions. The first regression examines the effects for the right hand 2D:4Ds on the GLR in Germany

[6]The pooled regressions that include both coutries can be found in the appendix

Table 4: Regression analysis for mixed prospects in both countries

Dep. var: GLR	Germany	Vietnam
RDR	0.398	-0.029
	(0.315)	(0.107)
RDR x female	-0.315	0.065
	(0.339)	(0.228)
female	-0.013	0.800***
	(0.222)	(0.249)
constant	2.210***	1.948***
	(0.181)	(0.129)
Subjects	188	162
R^2	0.03	0.06

Standard errors in parentheses; * , ** , *** indicate significance at the 10, 5 and 1 % level respectively; GLR is the Gain-Loss Ratio; RDR is the right hand 2D:4D; 2D:4Ds are entered as z-scores; female is a dummy variable with 1 for women.

and the second in Vietnam. Again, we find no effects in terms of 2D:4Ds. We do, however, find a gender effect in the expected direction of women being more risk averse than men.

Discussion

This study provided a systematic analysis of 2D:4D and risk preferences using an incentivized, extensive risk elicitation method. Although several studies in the literature suggested a positive correlation between 2D:4D and risk aversion, the results were not conclusivee and they were obtained from various samples and with coarse risk elicitation methods. Our results do not show any significant relationship between 2D:4D and risk taking neither in pure gains and loss nor in the mixed domains. This null result is consistent both in our Caucasian and Asian samples.

As a starting point, we suspected that the mixed evidence in the literature could be due to over-simplified risk elicitation methods that are based on expected utility theory. It has been repeatedly documented that expected utility theory is typically violated by decision makers (Starmer, 2000b). In particular, different elicitation mechanisms may be affected by loss aversion to differing degrees, thus accounting for the inconsistent conclusions reached in the literature. Prospect theory explicitly separates and identifies different aspects of risk preferences by introducing probabilistic insensitivity and distinguishing pure gain, pure loss and mixed prospects. With the task of Vieider et al. (2015)

we were able to study the above-mentioned aspects of risk preferences in detail. In particular, the design of the tasks was suchn as to explicitly avoid endogenous reference points in the elicitation of risk attitudes over gains and losses (Hershey and Schoemaker, 1985; Vieider, 2018), which allowed us to cleanly separate risk preference in the pure outcome domains from preferences over mixed gain-loss prospects.

Furthermore, according to dual inheritence theory (or gene-culture co-evolution) human behavior is shaped both by cultural and genetic factors (Boyd and Richerson, 1988; Richerson et al., 2010). As twin studies suggest that 2D:4D might be heritable, the relationship between behavior and 2D:4D may support dual inheritence theory (Paul et al., 2006). Furthermore, there is also a body of literature suggesting that genetic inheritance has a partial role in economic behavior (Zhong et al., 2009; Cesarini et al., 2009) and prospect theory has become an important benchmark for evolutionary theories like, risk-sensitive-foraging theoris (Kacelnik and El Mouden, 2013; Houston et al., 1993). These evidences make prospect theory an ideal device to analyze the relationship between 2D:4D and risk taking. Yet, our study did not detect any significant relationship between 2D:4D and risk taking in the framework of prospect theory.

One needs to apply considerable caution before interpreting results from this literature in a causal manner. The significant results in the literature do not suggest a direct biological channel that affects decision making process. The first reason is that we cannot disentangle if the genetic factor effects the decision making directly or if it mediates the cultural and environmental development of the decision patterns of individuals. In other words, PTE may have a partial role on the personality development and cognition rather than decision making itself. On the other hand, there is evidence that short term peaks of circulating testosterone can be organized by PTE suggesting a negative relationship between 2D:4D and sensitivity to testosterone (Crewther et al., 2015). Typically, these peaks are observed more in men than women (Manning et al., 2014). If this is the case the impact of 2D:4D on decision making would be via circulating testosterone.

Also, determinants of prenatal androgen exposure levels are not yet sufficiently understood, and some studies have presented evidence suggesting that there may be interactions between socio-economic status of the parents and biological determinants of prenatal androgen exposure. For example Toriola et al. (2011) showed that smoking and maternal age have significant impacts on sex steroid levels during the first half of the pregnancy. As smoking has been associated with low income and lower education (see

Hiscock et al. (2012) for a review), biology and and socio-economic status of the parents may jointly affect prenatal androgen exposure levels. Complex processes may thus be at work, and much richer data on both biological and socio-economic variables for both children and parents will be needed to cleanly disentangle the different channels.

Finally, the literature studying the associations between 2D:4D and economic behavior usually work with small samples and they usually do not register their pre-analysis plans beforehands. To the best of our knowledge, Parslow et al. (2018) is the only study which has a prior pre-analysis plan registered. As a result of possible publication biases, researcher degrees of freedom and false positive results, it gets even more challenging to reach a consensus on whether 2D:4D actually correlates with certain economic decisions.

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Risk Attitudes and Digit Ratio (2D:4D): Evidence from Prospect Theory

Appendix

Levent Neyse, Ferdinand M. Vieider, Patrick Ring, Catharina Probst, Christian Kaernbach, Thilo van Eimeren and Ulrich Schmidt

Table 1: Regression analysis for gains and losses in both countries

Dep. var:	Germany				Vietnam			
π_i	Losses		Gains		Losses		Gains	
	I	II	III	IV	V	VI	VII	VIII
probability	0.765***	0.764***	0.783***	0.785***	0.715***	0.707***	0.668***	0.670***
	(0.021)	(0.021)	(0.023)	(0.023)	(0.025)	(0.026)	(0.028)	(0.028)
LDR	0.003	-0.001	-0.026	-0.016	-0.015	-0.032**	-0.005	0.012
	(0.010)	(0.014)	(0.016)	(0.020)	(0.012)	(0.014)	(0.014)	(0.021)
LDR x female	0.001	-0.001	-0.023	-0.023	0.018	0.018	0.012	0.012
	(0.013)	(0.013)	(0.021)	(0.021)	(0.015)	(0.015)	(0.021)	(0.021)
LDR x probability	–	0.006	–	-0.019	–	0.035 *	–	0.013
	–	(0.023)	–	(0.026)	–	(0.021)	–	(0.027)
female	-0.008	-0.008	-0.013	-0.013	0.015	0.015	-0.090***	-0.090***
	(0.014)	(0.0143)	(0.018)	(0.018)	(0.018)	(0.018)	(0.026)	(0.026)
constant	0.120***	0.121***	0.081***	0.080***	0.110***	0.108***	0.235***	0.234***
	(0.013)	(0.013)	(0.015)	(0.015)	(0.018)	(0.018)	(0.025)	(0.025)
Observations	2405	2405	2534	2534	2106	2106	2268	2268
Subjects (clusters)	185	185	181	181	162	162	162	162
R^2 within	0.48	0.48	0.54	0.54	0.42	0.42	0.45	0.45
R^2 between	0.01	0.01	0.02	0.02	0.01	0.01	0.09	0.09

Standard errors in parentheses; * , ** , *** indicate significance at the 10, 5 and 1 % level respectively
π_i is the normalised certainty equivalent
LDR is the right 2D:4D; 2D:4Ds are entered as z-scores
female is a dummy variable with 1 for women

Table 2: Regression analysis

Dep. var: π_i	Gains	Losses
probability	0.722***	0.739***
	(0.183)	(0.016)
RDR	0.003	0.003
	(0.171)	(0.112)
Vietnam	0.107***	-0.033**
	(0.021)	(0.016)
female	-0.006	-0.007
	(0.018)	(0.013)
female x Vietnam	-0.089***	0.014
	(0.030)	(0.022)
RDR x Vietnam	0.003	-0.012
	(0.026)	(0.017)
RDR x female	-0.008	-0.011
	(0.020)	(0.014)
RDR x female x Vietnam	0.005	0.030
	(0.030)	(0.021)
constant	0.106***	0.134***
	(0.014)	(0.012)
Observations	4897	4537
Subjects	350	349
$R^2 within$	0.486	0.452
$R^2 between$	0.096	0.022

Standard errors in parentheses; * , ** , *** indicate significance at the 10, 5 and 1 % level respectively; π_i is the normalised certainty equivalent; RDR is the right hand 2D:4D; 2D:4Ds are entered as z-scores; female is a dummy variable with 1 for women.
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Table 3: Regression analysis for mixed prospects in both countries

Dep. var: GLR	Germany	Vietnam
LDR	0.347	-0.035
	(0.232)	(0.117)
LDR x female	-0.229	0.030
	(0.298)	(0.251)
female	0.042	0.823***
	(0.202)	(0.252)
constant	2.129***	1.938***
	(0.158)	(0.144)
Subjects	188	162
R^2	0.03	0.06

Standard errors in parentheses; * , ** , *** indicate significance at the 10, 5 and 1 % level respectively; GLR is the Gain-Loss Ratio; LDR is the left hand 2D:4D; 2D:4Ds are entered as z-scores; female is a dummy variable with 1 for women.