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Dopamine and Risk Preferences in Different Domains

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Abstract

Individuals differ significantly in their willingness to take risks. Such differences may stem, at least in part, from individual biological (genetic) differences. We explore how risk-taking behavior correlates with different versions of the dopamine receptor D4 gene (*DRD4*), which has been implicated in previous studies of risk taking. We investigate risk taking in three contexts: economic risk taking as proxied by a financial gamble, self-reported general risk taking, and self-reported behavior in risk-related activities. Our participants are serious tournament bridge players with substantial experience in risk taking. Presumably, this sample is much less varied in its environment than a random sample of the population, making genetic based differences easier to detect.

A prior study (Dreber et al. 2010) looked at risk taking by these individuals in their bridge decisions. Here we examine the riskiness of decisions they take in other contexts. We find evidence that individuals with a 7-repeat allele (7R+) of *DRD4* take significantly more economic risk in an investment game than individuals without this allele (7R-). Interestingly, this positive relationship is driven by the men in our study, while the women show a negative but non-significant result. Even though the number of 7R+ women in our sample is low, our results may indicate a gender difference in how the 7R+ genotype affects behavior, a possibility that merits further study. Considering other risk measures, we find no difference between 7R+ and 7R- individuals in general risk taking or any of the risk-related activities. Overall, our results indicate that the dopamine system plays an important role in explaining individual differences in economic risk taking in men, but not necessarily in other activities involving risk.

Keywords Risk preferences; Dopamine; Risk taking; Risk perception; *DRD4*.

JEL Classification C91, C93, D03, D81, D87, G0.

Non-Technical Summary

Many important decisions in life require choices among options that vary in their level of risk. Individuals differ significantly in their willingness to take risks, with women and older individuals typically being more risk averse than men and younger individuals. Some of this observed variation has been associated with biological factors. For example, studies on twins suggest that part of this variation can be explained by genetic factors. Relatively little is known about the specific genetic determinants of individual variation in risk preferences. In this study, we explore how risk-taking behavior correlates with different versions of the dopamine receptor D4 gene (*DRD4*), which has been implicated in previous studies of risk taking. We investigate risk taking in three contexts: economic risk taking as proxied by a financial gamble, self-reported general risk taking, and self-reported behavior in risk-related activities. Our participants are serious tournament bridge players with substantial experience in risk taking. Effective risk taking is a significant component of bridge expertise. Presumably, this sample is much less varied in its environment than a random sample of the population, making genetic based differences easier to detect.

In a prior study we looked at risk taking by these individuals in their bridge decisions. Here we examine the riskiness of decisions they take in other contexts. We find evidence that individuals with a 7-repeat allele (7R+) of *DRD4* take significantly more economic risk in an investment game than individuals without this allele (7R-). Interestingly, this positive relationship is driven by the men in our study, while the women show a negative but non-significant result. Even though the number of 7R+ women in our sample is low, our results may indicate a gender difference in how the 7R+ genotype affects behavior, a possibility that merits further study. Considering other risk measures, we find no difference between 7R+ and 7R- individuals in general risk taking or any of the risk-related activities. Overall, our results indicate that the dopamine system plays an important role in explaining individual differences in economic risk taking in men, but not necessarily in other activities involving risk.

1. Introduction

Many important decisions in life require choices among options that vary in their level of risk, as formalized say by the variance in the values of the possible outcomes an option implies. People tend to be risk averse in the domain of potential gains, i.e., they prefer a certain payoff over the same or possibly larger value in expectation for a variable payoff. By contrast, they tend to be risk loving in the domain of potential losses (Kahneman & Tversky 1979).

Risk preferences vary substantially across individuals, with women and older individuals typically being more risk averse than men and younger individuals (Barsky et al. 1997; Byrnes et al. 1999; Croson & Gneezy 2009; Dohmen et al. forthcoming). Some of this observed variation has been associated with biological factors (Apicella et al. 2008; Barnea et al. 2009; Carpenter et al. 2009; Cesarini et al. 2009a; Cesarini et al. 2009b; Coates et al. 2009; Crisan et al. 2009; Dreber et al. 2009; Kuhnen & Chiao 2009; Roe et al. 2009; Roiser et al. 2009; Sapienza et al. 2009; Zhong et al. 2009a; Zhong et al. 2009b; Zhong et al. 2009c; Calvet & Sodini 2010) (though see (Zethraeus et al. 2009)). For example, twin studies on Swedish and Chinese twins suggest that genetic differences account for 20% (Cesarini et al. 2009a) and 57% (Zhong et al. 2009a), respectively, of individual differences in risk preferences in these two nations. (This discrepancy by nation could be explained by population differences such as local cultural norms, heterogeneity in environments, or in the risk measures used, or population differences in relevant gene frequencies.)

Relatively little is known about the specific genetic determinants of individual variation in risk preferences, although a number of recent studies explore possible associations between specific genetic loci involved in chemical signaling in the brain (neurotransmission) and economic risk preferences (Carpenter et al. 2009; Crisan et al. 2009; Dreber et al. 2009; Kuhnen & Chiao 2009; Roe et al. 2009; Roiser et al. 2009; Zhong et al. 2009b; Zhong et al. 2009c). One neurotransmitter that has received particular attention is dopamine, due to its relation with reward processing in the brain. Activation of the dopaminergic reward pathways, and thus the release of dopamine neurotransmitters, can generate feelings of pleasure and well-being that become associated with the behaviors that triggered the activation. This makes dopamine a major player in reinforcement of behaviors that are associated with the anticipation of rewards.

Of the genetic markers for dopaminergic function, the dopamine receptor D4 gene (*DRD4*) has been identified as a candidate for explaining variation in economic behavior (Benjamin et al. 2008), and has received most of the attention in the literature thus far.[1] As with many other genes, *DRD4* comes in various versions ("alleles"), which differ among individuals. There is a specific region of the gene which contains a repeated sequence of DNA base pairs. In different individuals, this sequence is repeated a different number of times (typically 2-11 times) on each of the two relevant chromosomes. The multiple versions of the gene are frequently divided into two dichotomous classes, those with fewer than 7 repeats on both chromosomes (7R-) and those with 7 or more repeats on at least one chromosome (7R+)

[1] See Appendix 1 for more information on *DRD4* as well as the genotyping.

(Ding et al. 2002). Functionally, individuals with the 7R+ genotype are putatively less sensitive to dopamine uptake. Therefore 7R+ individuals require higher levels of dopamine to produce a response of similar magnitude to that of 7R- individuals. In order for 7R+ individuals to achieve a comparably satiating response in the brain's corticomesolimbic dopamine reward pathway, they may engage in more stimulating behaviors than do 7R- individuals. Such genetic variation in response to dopamine may thus contribute to individual differences in those personality and behavioral traits that are associated with the dopamine system. Such traits include novelty seeking (Ebstein et al. 1996) (though see (Munafo et al. 2008)), pathological gambling (Perez de Castro et al. 1997), attention deficit/hyperactivity disorder (Li et al. 2006), behavioral disinhibition (Congdon et al. 2008), alcoholism (Laucht et al. 2007), impulsivity (Eisenberg et al. 2007) (though see (Munafo et al. 2008)), sexual promiscuity (Garcia et al. in review), and many other behaviors. Economic risk taking may be another important behavioral trait related to the dopamine system. Four recent studies explore this possibility. Two of them find a positive association (Dreber et al. 2009, Kuhnen & Chiao 2009). In a study of 94 young men, Dreber et al. (2009) find that 7R+ men invest significantly more money into a risky investment than do 7R- men. They also examine a second dopamine receptor gene *DRD2*, and find no relationship between genetic variation in *DRD2* and risk taking. Kuhnen and Chiao (2009) similarly find a positive relationship between the 7R+ genotype and risk preferences in a laboratory measure, using a sample of 65 men and women. They also find that the serotonin transporter gene *5-HTTLPR* helps to predict risk preferences, as do Crisan et al. (2009), but not Roiser et al. (2009). So too, the findings on *DRD4* by Dreber et al. (2009) and Kuhnen and Chiao (2009) have been contradicted. Carpenter et al. (2009), in a laboratory study of 140 men and women, find a marginally significant negative relationship between 7R+ and risk taking. However, when the probabilities are ambiguous or when losses are possible, they find that 7R+ individuals do make riskier choices than 7R- individuals, in accord with the other studies. In another study where participants are either given the dopaminergic precursor drug L-dihydroxyphenyalanine (L-DOPA) or a placebo, Eisenegger et al. (in press) do not find any main effect of 7R+ on risk taking in a gambling task in the placebo group. However, 7R+ men who have been given L-DOPA become more risk taking than 7R- men given the drug (Eisenegger et al.).

Given these somewhat mixed results, we felt it important to investigate the association between the 7R+ genotype and different types of risk taking. We look only at the gene *DRD4* in order to avoid issues related to multiple testing. Moreover, we thought it particularly desirable to identify a group of participants who had considerable experience with and were regularly engaged in risk-taking situations. Thus, we recruited participants who were serious tournament bridge players. Effective risk taking is a significant component of bridge expertise.

We first investigate whether the positive association between the 7R+ genotype and economic risk taking found by Dreber et al. (2009) and Kuhnen and Chiao (2009) is identified in our study. While those prior studies mainly used college students, our participant pool is much more diverse in terms of age and background, though perhaps less diverse in terms of

economic well being.[2] A replication of the relationship between 7R+ and economic risk taking in our sample would thus provide evidence for some generalizability of studies on students, as well as provide further evidence of a positive effect of 7R+ on economic risk taking. We also examine the connection between the 7R+ genotype and self-reported general risk taking, as well as behavior in self-reported risk-related activities. We hypothesize that 7R+ individuals will be more risk taking than 7R- individuals on all risk measures.

2. Experimental design and procedure

a. The location and setup

In this field study, 237 participants were recruited at the Fall 2008 North American Bridge Championship in Boston, Massachusetts. (See Dreber et al. 2010.) This major event lasted 10 days, with two 26-hand sessions per day, and more than 42,000 player sessions in total. Almost all of the participants were serious tournament bridge players who play many dozens of sessions per year.[3] Tables for data collection were placed outside the major national championship game rooms one day and outside a secondary championship game room the following day. After reviewing and signing an informed consent form, participants provided a DNA sample by swishing 10ml of Scope® mouthwash from cheek to cheek for 45 seconds and spitting it back into a sterile 15ml collection tube (buccal wash). They then completed a bridge quiz and a questionnaire. The study was approved by Harvard University's institutional review board, and all genotyping procedures were additionally approved by Binghamton University's Human Subjects Research Review Committee. See Appendix 2 Table A1 for more information on the participants.

b. The tasks

Each participant first solved an incentivized bridge quiz (as described in Dreber et al. 2010) that tested both their skill and risk taking propensity in bridge contexts. After this, participants took part in a risky gamble involving real financial incentives. They then filled out a short questionnaire including a question on general risk taking and questions on behavior in risk-related activities.

i. Economic risk taking

Participants chose how to allocate money in an incentivized financial investment task, a modified version of another risk measure (Gneezy & Potters 1997). The same task was used in Dreber et al. (2009), where a positive relationship was found between the amount invested and the presence of the 7R+ genotype in a sample of male college students. Apicella et al. (2008) also found a positive relationship between risk taking in the same task and both

[2] Our participant pool was overwhelmingly at least middle class, given the costs of traveling out of town to attend tournaments.

[3] 300+ masterpoints, with an additional requirement that some fraction of them be won in regional or national championships, qualifies one to be a Life Master in competitive bridge. 79% of our participants have 300+ masterpoints.

circulating testosterone and a proxy of pubertal testosterone exposure in the same male sample as Dreber et al. (2009).

In the investment task, participants started with $250, of which they could choose an amount $X to invest into a risky investment. The outcome of the risky investment was decided by a coin flip. If successful, the amount X was multiplied by 2.5; if unsuccessful, the amount X was lost. The remainder ($250 - $X), the "safe investment" was kept regardless of the outcome of the coin flip. Thus if the coin flip was successful, participants ended up with $250+$1.5X; otherwise $250-$X. Participants were informed that after everyone had made an investment decision, three individuals would be randomly selected play for real money, bound by the investment amount they had indicated. Investing in this gamble increases both expected value and risk. Hence, participants had to weigh the two factors in determining their value for X. An individual's choice of X provides our measure of risk-taking.

ii. General risk taking and questionnaire

The questionnaire included a self-reported risk question used by Dohmen et al. (forthcoming). that asks about the individual's willingness to take risks on an 11-point Likert scale. In their sample of approximately 22,000 individuals, willingness to take risks is negatively correlated with age and female gender, but positively related to height and parental education. In a representative sample of 450 individuals, they find that this measure provides a good proxy of actual risk taking behaviors, such as traffic offenses, portfolio choice, smoking, occupational choice, participation in sports and migration. Dohmen et al. interpret this question to concern risk perception. We impose less interpretation and refer to it as general risk taking propensity. Our questionnaire also included questions on gender, age (binned with options <20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90 and 90+), height (analyzed in cm), sexual orientation, marital status, ethnicity, smoking and alcohol habits, proportion of assets invested in stocks and bonds, and whether participants had ever started a company. Most of the variables are categorical. (See Appendix 3 for the actual questionnaire.)

3. Data analysis and results

When the dependent variable is continuous, we use linear regressions (OLS) with robust standard errors; when it is binary, we employ a logit regression. We report two-tailed test statistics. Basic demographics are presented in Appendix 2 Table A1.

Variation in the *DRD4* gene was successfully analyzed for 190 men and women of our 237 participants. Genotype frequencies in our sample are as follows: Of the 105 men for whom *DRD4* data was obtained, 19 were 7R+ (18.1%). Among the 85 women successfully genotyped, only 6 were 7R+ (7.1%).[4] These two frequencies are significantly different (chi^2 test: p=0.025). This irregularity is surprising, as there is no previous evidence for the

[4] In the analysis looking at 7R+, we exclude those 8 men and 3 women for whom height and/or age data was not reported. Including these 11 individuals with imputed values at the gender-specific mean for the missing variables does not qualitatively alter the main results for the 7R+ genotype, except that 7R+ drops to marginally significant in Table A4 column 1, 3, 4 and 5 rather than significant. For all the analysis where 7R+ is not considered, we include all participants possible.

population frequency of 7R+ varying with gender. It may suggest a bias in the propensities of the women, compared to men, who are drawn to competitive bridge, which could also lead to systematic differences in the effect of the 7R+ genotype between men and women in our study. Thus, we include a 7R+ X gender interaction term in our analyses. When the interaction is significant, we also analyze men and women separately. We find no significant differences in 7R+/- frequency based on age or sexual orientation.

a. Correlation among risk measures

Dohmen et al. (forthcoming) and Roe et al. (2009) find only limited associations among risk measures from different domains. Here we correlate our two different risk measures with each other, expecting a positive association in a simple correlation analysis. Correlating economic risk taking and general risk taking in the male and female subsamples separately (including non-genotyped participants), we find these measures to be positively correlated for both genders (men: r=0.21, p=0.034, women: r=0.26, p=0.017). (See Tables A2 and A3.) Given these relationships, and related past evidence, we expect the 7R+ genotype to have a similar effect on economic risk taking and general risk taking.

b. Economic risk taking

Our dependent variable for economic risk taking is the amount of money participants put at risk. We regress economic risk taking on a dummy variable that takes the value 1 if an individual is 7R+ and the value 0 otherwise. (See Table A4.) 7R+ individuals are significantly more risk taking than 7R- individuals (coeff=39.01, p=0.043). This relationship becomes non-significant (p=0.183) when controlling for variables previously found to affect economic risk taking: gender, age and height, where the two former are significantly related to economic risk taking (gender: coeff=-70.20, p<0.001, age: coeff=-9.87, p=0.028). However, there is a significantly different effect of 7R+ on men and women, seen by interacting the variable for being a woman and 7R+ (coeff=-70.24, p=0.049). This indicates that 7R+ may have different effects on economic risk taking in men and women in our sample, and we thus pursue the analysis of men and women separately.

Looking only at males, 7R+ men take significantly more risk than their 7R- counterparts (coeff=39.19, p=0.004) when controlling for age and height. The effect is sizeable: 7R+ men take 22% more economic risk than 7R- men, corresponding to 1.13 standard deviations (Figure 1). Age is also significantly related (coeff=-13.3, p=0.013); older individuals take less risk. Height is not related (p=0.189). The effect of 7R+ on risk taking persists when neither age nor height is controlled (p=0.001). Looking at women only, the effect of 7R+ is non-significant when controlling for age and height (p=0.421) and when neither covariate is included (p=0.470).[5] It is interesting to note, however, that the sign of the effect of the 7R+ genotype on economic risk taking is negative in the female sample, the opposite of what is observed in the male sample.

[5] The lack of statistical significance of among women is not surprising given the very low number of 7R+ women.

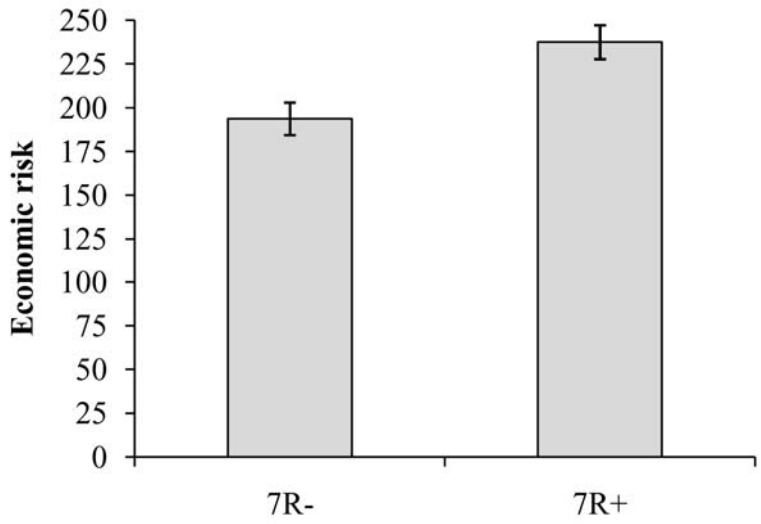

Figure 1. Men with the 7R+ genotype of the DRD4 gene take significantly more economic risk than 7R- men.

c. General risk taking/risk perception

Given the profound effect of 7R+ on economic risk taking in males, we might expect it to affect general risk taking, as indicated by the response on a 10-point scale to the question: "Are you a person who is generally prepared to take risks or do you try to avoid taking risks?" Indeed, in our sample economic risk taking was significantly positively correlated with general risk taking. Nevertheless, looking at the whole sample, perhaps surprisingly, 7R+ has no significant effect when controlling for gender, age and height (p=0.519), nor when no controls are included (p=0.874). (See Table A5.) We also find no significant effect of 7R+ on general risk taking for either gender, or that the effect differs between the genders. The only significant predictor of general risk taking is gender, where women take fewer risks (coeff=-1.24, p=0.002). It is interesting to note that Dohmen et al. (forthcoming) had about 7% of their sample answer 0 (lowest risk taking) on this risk question, whereas in our sample no one answered 0. This could be due to a variety of factors. There could be more risk taking men in our sample, or more familiarity in thinking about risk questions. It could also be a framing response: the individuals were in the midst of a bridge tournament, where risk taking is a prime ingredient. It is also interesting to note that Cesarini et al. (2009b), using the same general risk taking question in a twin study, find risk perception to have a genetic component (about 35%).

d. Risk-related activities

In the questionnaire, we ask a number of questions that logic would suggest are related to risk preferences. For example, we ask participants about the proportion of their assets that they have invested in stocks and in bonds. In our analysis we disregard participants who answered "don't know" (corresponding to 10 participants for stocks and 2 participants for bonds). Participants were given intervals that they could choose among, in increments of 10% (see

Appendix 3). If the participant chose the “less than 10%” category, it is coded as 0.05, “10-20%” is coded as 0.15, etc. The amounts invested do not add up to one, since there are other unspecified categories of investment. We assume that on average they are instruments that are less risky than stocks (such as money market funds or savings accounts), making proportion of assets in stocks a positive indicator of risk taking. The effect on bonds is more ambiguous, since bonds are more risky than a savings account but less risky than stocks. For this reason we create a variable that is stocks/(stocks+bonds). We also asked about whether the participant had ever started a company (as a proxy of entrepreneurship), a positive risk indicator. Moreover, participants indicated how many cigarettes they smoke each month and how many alcoholic drinks they consume each month, both risk taking activities. More specifically, there is a large literature linking variation in *DRD4* to addiction. To analyze this we create two dummy variables, that each take the value 0 if the answer is 0 to the specific question (i.e. never drink or smoke), and 1 otherwise.

i. Correlations among risk measures and activities

To begin, we ask if our risk measures (economic risk taking and general risk taking) are associated with risk-related activities. Note that this section is largely exploratory, and as such we do not adjust p-values for multiple testing. (See Tables A2 and A3 for correlation matrices.) We look at men and women separately, since there is a strong gender difference in many of the measures.

First we consider economic risk taking. Correlating economic risk taking with stocks/(stocks+bonds), and including both genotyped and non-genotyped participants, the relationship is not significant for either men or women. We also find no relationships between economic risk taking and entrepreneurship (having started at least 1 company). Note however, that about half of both men and women in our sample have started a company. This is many times higher than the national (US) average. There are no significant associations between economic risk taking and being a smoker. Looking at the relationship between economic risk taking and drinking alcohol (0=never drink, 1=sometimes drink), the relationship is not significant for either men or women.

We now consider general risk taking. There is no significant relationship between general risk taking and our variable stocks/(stocks+bonds) in the male or female subsamples. General risk taking proved to be not related to having started a company, smoking or drinking alcohol for women. For men, however, the relationship between general risk taking and entrepreneurship is significant and in fact negative ($r=-0.27$, $p=0.006$). There is also a significant positive relationship between general risk taking and drinking alcohol in the male subsample ($r=0.18$, $p=0.06$).

ii. 7R+ and risky activities

To explore potential effects of the 7R+ genotype on investment allocations, we look at our variable stocks/(stocks+bonds). In a regression analysis, we find no significant relationship between the 7R+ genotype and investment in stocks and bonds either with ($p=0.296$) or with

covariates (p=0. 486). (See Table A6.) Being female is however negatively associated with more risky investments (coeff=-0.071, p=0.01), whereas height is positively correlated (coeff=0.0007, p<0.001), effects in the expected direction. The interaction effect between 7R+ and gender is not significant, thus we do not look at the male and female samples separately.

Exploring our entrepreneurship variable (whether participants have started a company or not) in a logit regression, this variable is not significantly correlated with 7R+ in the total sample when controls are included (p=0.725) or not (p=0. 941), nor for either gender alone. The control variables female, age and height are also not related. (See Table A6.)

For smoking and drinking alcohol, we perform logit regressions and find no significant relationship between 7R+ and smoking or drinking with (p=0.342 resp. 0.804) or without control variables (p=0.205 resp. p=0.968). Among the control variables, the only near significant relationship is between drinking and height (coeff=0.04, p=0.062). (See Table A7.) The respective interaction effects between 7R+ and gender are not significant.

4. Discussion and conclusion

An emerging strand of literature explores the potential role of genetic factors in explaining individual variation in economic decision making. Twin studies and molecular genetics studies have been used to address behaviors such as altruism in the dictator game (Knafo et al. 2007; Cesarini et al. 2009a; Israel et al. 2009), rejection behavior in the ultimatum game (Wallace et al. 2007), trust behavior in the trust game (Cesarini et al. 2008), risk preferences (Eisenegger et al. ; Barnea et al. 2009; Carpenter et al. 2009; Cesarini et al. 2009a; Cesarini et al. 2009b; Crisan et al. 2009; Kuhnen & Chiao 2009; Roe et al. 2009; Zhong et al. 2009a; Zhong et al. 2009b; Zhong et al. 2009c; Calvet & Sodini 2010), sensitivity to the framing effect (Crisan et al. 2009; Roiser et al. 2009) and behavioral aggression in an economic game (McDermott et al. 2009). This literature suggests that genetic contributions to individual (biological) differences have substantial implications for economic and behavioral studies. Further, genetic inheritance is a potentially important mechanism to consider when interpreting correlations in preferences between parents and offspring, and when considering determinants of preferences more generally. This is not to say that heritable genetic factors fully determine behavior; experience and environment clearly matters. But the addition of genetic factors to economic models is highly likely to improve our understanding of behavior, thereby improving our models and increasing their predictive power.

The focus of this study is on risk taking. The vast literature on this topic reports significant heterogeneity in levels of aversion within and across populations (Barsky et al. 1997; Donkers et al. 2001; Halek & Eisenhauer 2001; Dohmen et al. Forthcoming). Risk preferences appear to be a complex and multi-dimensional trait, perhaps explaining why some studies report correlations across risk domains (Barsky et al. 1997; Guiso & Paiella 2005; Dohmen et al. Forthcoming), whereas others do not (Anderson & Mellor 2009). Risk preferences have been analyzed using a wide variety of experimental approaches (Slovic 1964), and this presumably accounts for some of the reported variance (though there is a discussion of how to extract innate risk attitudes from experimental work (Schoemaker 1993)). However, holding the

experimental methodology constant, significant differences in risk preferences emerge across varying populations (Hsee & Weber 1999). Though a variety of environmental forces, e.g., culture, no doubt contribute to such results, genetic variation may be a strong contributor as well.[6] Whereas genes do not vary across an individual's lifespan, the environment does. This may explain the within participant heterogeneity observed in another study (Isaac & James 2000).

This study focuses on variation in the dopamine receptor gene *DRD4*. This gene has previously been related to risk preferences in the economic domain, though with some inconsistent results. Two studies found a positive relationship between the 7R+ genotype and economic risk taking; one study found a positive relationship with risk taking in bridge; one study found a negative relationship with economic risk taking whereas another study found no relationship. This analysis seeks to deepen our understanding of the 7R+ genotype's relationship to risk taking by looking at a variety of risk-related activities, with a focus on economic risk taking.

We find that 7R+ men take more economic risk than 7R- men, and that this relationship is highly significant. These results are in line with Dreber et al. (2009) – who only had male participants in their study – and use the same economic risk measure. Among women, there is a non-significant but trending negative relationship. This lends some support to the possibility that there may be systematic differences in the types of men and women in our sample, something that is further supported by the fact that the difference in frequency of the 7R+ genotype between men and women is significant. This difference across genders remains a puzzle to be disentangled in the future studies. While nothing (to our knowledge) has been reported on the 7R+ genotype acting differently in men and women in general, or in the other two studies on *DRD4* and economic risk taking that include both genders, our sample is far from representative. It seems quite plausible that systematic differences exist in the types of men versus women attracted to serious bridge tournaments, or that extensive experience with risk taking in bridge alters the behavior of female bridge players, and that these differences explain the gender differences in both the frequency of the 7R+ genotype and its effects that we observe. Alternatively, it is entirely possible that the negative trend in women is a statistical anomaly arising from the extremely small of number of 7R+ women. It is interesting to note that the frequency of the 7R+ genotype in our study is low for both men and women compared to previous studies (e.g., Carpenter et al. 2009, Kuhnen & Chiao 2009). It is also conceivable that the observed effect of the 7R+ genotype in men is a false positive, but this seems unlikely given the size of the sample and other replications of this finding (Dreber et al. 2009, Kuhnen & Chiao 2009).

Despite the significant positive correlation between economic risk taking and general risk taking, and the positive effect of 7R+ among men on economic risk taking, we find no relationship between 7R+ and self-reported general risk taking. It could perhaps be the case that 7R+ individuals don't realize that many of their behaviors are considered risky by others.

[6] Indeed, the prevalence of many alleles varies significantly across populations. In the case of the 7R+ genotype of *DRD4*, allele frequencies in populations ranging from 0% to 78% have been reported in a study of prevalence rates across the globe (Chen et al. 1999).

Moreover, the lack of correlation between 7R+ and self-reported risk taking is in line with the results of Roe et al. (2009), who find different genes correlating with economic and psychological risk measures. This does not imply that risk preferences are unstable, nor that they are context dependent. In fact, Dohmen et al. (forthcoming) find evidence for a single trait operating in the different risk contexts they explore, but with some variation across contexts, perhaps due to differences in risk perception. In their study, it is interesting to note, the general risk question effectively predicted all behaviors (including portfolio choice and smoking). That was not the finding in our study, though our sample is substantially smaller and drawn from a specific population. Moreover, general risk taking/risk perception has been shown to have a genetic component (Cesarini et al. 2009a; Crisan et al. 2009); thus perhaps genes other than *DRD4* are involved in that process.

We have previously reported a positive correlation between the 7R+ genotype and risk taking in bridge decisions among men, using the same sample as in this paper. We also reported results indicating that the fitness/performance of the 7R+ genotype is dependent on the experience of the possessor; highly experienced 7R+ men take more good risk whereas less experienced 7R+ men take more bad risk in bridge, where good and bad risks are defined in terms of their expected value. The economic risk taking measure that we used in this study only entails good risk, since the expected value of taking risk always is significantly greater than the certain value. Thus, it would be interesting to explore in a future study to what extent experience with economic risk taking interacts with 7R+ when looking at both good and bad risk taking on a pure monetary basis.

Risk preferences are of great practical importance given their relationship with economically significant behaviors such as competitiveness, career choice, savings behavior, and pension choice, among many others. We are only beginning to understand the potential role of variation in specific genes, such as the dopamine gene *DRD4*, in contexts involving risk preferences. This implies that more studies on *DRD4* are merited, as well as the identification of other genes which may influence risk preferences in the domain of economic games, psychological measures, and human behavior in the field. Understanding risk preferences is essential for understanding economic behavior, and incorporating the role of genetics into that understanding is a central interdisciplinary challenge in the study of human behavior.

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Appendix 1

Background on *DRD4*

The human DRD4 gene on chromosome 11 contains a 48bp variable number tandem repeat (VNTR) polymorphism (variation) in exon 3 and consists of 2-11 repeats (Ding et al. 2002) likely involved in modulating expression of the gene (Schoots & Van Tol 2003). There is generally a trimodal distribution of 2, 4 and 7 repeat alleles (2R, 4R and 7R) in most populations (Ding et al. 2002).

Genotyping

Genotyping was performed at the Laboratory of Evolutionary Anthropology and Health at Binghamton University, New York. Each participant was given a 15ml centrifuge tube containing approximately 10ml of Scope® mouthwash (Feigelson et al. 2001). Participants gently swirled the mouthwash from cheek to cheek for 45 seconds, to collect buccal cells. Using a sterile straw, participants were instructed to spit the sample back into the same centrifuge tube. Samples were later centrifuged and prepared for DNA extraction using the Maxwell® 16 System (Promega).

Sufficient DNA for *DRD4* PCR amplification was extracted from 86% (203/237) of the buccal cell samples. Genotyping was only performed for the one candidate gene *DRD4*. Previous studies have highlighted problems associated with consistent genotyping of the *DRD4* VNTR region (Eisenberg et al. 2008), suggesting multiple PCR runs for each sample to control for allelic dropout. Thus, the PCR reaction was modified to reflect the high GC content (see below) and all samples that were initially scored as homozygotes were reanalyzed two additional times with different starting template concentrations to confirm genotypes. The PCR reaction consisted of 1x Q-Solution (Qiagen), 1x Buffer (Qiagen), 1 µM Primer 1 (5' GCGACTACGTGGTCTACTCG 3'), 1 µM Primer 2 (5' AGGACCCTCATGGCCTTG 3'), 200 µM dATP, 200 µM dTTP, 200 µM dCTP, 100 µM dITP, 100 µM dGTP, 0.3 units HotStar Taq (Qiagen), and 1 µl of DNA template, in a total volume of 10 µl. The PCR profile began with 15 minutes at 95°C for enzyme activation and denaturing of template DNA followed by 40 cycles consisting of 1 minute denaturation at 94°C, 1 minute annealing at 55°C, 1.5 minute extension at 72°C, and finished with a 10 minute extension at 72°C. Amplicons were electrophoresed through 1.4 – 2.0% agarose gels containing ethidium bromide and genotypes were determined by comparison with a 100 bp ladder. Participants were then scored as either 7R+ (at least one allele of at least 7-repeats or more) or 7R- (both alleles less than 7-repeats).

Population stratification can be an issue in this type of candidate gene study (see (Hamer & Sirota 2000)). Population stratification in this case could lead to biased results due to allele frequency similarities amongst subpopulations with homogenous ancestry. In the sample studied here, an overwhelming majority of participants self-reported Caucasian race, hence we believe these legitimate concerns to be minimal for our particular results.

Appendix 2

Table A1. Summary statistics for genotyped participants.

Variable	**All**	**Men**	**Women**
7R+	N=190, M=0.13, SD=0.34	N=105, M=0.18, SD=0.39	N=85, M=0.07, SD=0.26
Age (9 categories)	N=188, M=5.36, SD=1.35	N=103, M=4.98, SD=1.35	N=85, M=5.83, SD=1.19
Economic risk (0 to 250)	N=186, M=164.6, SD=92.3	N=105, M=198.8, SD=79.7	N=81, M=120.1, SD=88.8
Risk perception (0 to 10)	N=176, M=6.31, SD=2.30	N=97, M=6.84, SD=2.26	N=79, M=5.66, SD=2.20
Stocks (11 categories)	N=170, M=4.58, SD=2.85	N=98, M=4.84, SD=3.01	N=72, M=4.22, SD=2.60
Bonds (11 categories)	N=164, M=2.24, SD=1.79	N=96, M=2.02, SD=1.78	N=68, M=2.56, SD=1.78
Started company (yes=1, no=0)	N=187, M=0.62, SD=0.49	N=103, M=0.60, SD=0.49	N=84, M=0.64, SD=0.48
Cigarette consumption (packages/month)	N=172, M=1.40, SD=21.51*	N=99, M=1.16, SD=23.81*	N=73, M=1.71, SD=21.73*
Alcohol consumption (drinks/month)	N=185, M=19.88, SD=36.16*	N=101, M=24.2, SD=41.80*	N=84, M=14.7, SD=25.69*
Sexual orientation (1= hetero, 0=other)	N=190, M=0.93, SD=0.25	N=105, M=0.94, SD=0.23	N=85, M=0.92, SD=0.28
Marital status (4 categories)	N=186, M=2.09	N=103, M=1.94	N=83, M=2.28
Height in cm	N=179, M=173.9, SD=29.4	N=97, M=182.2, SD=137.6	N=82, M=164.2, SD=7.00

*The reported standard deviations are for those that smoke or drink alcohol.

Table A2. Correlation matrix for economic risk taking, investments in stocks and bonds, entrepreneurship, smoker, drinker. Men only.

Men	Econ risk	Gen risk	Stocks&bonds	Entrepreneur	Smoker	Drinker
Econ risk	1.0000					
Gen risk	0.2063**	1.0000				
Stocks&bonds	0.1584	0.1111	1.0000			
Entrepreneur	-0.0719	-0.2666***	-0.0801	1.0000		
Smoker	-0.0549	-0.0387	0.0904	0.1624*	1.0000	
Drinker	0.1026	0.1832*	0.0697	-0.0679	0.1329	1.0000
*** significant at 10%; ** significant at 5%; *** significant at 1%**						

Table A3. Correlation matrix for economic risk taking, investments in stocks and bonds, entrepreneurship, smoker, drinker. Women only.

Women	Econ risk	Gen risk	Stocks&bonds	Entrepreneur	Smoker	Drinker
Econ risk	1.0000					
Gen risk	0.2562**	1.0000				
Stocks&bonds	0.1124	0.0999	1.0000			
Entrepreneur	-0.1023	0.1182	-0.1467	1.0000		
Smoker	0.0124	-0.0968	0.0990	-0.0832	1.0000	
Drinker	0.0513	-0.0486	0.2576**	-0.0269	0.0545	1.0000
*** significant at 10%; ** significant at 5%; *** significant at 1%**						

Table A4. Economic risk taking. All observations (columns 1-3), men only (columns 4-5), women only (columns 6-7).

	All observations			**Men only**		**Women only**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
	Econ risk	Econ risk	Econ risk	Econ risk	Econ risk	Econ risk	Econ risk
7R+	39.007	19.730	40.363	43.019	39.190	-25.069	-28.021
	(2.04)**	(1.34)	(3.09)***	(3.27)***	(2.99)***	(0.73)	(0.81)
Female		-70.201	-62.619				
		(4.89)***	(4.13)***				
7R+ X Female			-70.244				
			(1.98)**				
Age		-9.873	-9.983		-13.297		-5.232
		(2.22)**	(2.25)**		(2.54)**		(0.63)
Height		0.125	0.140		0.153		-0.261
		(1.11)	(1.23)		(1.32)		(0.16)
Constant	159.856	224.355	218.841	194.481	233.116	120.903	194.132
	(21.40)***	(7.73)***	(7.51)***	(21.35)***	(7.80)***	(11.57)***	(0.68)
Observations	175	175	175	97	97	78	78
R-squared	0.02	0.23	0.24	0.04	0.10	0.01	0.01
Robust t statistics in parentheses							
*** significant at 10%; ** significant at 5%; *** significant at 1%**							

Table A5. General risk taking. All observations.

	(1)	(2)	(3)
	Gen risk	Gen risk	Gen risk
7R+	-0.095	-0.393	-0.464
	(0.16)	(0.65)	(0.59)
Female		-1.237	-1.262
		(3.22)***	(3.10)***
7R+ X Female			0.253
			(0.23)
Age		-0.039	-0.038
		(0.27)	(0.27)
Height		-0.000	-0.001
		(0.14)	(0.15)
Constant	6.253	7.141	7.158
	(32.80)***	(6.58)***	(6.53)***
Observations	167	167	167
R-squared	0.00	0.07	0.07
Robust t statistics in parentheses			
*** significant at 10%; ** significant at 5%; *** significant at 1%**			

Table A6. Investments in stocks and bonds, entrepreneurship. All observations.

	(1)	(2)	(3)	(4)	(5)	(6)
	Stocks&bonds	Stocks&bonds	Stocks&bonds	Entreprenurship	Entreprenurship	Entreprenurship
7R+	-0.026	-0.037	-0.024	0.035	0.169	-0.172
	(0.70)	(1.05)	(0.53)	(0.07)	(0.35)	(0.31)
Female		-0.071	-0.066		0.043	-0.084
		(2.60)**	(2.23)**		(0.12)	(0.23)
7R+ X Female			-0.054			1.379
			(0.82)			(1.08)
Age		0.006	0.005		0.186	0.189
		(0.58)	(0.53)		(1.48)	(1.53)
Height		0.001	0.001		0.006	0.005
		(4.06)***	(4.07)***		(1.28)	(1.22)
Constant	0.621	0.503	0.502	0.525	-1.458	-1.371
	(44.94)***	(8.13)***	(8.10)***	(3.16)***	(1.39)	(1.32)
Observations	145	145	145	178	178	178
R-squared	0.00	0.09	0.09			
Robust t statistics in parentheses						
*** significant at 10%; ** significant at 5%; *** significant at 1%**						

Table A7. Smoker, drinker. All observations.

	(1)	(2)	(3)	(4)	(5)	(6)
	Smoker	Smoker	Smoker	Drinker	Drinker	Drinker
7R+	-1.332	-1.030	-0.378	-0.024	-0.153	0.006
	(1.27)	(0.95)	(0.34)	(0.04)	(0.25)	(0.01)
Female		0.440	0.535		-0.536	-0.489
		(0.90)	(1.04)		(1.06)	(0.93)
7R+ X Female						-0.353
						(0.28)
Age		0.342	0.340		-0.000	0.001
		(1.83)*	(1.84)*		(0.00)	(0.01)
Height		-0.006	-0.006		0.040	0.040
		(0.79)	(0.77)		(1.86)*	(1.86)*
Constant	-1.712	-2.945	-2.988	1.528	-4.873	-4.946
	(7.70)***	(1.77)*	(1.76)*	(7.31)***	(1.22)	(1.23)
Observations	179	179	173	179	179	179
R-squared	0.02	0.06	0.06	0.00	0.06	0.06
Robust z statistics in parentheses						
*** significant at 10%; ** significant at 5%; *** significant at 1%**						

Appendix 3

Brief questionnaire

Please respond to all questions. You can skip a question if it makes you feel uncomfortable.

Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?

(Unwilling to take risks) 0 1 2 3 4 5 6 7 8 9 10 (Fully prepared to take risks)

Age (years):

<20 20-30 30-40 40-50 50-60 60-70

70-80 80-90 90+

Gender/sex: Male Female

What is your marital status?

Single Married Divorced/Separated Widowed

Height: _____

Over the last five years, approximately what proportion of your assets, apart from residence(s), have been invested in stocks?

Less than 10% 10-20% 20-30% 30-40% 40-50% 50-60%

60-70% 70-80% 80-90% More than 90% Don't Know

Over the last five years, approximately what proportion of your assets, apart from residence(s), have been invested in bonds?

Less than 10% 10-20% 20-30% 30-40% 40-50% 50-60%

60-70% 70-80% 80-90% More than 90% Don't Know

Have you ever started your own company?

Yes No

If you smoke cigarettes, on average how many packs of cigarettes do you smoke each month? (enter 0 if non-smoker)?

_____ packs

If you drink alcoholic beverages, on average how many alcoholic drinks do you have each month? (enter 0 if non-drinker)?

_____ drinks

How would you describe your sexual orientation?

Heterosexual Homosexual Bisexual Transsexual/Transgender Decline to state

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