The behavioral genetics of behavioral anomalies*

David Cesarini, Magnus Johannesson, Patrik KE Magnusson , Björn Wallace

Abstract

A number of recent papers have examined the environmental and genetic sources of individual differences in economic and financial decision-making. Here we contribute to this burgeoning literature by extending it to a number of key behavioral anomalies that are thought to be of importance for consumption, savings and portfolio selection decisions. Using survey-based evidence from more than 11,000 Swedish twins we demonstrate that a number of anomalies such as for instance the conjunction fallacy, default bias and loss aversion are moderately heritable. In contrast, our estimates imply that variation in common environment explains only a small share of individual differences. We also report suggestive evidence in favor of a shared genetic architecture between cognitive reflection and a subset of the studied anomalies. These results offer some support for the proposition that the heritable variation in the behavioral anomalies is partly mediated by genetic variance in cognitive ability. Taken together with previous findings our results underline the importance of genetic differences as a source of heterogeneity in economic and financial decision-making.

Keywords: behavioral anomalies, genetics.

*This paper has benefited from the feedback of the editors and an anonymous reviewer. We also thank seminar participants at Carnegie Mellon, London Business School, NYU Stern and Syracuse University and for helpful comments. Jonathan Beauchamp helped us with programming and offered a number of suggestions on how to improve the paper. Financial support from the Hedelius Wallander Foundation is gratefully acknowledged. All errors remain our own.

1 INTRODUCTION

Behavioral economics and behavioral genetics both represent successful developments in the post-war social sciences (Camerer and Loewenstein 2004, Plomin et al. 2009). Yet, despite their obvious common denominator there has been very little interaction between the two. A possible explanation for this state of affairs is that the intellectual roots of the "heuristics and biases" research program pioneered by Kahneman and Tversky (1972, Tversky and Kahneman 1974) can be found in social psychology which typically focuses on the identification of contextual effects. Behavioral genetics in contrast takes context as given and tries to understand the underlying environmental and genetic sources of individual variation (Plomin et al. 2009). The advantages of combining these two research methodologies are substantial. Behavioral economics has been successful in documenting deviations from the assumptions and predictions of the neoclassical model, but has been unsuccessful in explaining the origins of, and variation in, these deviations (Cohen and Dickens 2002, Camerer 2003, Fudenberg 2006, Gigerenzer et al. 2008). Indeed, a criticism that has at times been levelled against the behavioral economics approach is that it lacks a theory of individual differences and, significantly, that efforts to find empirically robust and theoretically plausible sources of interpersonal variation have failed. The only convincing exception to this rule of which we are aware is the relationship between cognitive ability and a number of behavioral anomalies (Stanovich and West 1998, Stanovich 2003, Frederick 2005, Benjamin et al. 2006).

Partly in response to these challenges a literature that studies the neuropsychological foundations of economic behavior has developed (Camerer et al. 2005) alongside a smaller and more recent behavioral genetics literature (Cesarini et al. 2009a). Here, we contribute to the emerging behavioral genetics literature by extending it to behavioral biases. Following in the footsteps of Ellsberg (1961) and Kahneman and Tversky (1972, 1984, Tversky and Kahneman 1981, 1983) we examine a wide array of behavioral biases that are believed to influence economic decision-making. The anomalies we study have attracted substantial interest in both economics and finance where their relevance for explaining real world asset pricing (Fama 1998, Barberis and Thaler 2003) and consumption/savings patterns (Angeletos et al. 2006) is the topic of much debate. Similarly, the prevalence of behavioral anomalies in the laboratory has sparked an intense methodological de-

bate in psychology and economics on whether or not they are in fact artefacts of their potentially unfamiliar and unintuitive framing (Gigerenzer 1991, Cosmides and Tooby 1994, Kahneman and Tversky 1996, Thaler 1999), and under what conditions they can be switched off.

Behavioral genetics offers a number of methods that can help to resolve important questions concerning the etiology of behavioral anomalies by informing us about the relative contributions of differences in genes and environment to variation in economic decision-making. The simplest and most popular of these behavioral genetic methods is the twin method, which relies on comparisons of correlations between monozygotic (MZ, also know as identical) and dizygotic (DZ, also known as fraternal) twins. The twin method is a form of quasi-experiment since MZ twins reared together share both family environment and their genes, whereas the genes of DZ twins reared together are no more correlated than those of any other pair of full biological siblings. Therefore, a higher MZ resemblance for a studied trait is typically interpreted as evidence for heritability in susceptibility to that trait. Using an extensive survey of a large cohort of Swedish twins we demonstrate that for a wide range of behavioral anomalies the responses of MZ twins are indeed more concordant than those of DZ twins.

In addition to studying intrapair correlations, we estimate standard models and find that genetic variation typically accounts for 20-30 percent of the variance in the surveyed anomalies. Varition in rearing conditions on the other hand appear to explain most a modest share of individual differences. The finding that variation in susceptibility to behavioral biases is moderately heritable, and hence that there are systematic individual differences, is important in and of itself. It also points to a source of behavioral heterogeneity, namely genes, which is only beginning to be explored in economics and finance (see Benjamin et al. 2007). Recent papers have, in fact, documented heritabilities for risk taking, giving and ultimatum game rejections that are quite similar to those reported here (Wallace et al. 2007, Cesarini et al. 2009a, 2009b, Zhong et al. 2009, Zyphur et al. 2009), a consistency of results which we find reassuring.

Having established that these behavioral anomalies are heritable, we then ask if there is evidence that some of this heritable variation is mediated by genetic variance in cognitive ability. For a subset of our sample we have data on performance on Frederick's cognitive reflection test (CRT, Frederick 2005). An individual's score on the CRT is usually interpreted as measuring what is usually referred to as system 2 decision-making abilities in dual process theory. Dual process theory distinguishes

between two types of thinking: system 1 thinking, which corresponds to intuitive judgments, and system 2 thinking, which applies to the class of problems which require reasoning (Sloman, 1996). The intuitive answer to each question in Frederick's CRT is wrong and finding the correct answer requires both reflection and the mobilization of costly cognitive resources (Frederick 2005). Using standard multivariate behavioral genetic methods, we attempt to estimate the covariance between the genetic endowment for this measure of cognitive ability and the genetic endowments for each of the behavioral anomalies. The estimates are quite imprecise, but broadly consistent with the notion that these endowments covary, which is consistent with the mediation hypothesis.

Overall, our results suggest that researchers in economics, finance and the decision sciences may be well advised to study further the role of biological and genetic factors in generating individual differences. Such information, beyond its intrinsic scientific value, may also be useful for understanding heterogeneity across individuals in response to policy and the different debiasing strategies which have been proposed in the literature.

The remainder of the paper is organized as follows. In sections 2 and 3 we describe the data and the behavioral anomalies included in the survey. Section 4 outlines the behavioral genetics methodology and in section 5 we present the results. We discuss our findings in section 6, and section 7 concludes the paper.

2 DATA

The Swedish Twin Registry (STR) is the largest twin registry in the world and it routinely administers surveys to Swedish twins (Lichtenstein et al. 2006). Here, we use data from the most recent of these surveys, SALTY, which is a collaborative effort between researchers in epidemiology, medicine and economics initiated in 2007. SALTY is the first major survey of twins which features an entire section specifically devoted to economic decision-making. Beginning in early 2009, the survey was sent out to 24,914 Swedish twins born between 1943 and 1958. Final reminders were sent out in the spring of 2010 to those who did not initially respond to the survey, and the data collection was completed in the summer of 2010. The survey generated a total of 11,743 responses, equalling a response rate of 47.1%. Out of the respondents 11,418 (97.2%) gave informed consent to have their answers stored and analyzed. Zygosity was resolved either by questionnaire items

with high reliability or, when available, by analysis of biosamples (Lichtenstein *et al.,* 2006). In total, our sample is comprised of 1150 MZ, 1245 same-sex DZ, and 1117 opposite sex DZ pairs. Remaining responses were from individuals whose twin siblings did not fill in the survey.

For most of the respondents we were able to obtain background statistics on education, income and marital status from administrative records by matching individuals to a dataset previously collected by Cesarini et al. (2010). To ascertain how representative our sample is, we present summary statistics for the background variables in Table I. Like in other twin studies there is some overrepresentation of women (Lykken et al. 1987). Respondents are also better educated compared to non-respondents, the difference being approximately 0.5 years of educational attainment. There are, however, only small differences in the other background variables and our sample is arguably more representative of its study cohort, and the general population, than most other studies in the behavioral economics literature.[1]

3 THE SURVEY

Throughout the remainder of the paper, we use the term behavioral anomaly to describe behaviors that are inconsistent with the standard assumptions made in economic models, e.g. about decision-making under uncertainty or the discounting of future rewards. In total, we examine seven types of behavioral anomalies using 11 variables and 17 questions, most of which were derived from seminal papers in the behavioral economics literature. Below, we describe how the measures that we analyze were constructed and, when applicable, how the questions were modified to fit the format of the survey. Throughout, we consistently code the variables so that a higher value corresponds to less susceptibility to the behavioral anomaly. The English translation of the questions used can be found in Appendix A.

3.1 Loss Aversion

To study loss aversion, or small-stakes risk-aversion, we use three questions that represent binary choices over participation in hypothetical gambles. These questions were constructed in the mold of, but were not identical to, those used by Tversky and Kahneman (1992). In each question

[1] For a more exhaustive discussion on representativeness in experimental economics we refer the reader to Harrison and List (2004) and similarly, for a discussion of recruitment bias in twin research, see Lykken et al. (1987).

respondents were asked to either accept or reject a gamble that was associated with a 50% chance of losing 1000 SEK and a 50% chance of winning either 1500, 2000 or 2500 SEK.[2] It has been known at least since Arrow (1971) that an implication of expected utility theory, when the utility function is concave in wealth, is that individuals should be approximately risk neutral over small-stakes gambles. Rabin (2000) extended the insight and demonstrated that even risk-aversion over modest stakes imply implausible levels of risk-aversion over larger stakes. For the purpose of analysis the individual responses to the three questions were used to define four separate categories with values ranging from 0 to 3: "always loss averse" (0), "loss averse only at 2000" (1), "loss averse only at 1500 and above" (2) and "never loss averse" (3). Fewer than two percent of respondents provided answers which were inconsistent, in the sense that the individual accepted the gamble at either the 1500 or 2000 prize, but then rejected a gamble with higher monetary reward. These inconsistent responses were omitted from the analysis.[3]

3.2 Self-Control

Self-control problems, typically modelled as quasi-hyperbolic discounting (Laibson 1997), have received substantial attention in recent years. Here, we use two different measures of self-control problems; one that is based on trade-offs between immediate and delayed outcomes and one that is based on the subject's self-reported actual behavior.

3.2.1 Short Term Time Preference

An indication of self-control problems is excessive discounting of future outcomes. Frederick et al. (2002) provide a comprehensive survey of the different approaches to measuring discount factors that have been proposed in the literature and note that each approach is associated with difficulties. Here, we use a simple choice task in which subjects were asked to respond to three questions that represent binary hypothetical choices between an amount of money today and a larger amount of money in the future. In each question, respondents had to choose between 5000 SEK today or a larger amount in a week, where the larger amount was either 5500, 6000 or 7000 SEK. For the purpose of analysis individual responses to the three questions were aggregated and

[2] The exchange rate is approximately seven SEK to the US dollar (Nov. 2010).

[3] However, in analyses not reported here, we verified that including the inconsistent observations, by simply letting the outcome variable be the number of rejected gambles, yielded substantively identical results.

coded into four categories. Each category is represented by an integer between 0 and 3, where 0 denotes never choosing the delayed reward and 3 denotes always choosing the delayed reward. We eliminated inconsistent responses in the analyses, but such responses were, again, rare.

3.2.2 Procrastination

To supplement the evidence on discounting, we also studied self-reported actual behavior. In particular, to obtain a proxy for self-control problems in every day life we asked subjects how often they fail to pay their bills on time. There were six alternative responses to the question ranging from "never" (5) to "several times a month"(0). Self-control problems can lead to this type of procrastination behavior, and we refer to the measure as procrastination.

3.3 Default Bias

Default bias, also known as status quo bias (Samuelson and Zeckhauser 1988), implies that there is a bias towards choosing the default option. Studies of 401(k) savings behavior have, for instance, demonstrated that the default option offered to households can have pronounced effects on investment choices (Madrian and Shea 2001, Choi et al. 2003). We used three questions on self-reported actual behavior as indicators of default bias. Two questions asked the subjects if they had changed (i) telephone and (ii) electricity provider following the recent deregulation of these industries in Sweden. It is widely known that changing provider was associated with large potential reductions in costs, even though the products offered were close to perfect substitutes. Despite this, many consumers failed to make the transition and instead stayed with the default provider. The third and final question asked if, conditional on having previously been a member, the subject had left the Church of Sweden after the separation from the state. Each response was coded with the value 1 if the individual reported a change of provider and 0 otherwise. Similarly, individuals who reported having left the Church of Sweden were coded as 1 and individuals who reported not having left were coded as 0. We compute an index of default bias by summing the responses to the three questions, so that a higher number denotes less susceptibility to status quo bias.[4]

[4]The question about leaving the Church of Sweden may not be a good measure of default bias insofar as it is confounded with religiosity. Since MZ twins are more similar in the strength of their religious attitudes, this may generate greater concordance in the decision to leave the Church of Sweden for reasons which have nothing to do with their susceptibility to "default bias". Excluding this question from the index generates an MZ correlation of 0.20 and a DZ correlation of 0.08, compared to 0.25 and 0.10 with the question included.

3.4 Illusion of Control

To study illusion of control we follow Langer (1975) and investigate if valuations of gambles over random outcomes are affected by the amount of control respondents perceive that they exercise over the outcome of a lottery. Respondents were asked to make a binary choice between two hypothetical lotteries. The first lottery assigned participants a ticket with higher expected value than the ticket offered in the second lottery in which participants instead were allowed to choose their own ticket, thus introducing a trade-off between perceived control and expected return. If respondents preferred the second lottery they were coded as being subject to the illusion of control. The responses of individuals who preferred the first lottery, with higher expected value, were assigned the value 1.

3.5 Ambiguity Aversion

To study ambiguity aversion, we use a slightly modified version of Ellsberg's (1961) urn with 30 red balls and 60 black and yellow balls of unknown proportions. Subjects were asked to choose between three hypothetical lotteries, one paying 900 SEK if a red ball was chosen, one paying 1000 SEK if a black ball was chosen and one paying 1000 SEK if a yellow ball was chosen. If respondents preferred the lottery with red as the winning color they were coded as ambiguity averse. These responses were coded as 0, and all other responses as 1.

3.6 Fungibility of Money

To study fungibility we use slightly modified versions of the two theater ticket questions in Tversky and Kahneman (1981). Subjects were asked to make a hypothetical binary choice between going to the theater or not when they had already decided to go but either lost the ticket, or the money with which they had intended to buy the ticket. The responses to the two questions were aggregated. If the subjects gave answers that were incompatible with fungibility they were coded as being subject to the bias, with a value of 0. If the answers were compatible with fungibility the response was coded as 1.

3.7 The Representativeness Heuristic

In a series of classical papers, Kahneman and Tversky (see e.g. Kahneman and Tversky 1972, 1973, Tversky and Kahneman 1974) documented several prevalent violations of the laws of probability in human statistical reasoning. They traced these failures to the so called "representativeness heuristic", according to which people, ignoring other relevant factors, use similarity as a basis for judgment when making probabilistic assessments. To study the "representativeness heuristic", we administered three questions that are described below. The three questions were analyzed separately, but they were also collapsed into a total "representativeness index".

3.7.1 Conjunction Fallacy

To study the conjunction fallacy we use a reduced version of the Linda question in Kahneman and Tversky (1983). In our version, subjects only faced two alternatives instead of the original eight. If they answered that Linda was a bank teller and a feminist they were coded as being subject to the conjunction fallacy with a value of 0. Subjects who did not commit the conjunction fallacy were coded as 1.

3.7.2 Base Rate Fallacy

To examine the base rate fallacy, according to which subjects pay insufficient attention to base rates in making probability assessments, we use a question that conceptually draws on Kahneman and Tversky's (1983) Linda question and their 1973 paper (Kahneman and Tversky 1973) which demonstrated insensitivity to base rates. Subjects were asked to judge whether a described man was most likely to be a nurse or a professional tennis player. If respondents answered that he was more likely to be a professional tennis player, they were coded as being subject to the base rate fallacy, as this answer fails to take into account the vastly higher base rate of male nurses than male professional tennis players. Subjects who answered that he was more likely to be a nurse were coded as 1.

3.7.3 Insensitivity to Sample Size

To study the subjects understanding of basic laws of statistics, and in particular the law of large numbers, we use a slightly modified and reduced version of the question on sex ratios and hospitals from Kahneman and Tversky (1972). Subjects were asked to assess whether it was more likely that 60 percent of the children born at a hospital were boys when the hospital was small rather than large. Respondents who answered that it was more likely that the unusually high fraction of boys would occur in the larger hospital were coded as being insensitive to sample size, with a value 0. Subjects who correctly answered that it was more likely that the fraction of boys would exceed 0.6 in the smaller hospital were coded as 1.

3.8 Cognitive Reflection

Finally, we administered Frederick's (2005) cognitive reflection test to approximately half of the sample. We used exactly the same three questions as in the original article and summed the number of correct answers for the purpose of analysis.[5]

4 Methods

4.1 The ACE Framework

The basic idea behind a twin study is simple. MZ and DZ twins differ in their genetic relatedness but are reared in the same family. Therefore, any greater similarity between MZ twins in some trait is usually taken as evidence that the trait is under genetic influence. The workhorse model in the behavioral genetics literature, known as the ACE model, posits that additive genetic factors (A), common environmental factors (C), and non-shared environmental factors (E) account for all individual differences in the trait of interest.

Additive genetic effects are defined as the sum of the effects of individual genes influencing a trait. The assumption that genetic effects are purely additive, i.e. linear, rules out possibilities such as dominant genes, where nonlinearities exists in the relationship between the amount of genetic material coding for a certain trait, and the actual realized trait. Common environment effects

[5] Regrettably, the cognitive reflection test was removed from later waves of the survey as part of a general effort to reduce the number of questions.

are those environmental influences shared by both twins, such as the quality of local schooling, parental education and income. Non-shared environmental effects include influences not shared by the co-twins as well as measurement and response error.

For a formal development of the ACE model in the case of MZ and DZ twins reared together, consider first a pair of MZ twins. Let all variables, including the trait, be expressed as deviations from zero and standardize them to have unit variance. Suppose first that the outcome variable can be written as the sum of two independent influences: additive genetic effects, A, and environmental influences, U. We then have that,

$$P = aA + uU,$$

and, using a superscript to denote the variables for twin 2 in a pair,

$$P' = aA' + uU'.$$

Since for MZ twins $A = A'$, the covariance (which, due to our normalization, is also a correlation) between the outcome variables of the two twins is given by,

$$\rho_{MZ} = a^2 + u^2 COV(U, U')_{MZ}.$$

Now consider a DZ pair. Under the assumption that parents match randomly with respect to their values of A, so that the correlation between the additive genetic effects of the father and of the mother is zero, it will be the case that $Cov(A, A') = 0.5$. We then have that,

$$\rho_{DZ} = \frac{1}{2}a^2 + u^2 COV(U, U')_{DZ}.$$

Finally, we impose the equal environment assumption, namely that,

$$COV(U, U')_{MZ} = COV(U, U')_{DZ}.$$

Under these, admittedly strong, assumptions it is easy to see that heritability, the fraction of variance explained by genetic factors, is identified as $a^2 = 2(\rho_{MZ} - \rho_{DZ})$. In the standard behavioral genetics framework, environmental influences are generally written as the sum of a common

environmental component (C) and a non-shared environmental component (E) such that,

$$P = aA + cC + eE.$$

With this terminology, the environmental covariance component of the trait correlation, $u^2COV(U, U')$, can be written as c^2, since by definition any covariance must derive only from the common component. This allows us to write the individual variation as the sum of three components a^2, c^2, and e^2; a^2 is the share of variance explained by genetic differences, c^2 is the share of variance explained by common environmental influences, and e^2 the share of variance explained by non-shared environmental influences. There are a number of ways in which the parameters of this model can be estimated. In particular, following directly from the above derivation, the variance-covariance matrix is of the form,

$$\sum = \begin{bmatrix} a^2 + c^2 + e^2 & R_i a^2 + c^2 \\ R_i a^2 + c^2 & a^2 + c^2 + e^2 \end{bmatrix} \tag{1}$$

where R_i takes the value 1 if the observation is an MZ pair, and 0.5 otherwise. The ACE framework is frequently criticized for being overly simplistic and it is indeed based on strong assumptions about the absence of assortative mating and additive gene action (Goldberger 1977). Additionally, the functional form and independence assumptions needed to identify the model are likely to be wrong. Yet, the basic stylized facts from behavioral genetics have proven to be quite resilient to alternative modeling assumptions. In particular, empirical work using sibling types other than twins reared together, e.g. adoptees, half and full siblings and twins reared apart, tend to produce estimates which are quite similar to twins-based estimates. For a thoughtful discussion of the various objections that have been raised against twin studies, see Bouchard and McGue (2003).

There are, however, several interpretational issues which require attention. The first is that it is quite possible that many of the genetic effects estimated in behavioral genetics may be mediated by environments (Jencks 1980, Dickens and Flynn 2001). An individual's environment is often endogenous to genotype, either because genes cause selection into certain environments or because genes evoke certain behavioral reactions (Jencks, 1980). For this reason, the estimates from the

behavioral genetic model are often interpreted as reduced form coefficients from a more general model in which some environments are endogenous to genotype.

In Appendix B, we sketch how, under some additional assumptions, the model can be extended to the two variable case. This model, known as the bivariate, or Cholesky, decomposition (Martin and Eaves 1977) can be used to decompose covariation between two variables into genetic, common environmental and non-shared environmental components. It also allows us to investigate whether the genes which are correlated with a particular behavioral anomaly are in fact also correlated with the genetic endowments for cognitive reflection.

4.2 Estimation

Since the variables we study are ordinal, we follow the standard approach in the literature which is to estimate a threshold model. A threshold model assumes that the categories observed (for example, being susceptible to the conjunction fallacy) are cutoffs of some underlying distribution of the studied trait. For each twin pair, the distribution of the variable is assumed to have a bivariate normal distribution with unit variance and correlation varying as a function of zygosity, as specified in equation (1). Maximum likelihood estimation is then carried out with respect to the variance components and the threshold, which also is estimated as a part of the model. The maximand in the optimization problem is simply the log-likelihood of the observed data,

$$\ln L = \sum_{c=1}^{2} \sum_{i=1}^{k} \sum_{j=1}^{l} n_{ijc} \ln \left(p_{ijc} \right), \tag{2}$$

where n_{ijc} is the observed frequency of data in cell n_{ij} for zygosity c, k and l are, respectively, the maximum number of categories of the two variables, and the expected proportions in each cell can be calculated by numerical integration as,

$$p_{ij1} = \int_{t_i}^{t_{i+1}} \int_{t_j}^{t_{j+1}} \phi(x_1, x_2, \sum_{MZ}) dx_1 dx_2, \tag{3}$$

$$p_{ij2} = \int_{t_i}^{t_{i+1}} \int_{t_j}^{t_{j+1}} \phi(x_1, x_2, \sum_{DZ}) dx_1 dx_2, \tag{4}$$

where $\phi(x_1, x_2, \sum)$ is the bivariate standard normal distribution, $\sum$ is the correlation matrix, whose diagonal elements are normalized to 1 ($a^2 + c^2 + e^2 = 1$), and t_i is the lower threshold of category i. The number of thresholds will be equal to the number of categories minus one, and the thresholds are estimated as part of the model. Of course, the lower threshold of category 0 is $-\infty$, and the upper threshold for the highest category is ∞. Thresholds are constrained to be the same for monozygotic and dizygotic twins[6], but in our estimation we allow men and women to have different thresholds.

For inference, we use likelihood ratio tests, following the suggestion of Neale and Miller (1997). In particular, confidence intervals are obtained by fixing the parameter of interest at some value different than its optimal value, whilst simultaneously optimizing the remaining parameters. Under some regularity conditions, the distribution of the likelihood ratio test statistic $-2ln(L_1/L_2)$, L_1 and L_2 being respectively the maximized likelihoods of the nested and the more general model, follows a $\chi^2(1)$ distribution. The parameter is displaced until the deterioration in likelihood is significant.

However, the approach we take to estimating confidence intervals is known to be conservative when the parameter value is on the boundary of the parameter space under the null hypothesis (Dominicus et al. 2006). Dominicus et al. (2006) derive the asymptotic distribution of the test statistic for the case when estimates from an ACE model are compared to a model where the a^2 or the c^2 coefficients are constrained to equal zero. They report that as a rule of thumb, p-values derived under the assumption of an asymptotic $\chi^2(1)$ distribution need to be divided by two in this context. We prefer to err on the side of caution and therefore report confidence intervals constructed using the conventional approach. The reported p-values are hence likely to be conservative and our confidence intervals too wide.

5 RESULTS

In Table II we report descriptive statistics for the eleven outcome variables and the CRT along with intrapair polychoric correlations separated by the zygosity and sex composition of the pairs. As can be seen there is a lot of variation in susceptibility to the different behavioral anomalies. For

[6] This is a testable restriction which we fail to reject for all 11 variables.

example, an overwhelming majority of subjects exhibit the base rate and conjunction fallacies, as well as loss aversion. On the other hand, suffering from the illusion of control or treating money as non-fungible is less common. Of course, these differences may simply reflect the choice of questions used to measure the anomalies and alternative elicitation procedures might have generated different results.

If there is heritable variation in a trait then one should expect MZ twins to exhibit greater similarity in the trait than DZ twins. As can be seen in Table II this is indeed what we observe in our data. MZ correlations are consistently higher than same sex DZ correlations, and the difference is significant at the 5% level for seven out of the 11 studied anomalies. At the 10% level only the variables that we refer to as "Short Time Preferences" and "Base Rate Fallacy" fail to achieve significance. These results imply that genetic differences are important for explaining heterogeneity in the susceptibility of behavioral anomalies.

The correlations of opposite sex DZ twins are also shown in the table, and these correlations tend to be smaller than the correlations of same-sex DZ twins. Even though the difference between same-sex and opposite sex twins only approaches statistical significance in one instance (fungibility), the evidence should be considered in its entirety. In 10 cases out of 11 same-sex twins exhibit greater similarity than opposite sex twins. There are several plausible interpretations of these lower opposite sex correlations. The first is that different features of the family environment are etiologically relevant in males and females, thereby depressing their similarity. This argument is only plausible in variables for which variation in rearing conditions explains a large portion of the variation. Alternatively, a different set of genes may account for the heritable variation in males and females (Neale and Maes 2002). A third, perhaps more speculative, possibility is that sibling imitation is stronger in same sex sibling pairs.[7]

Table III provides estimates from the ACE model, using only the same-sex MZ and DZ twins, along with the likelihood-ratio based 95% confidence intervals. The point estimates for heritability are in the range 0.16-0.43, with a median estimate of 0.24. Even using the conservative likelihood-based confidence intervals, the heritability estimates are significantly different from zero, at the 5% level, for six out of 11 variables. As is often found in this literature, variation in family environments

[7] Of course, such interactions are absent in the standard ACE model. For a review of sibling interaction models in behavior genetics, see chapter 8 in Neale and Maes (2004).

explain a relatively small share of variation. In fact, the median point estimate is that the family variable explains none of the variation in susceptibility to behavioral anomalies that we observe. The remaining, and by far largest in all specifications, variance component is the so called non-shared environment, which includes all influences on the phenotype, including noise, that are independent of genotype and rearing conditions.

Finally, in Table IV we report the correlations between the behavioral anomalies and performance on the CRT as well as the results of the bivariate model for behavioral anomalies and CRT. To a certain extent these correlations confirm the previously established link to cognitive ability (Stanovich and West 1998, Stanovich 2003, Frederick 2005, Benjamin et al. 2006). Eight out of the 11 anomalies are positively correlated with CRT, and seven significantly so reinforcing the findings of Oechssler et al. (2009). Only "Ambiguity Aversion" and "Procrastination" are negatively correlated with CRT. However, the association between CRT and procrastination is complicated by the fact that the underlying relationship is nonmonotonic[8]. Overall, magnitudes are low to moderate, the range being 0.03 to 0.41, with a median of 0.15. Thus, higher cognitive ability as proxied by CRT is weakly associated with less susceptibility to behavioral anomalies.

Turning finally to the multivariate results, we find that the heritable variation in susceptibility to eight of the studied anomalies is positively correlated with the heritable variation in CRT scores. However, most estimates are very imprecise and only three are statistically significant at the 5% level. For these three the correlations are on the other hand substantial, 0.8 or above, and suggestive of a common etiology. A partial explanation the lack of significant correlations could be that the CRT data is only available for a subset of the SALTY survey respondents and that the phenotypic correlations between cognitive reflection and the anomalies are quite low. Our power to detect significant associations is therefore quite limited.

6 DISCUSSION

In this paper we report the first set of results from a survey, unique in both its scale and scope, on the economic behavior of twins. We build on an emerging literature wherein behavioral

[8] Those who respond that they fail to pay their bills "once a month" or "several times a month" do have significantly lower CRT scores than those whose responses lie in the medium categories "once every six months" or "several times every six months". However, the respondents who "never" or "once a year" fail to pay their bills on time fare worse on the cognitive reflection task than respondents in the medium category, resulting in a negative correlation.

genetic techniques are used to study the genetic and environmental sources of variation in economic decision-making (Barnea et al., 2010; Cesarini et al. 2008, 2009a, 2009b, Cronqvist and Siegel 2011, Simonson and Sela 2011, Zhong et al., 2009, Zyphur et al. 2009; Wallace et al. 2007). We find that well-documented behavioral anomalies such as the conjunction fallacy, loss aversion, default bias and representativeness are moderately heritable. Overall, MZ twins consistently exhibit greater resemblance for susceptibility to behavioral anomalies than do DZ twins. Typically, genetic differences account for 20-30 percent of individual variation. In sharp contrast to the genetic effects, variation in common environment accounts for only a small fraction of observed interpersonal differences. Finally, a large portion of variation is due to non-shared environment. This set of results is consistent with a broad consensus in behavioral genetics, which is now so firmly established that it is often referred to as a law (Turkheimer 2000).[9]

Our work is also closely related to a number of recent papers that study more conventional aspects of economic preferences and behavior (Wallace et al. 2007, Cesarini et al. 2009a, 2009b, Zhong et al. 2009, Zyphur et al. 2009). In fact, our variance component estimates are quite similar to those reported in Cesarini et al. (2009a, 2009b, 2010) for risk and giving, but somewhat lower than the heritability estimates in Zhong et al. (2009). Compared to the consensus estimates in the literature on the heritability of intelligence (Bouchard and McGue 1981) and the so called "big five" factors of personality (Jang et al. 1996), it is clear that our estimates are low. Much of this difference likely reflects noise; with dichotomous response items, there will be a lot of error variance in comparison to a variable constructed by aggregating multiple responses. Indeed, we conjecture that once noise is filtered out, the heritability of most economic preferences will look quite similar to that of the "big five" in personality research.

There is some evidence in the previous literature on the heritability of susceptibility to behavioral anomalies, including the demonstration in Cesarini et al. (2010) that MZ twins are more likely to exhibit concordance in a binary variable proxying for returns-chasing behavior. The first paper exclusively devoted to exclusively to decision-making anomalies was Simonson and Sela (2011), who

[9] A common misunderstanding is to equate high heritability with "immutability" (Goldbeger 1979, Pigliucci 2001, Beauchamp et al. 2010b). This is a mistake for a number of reasons. One is that the causal pathway from molecular genetic variants to complex social outcomes often involve environmental variables which are manipulable. Indeed, behavioral anomalies are sensitive to subtle contextual differences and changes in the instructions (Gigerenzer 1991). Moreover, as explained in Goldberger (1979) heritability estimates tell us what fraction of phenotypic variance is explained by genes, not whether a particular policy passes the cost benefit test.

administered a rich set of questions on decision-making to a sample of 110 MZ and 70 DZ pairs of twins. They did not find significant heritabilities for a number of judgment heuristics and discounting and tentatively proposed that decision tasks involving "prudence" have higher heritabilities. This paper's findings are broadly consistent with many of the results in Simonson and Sela (2011), though we find no evidence of different heritabilities across domains.[10]

Interestingly, we find that opposite sex DZ twins tend to be less similar than same-sex DZ twins. There are several potential, and not mutually exclusive, explanations for this finding. One is that different genes, or different features of the family environment, explain variation in men and women. Another is that there are forces not captured by the simple ACE model, such as sibling interactions, which inflate sibling similarity. If such interactions are more intense in same-sex twin pairs, this may help explain the excess similarity of same sex DZ twins over opposite sex pairs, without having to invoke explanations based on heterogeneous environmental or genetic effects which vary by sex.

The finding that genes can account for a considerable share of individual differences in behavioral anomalies points to a source of heterogeneity which has traditionally been somewhat overlooked in economics and finance, namely genetic and biological variation. Obtaining a better understanding of the biological and genetic mechanisms which account for the heritable variation in anomalies is an important next step in the effort to integrate behavioral genetics into economics. There are several complementary approaches which one might take to answering this question. One strategy has been to try to directly identify hormonal and molecular genetic associates of economic preferences (for a review see Beauchamp et al. 2011). While this is an exciting area of research several authors have cautioned that given the small samples typically used in these studies, the false discovery rate is likely to be very high (Beauchamp et al. 2011, Benjamin 2010). It is as of yet an open question whether biological variables such as genetic markers and hormone levels will prove to be more reliable predictors of individual differences than traditional demographic variables.

Although the search for robust demographic correlates to behavioral anomalies has largely been disappointing, it seems clear that, individuals with low cognitive ability are more prone to making economic decisions which defy standard assumptions (Stanovich and West 1998, Stanovich and West

[10] A convincing demonstration that heritabilities differ significantly across domains would require very large samples and should ideally also be based on measurement error adjusted estimated of the variance components.

2000; Stanovich 2003, Frederick 2005, Benjamin et al. 2006), suggesting that cognitive ability might be a mechanism mediating some of the heritable variation in the behavioral anomalies. Consistent with the findings in this literature, a majority of the anomalies in our data are positively and significantly correlated with performance on the CRT (Frederick, 2005). However the correlations are rather small, with the exception of three variables: "Illusion of Control", "Insensitivity to Sample Size" and "Representativeness". These were also the only variables for which there was a significant genetic correlation between the CRT scores and the anomaly. Given that "Insensitivity to Sample Size" and "Representativeness" are by construction very similar to the type of questions used in standard tests of cognitive ability their common origins can hardly be considered surprising. Somewhat more intriguingly, there was a significant negative correlation between "Procrastination", "Ambiguity Aversion", on the one hand, and CRT on the other hand. For "Procrastination" the finding may be driven by a non-monotonic relationship between the CRT score and the response to the question. For "Ambiguity Aversion" no obvious explanations suggests itself.[11]

There are a number of reasons to expect that a better understanding of the genetic factors that underlie individual differences in behavioral anomalies will benefit economics, finance and the decision sciences. First, insofar as it is reasonable to classify most of these behaviors as mistakes, knowledge of the forces that generate these mistakes may provide cues about where to look for policy levers that reduce their prevalence and their impact. Such information may also turn out to be helpful for understanding how various environmental conditions interact with genetic endowments (Benjamin et al. 2007). A second motivation for studying individual differences is that knowledge about which economic agents are the most vulnerable to behavioral anomalies may have implications for efforts to predict when individual-level biases can be expected to have aggregate effects. An important strand of work in economics has demonstrated that, at least in some economic environments, people who interact in a market frequently tend to exhibit behavior that more closely resembles that predicted by standard economic theory (List 2003, Levitt and List 2007). Much remains to be learnt about the extent to which these patterns are generated by social and market forces, or if they instead to a large extent are driven by selection into economic environments based on individual differences, for example in genetic endowments.

[11] The existing literature offers no real clue to the rather puzzling negative correlation, as previous studies found no correlation between ambiguity aversion and cognitive ability, albeit one between ambiguity aversion and orbitofrontal lesions (Hsu et al. 2005, Borghans et al. 2009).

7 CONCLUSION

Recent years have witnessed an increasing interest in the sources of individual differences in economic and financial decision-making. Many of the papers in this vein of research use behavioral genetic methodologies to separately identify the role of rearing conditions, genetic factors and other influences. This paper extends the existing literature to an important set of behaviors which has so far only received limited attention, namely behavioral anomalies. Using survey-based evidence from more than 11,000 Swedish twins we demonstrate that well documented departures from expected utility maximization are moderately heritable with most point estimates suggesting that 20 to 30 percent of individual variation can be accounted for by genes. These results underline the importance of genetic differences as a source of heterogeneity in susceptibility to behavioral anomalies.

8 References

Angeletos, G. M., D. Laibson, A. Repetto, J. Tobacman, S. Weinberg. 2006. The Hyperbolic Consumption Model: Calibration, Simulation, and Empirical Evaluation. *J. Econom. Perspect.* **15**(3) 47–68.

Arrow, K. 1971. *Essays in the Theory of Risk-Bearing.* North-Holland, Amsterdam.

Barnea, A., H. Cronqvist, S. Siegel. 2010. Nature or Nurture: What Determines Investor Behavior? *J. Financ. Econ.* 98(3): 583–604.

Barberis, N., R. H. Thaler. 2003. A Survey of Behavioral Finance. G. M. Constantinides, M. Harris, R. Stulz, eds. *Handbook of the Economics of Finance.* Elsevier, Amsterdam, 1051–1121.

Beauchamp, J. P., D. Cesarini, M. Johannesson, M. van der Loos, P. Koellinger, P. J. F. Groenen, J. H. Fowler, N. Rosenquist, A. R. Thurik, N. A. Christakis. 2011. Genetics and Economics. *J. Econom. Perspect.*, forthcoming.

Beauchamp, J. P., D. Cesarini, M. Johannesson, E. Lindqvist, C. Apicella. 2010. On the sources of the height–intelligence correlation: New insights from a bivariate ACE model with assortative mating. *Behav. Genet.*, doi 10.1007/s10519-010-9376-7.

Benjamin, D. J. 2010. White Paper for NSF Workshop on Genes, Cognition, and Social Behavior. Manuscript.

Benjamin, D. J., S. Brown, S. Shapiro. 2006. Who is "Behavioral"? Cognitive Ability and Anomalous Preferences. Manuscript.

Benjamin, D. J., C. F. Chabris, E. L. Glaeser, V. Gudnason, T. B. Harris, D. I. Laibson, L. J. Launer, S. Purcell. 2007. Genoeconomics. M. Weinstein, J. W. Vaupel, and K. W. Wachter, eds. *Biosocial Surveys.* The National Academies Press, Washington, 304–335.

Borghans, L., B. H. H. Golsteyn, J. J. Heckman, H. Meijers. 2009. Gender Differences in Risk Aversion and Ambiguity Aversion. *J. Europ. Econom. Assoc.*, **7**(2–3) 649-658.

Bouchard Jr, T. J., M. McGue. 1981. Familial Studies of Intelligence: A Review. *Science* **212** 1055–1059.

Bouchard Jr, T. J., M. McGue. 2003. Genetic and Environmental Influences on Human Psychological Differences. *J. Neurobiol.* **54**(1) 4–45.

Camerer, C. F. 2003. *Behavioral Game Theory: Experiments in Strategic Interaction.* Princeton University Press, Princeton.

Camerer, C. F. 2008. Neuroeconomics: Opening the Gray Box. *Neuron* **60** 416–419.

Camerer, C. F., G. Loewenstein. 2004. Behavioral Economics: Past, Present, Future. C. F. Camerer, G. Loewenstein, M. Rabin, eds. *Advances in Behavioral Economics.* Princeton University Press, Princeton, 3–51.

Camerer, C. F., G. Loewenstein, D. Prelec. 2005. Neuroeconomics: How Neuroscience Can Inform Economics. *J. Econom. Lit.* **43**(1) 9–64

Cesarini, D., C. T. Dawes, J. H. Fowler, M. Johannesson, P. Lichtenstein, B. Wallace. 2008. Heritability of Cooperative Behavior in the Trust Game. *Proc. Natl. Acad. Sci. USA* **105**(10) 3721–3726.

Cesarini, D., C. T. Dawes, M. Johannesson, P. Lichtenstein, B. Wallace. 2009a. Experimental Game Theory and Behavior Genetics. *Ann. NY Acad. Sci.* **1167** 66–75.

Cesarini, D., C. T. Dawes, M. Johannesson, P. Lichtenstein, B. Wallace. 2009b. Genetic Variation in Preferences for Giving and Risk-Taking. *Quart. J. Econom.* **124**(2) 809–842.

Cesarini, D., M. Johannesson, P. Lichtenstein, Ö. Sandewall, B. Wallace. 2010. Genetic Variation in Financial Decision Making. *J. Finance* **65**(5) 1725–1754.

Choi, J. J., D. Laibson, B. Madrian, A. Metrick. 2003. Optimal Defaults. *Amer. Econom. Rev. Papers Proc.* **93**(2) 180–185.

Cohen, J. L., W. T. Dickens. 2002. A Foundation for Behavioral Economics. *Amer. Econom. Rev. Papers Proc.* **92**(2) 335–338.

Cosmides, L., J. Tooby. 1994. Better than Rational: Evolutionary Psychology and the Invisible Hand. *Amer. Econom. Rev. Papers Proc.* **84**(2) 327–335.

Cronqvist, H., S. Siegel. 2011. The Origins of Savings Behavior. AFA 2011 Denver Meetings Paper.

Dickens, W. T., J. R. Flynn. 2001. Heritability Estimates versus Large Environmental Effects: The IQ Paradox Resolved. *Psychol. Rev.* **108**(2) 346–369.

Dominicus, A., A. Skrondal, H. K. Gjessing, N. L. Pedersen, J. Palmgren. 2006. Likelihood Ratio Tests in Behavioral Genetics: Problems and Solutions. *Behav. Genet.* **36**(2) 331–340.

Ellsberg, D. 1961. Risk, Ambiguity, and the Savage Axioms. *Quart. J. Econom.* **75**(4) 643–669.

Fama, E. 1998. Market Efficiency, Long-Term Returns, and Behavioral Finance. *J. Financial Econom.* **49**(3)283–306.

Frederick, S. 2005. Cognitive Reflection and Decision Making. *J. Econom. Perspect.* **19**(4) 25–42.

Frederick, S., G. Loewenstein, T. O'Donoghue. 2001. Time Discounting and Time Preference: A Critical Review. *J. Econom Lit.* **40**(2) 351–401.

Fudenberg, D. 2006. Time Discounting and Time Preference". *J. Econom. Lit.* **44**(3) 694–711.

Gigerenzer, G. 1991. How to Make Cognitive Illusions Disappear: Beyond "Heuristics and Biases". *Europ. Rev. Soc. Psych.* **2** 83–115.

Gigerenzer, G., R. Hertwig, U. Hoffrage. 2008. Cognitive Illusions Reconsidered. C. R. Plott and V. L. Smith, eds. *Handbook of Experimental Economics Results, vol. 1.* Elsevier, Amsterdam, 1018–1034.

Goldberger, A. S. 1977. Twin Methods: a Skeptical View. P. Taubman, ed. *Kinometrics: Determinants of Socioeconomic Success Within and Between Families*, North-Holland, Amsterdam, 299–324.

Goldberger, A. S. 1979. Heritability. *Economica* **46**(184) 327–347.

Harrison, G. W., J. List. 2004. Field Experiments. *J. Econom. Lit.* **42**(4) 1009–1055.

Hsu, M., M. Bhatt, R. Adolphs, D. Tranel, C. F. Camerer. 2005. Neural Systems Responding to Degrees of Uncertainty in Human Decision-Making. *Science* **310** 1680–1683.

Isacsson, G. Estimating the economic return to educational levels using data on twins. *J. App. Econom.* **19**(1) 99–119.

Jang, K. L., W. J. Livesley, P. A. Vernon. 1996. Heritability of the Big Five Personality Dimensions and Their Facets: A Twin Study. *J. Pers.*, **64**(3) 577–592.

Jencks, C. 1980. Heredity, Environment, and Public Policy Reconsidered. *Amer. Sociology Rev.*, **45**(5) 723–736.

Kahneman, D., A. Tversky. 1972. Subjective Probability: A Judgment of Representativeness. *Cogn. Psych.* **3**(3) 430–454.

Kahneman, D., A. Tversky. 1973. On the psychology of prediction. *Psychol. Rev.* **80**(4) 237–251.

Kahneman, D., A. Tversky. 1984. Choices, Values, and Frames. *Amer. Psychol.* **39**(4) 341–350.

Kahneman, D., A. Tversky. 1996. On the Reality of Cognitive Illusions. *Psychol. Rev.* **103**(3) 582–591.

Laibson, D. 1997. Golden Eggs and Hyperbolic Discounting. *Quart. J. Econom.* **112**(2), 443–477.

Langer, E. J. 1975. The Illusion of Control. *J. Pers. Soc. Psych.* **32**(2) 311–328.

Lichtenstein, P., P. F. Sullivan, S. Cnattingius, M. Gatz, S. Johansson, E. Carlström, C. Björk, M. Svartengren, A. Volk, L,. Klareskog, U. de Faire, M. Schalling, J. Palmgren, N. L. Pedersen. 2006. The Swedish Twin Registry in the Third Millennium : An Update. *Twin Res.* **9**(6) 875–882.

Levitt, S., J. List. 2007. What Do Laboratory Experiments Measuring Social Preferences Tell us About the Real World? *J. Econom. Perspect.* **21**(2) 153–174.

List, J. 2003. Does Market Experience Eliminate Market Anomalies? *Q. J. Econom.* **118**(1) 41–71.

Lykken, D. T., M. K. McGue, A. Tellegen. 1987. Recruitment Bias in Twin Research: The Rule of Two-Thirds Reconsidered. *Behav. Genet.* **17**(4) 343–362.

Madrian, B., D. F. Shea. 2001. The Power of Suggestion: Inertia in 401(k) Participation and Savings Behavior. *Quart. J. Econom.* **116**(4) 1149–1187.

Martin, N., L. Eaves. 1977. The Genetic Analysis of Covariance Structure. *Heredity* **38**(1) 79–95.

Neale, M. C., M. M. Miller. 1997. The Use of Likelihood-Based Confidence Intervals in Genetic Models. *Behav. Genet.* **27**(2) 113–120.

Neale, M. C, H. Maes. 2004. *Methodology for Genetic Studies of Twins and Families.* Kluwer Academic Publishers B.V, Dordrecht.

Oechssler, J., A. Roider, P.W. Schmitz. 2009. "Cognitive Abilities and Behavioral Biases" *J. Econ. Behav. Organ.* **72**(1): 147–152.

Pigliucci, M. 2001. *Phenotypic plasticity: beyond nature and nurture.* Johns Hopkins University Press, Baltimore.

Plomin, R., J. C. DeFries, G. E. McClearn, P. McGuffin. 2009. *Behavioral Genetics, 5th ed.* Worth Publishers, New York.

Rabin, M. 2000. Risk Aversion and Expected-Utility Theory: A Calibration Theorem. *Econometrica* **68**(5) 1281–1292.

Samuelson, W., R. Zeckhauser. 1988. Status-Quo Bias in Decision-Making. *J. Risk Uncertainty* **1**(1) 7–59.

Simonson, I., A. Sela. 2011. On the Heritability of Consumer Decision Making: An Exploratory Approach for Studying Genetic Effects on Judgment and Choice. *J Consum. Res.*, **37**(5)

Sloman S.A. 1996 The Empirical Case for Two Systems of Reasoning. *Psychol. Bull.*, 119(1): 3–22.

Stanovich, K. E. 2003. *Who Is Rational? Studies of Individual Differences in Reasoning.* Lawrence Erlbaum Associates, Mahwah.

Stanovich, K. E., R. F. West. 1998. Individual Differences in Rational Thought. *J. Exp. Psych. [Gen.]* **127**(2) 161–188.

Stanovich, K. E., R. F. West. 2000. Individual differences in reasoning: Implications for the rationality debate? *Behav. Brain Sci.* **23** 645–726.

Thaler, R. H. 1999. Mental Accounting Matters. *J. Behav. Decision Making* **12**(3) 183–206.

Turkheimer, E. 2000. Three Laws of Behavior Genetics and What They Mean. *Curr. Dir. Psych. Sci.* **9**(5) 160–164.

Tversky, A., D. Kahneman. 1974. Judgment under Uncertainty: Heuristics and Biases. *Science* **185** 1124–1131.

Tversky, A., D. Kahneman. 1981. The Framing of Decisions and the Psychology of Choice.

Science **211** 453–458.

Tversky, A., D. Kahneman. 1983. Extensional Versus Intuitive Reasoning: The Conjunction Fallacy in Probability Judgement. *Psychol. Rev.* **90**(4) 293–315.

Tversky, A., D. Kahneman. 1992. Advances in Prospect Theory: Cumulative Representation of Uncertainty. *J. Risk Uncertainty* **5**(4) 297-323.

Wallace, B., D. Cesarini, P. Lichtenstein, M. Johannesson. 2007. Heritability of Ultimatum Game Responder Behavior. *Proc. Natl. Acad. Sci. USA* **104**(40) 15631–15634.

Zhong, S., S. H. Chew, E. Set, J. Zhang, H. Xue, P. C. Sham, R. P. Ebstein, S. Israel. 2009. The Heritability of Attitude Toward Economic Risk. *Twin Res. Human Genet.* **12**(1) 103–107.

Zyphur, M.J, J. Narayanan, R. D. Arvey, G. J. Alexander. 2009. The Genetics of Economic Risk Preferences. *J. Behav. Dec. Making*, **22**(4) 367–377.

Table I. Sample Background Statistics

	Respondents			Non-Respondents		
	Mean	S.D.	#	Mean	S.D.	#
Birth year	1949.9	4.57	11418	1950.4	4.59	13171
1 if Female	.54	.50	11418	.48	.50	13171
1 if MZ	.27	.44	11418	.23	.42	13170
1 if SS DZ	.36	.48	11418	.37	.48	13170
1 if OS DZ	.36	.48	11418	.39	.49	13170
Education	11.94	2.72	11167	11.42	2.64	12024
Income	294000	186000	11188	275000	213000	12070
1 if married	.65	.48	11191	.59	.49	12076

MZ: monozygotic twin. SS DZ: same sex dizygotic twin. OS DZ: opposite sex dizygotic twin. Income is defined as the sum of income earned from wage labor from own business, pension income and unemployment income compensation. The education variable produced by Statistics Sweden is categorical. The categorical scores are converted into years of education using the population averages in Isacsson (2004) A survey respondent is defined here as an individual who responded to the survey and gave informed consent to have his or responses analyzed. Non-respondents are the individuals who failed to respond to the survey.

Table II. Sample Summary Statistics

	Mean	S.D.	Min	Max	ρ_{MZ}	#	ρ_{DZ}	p-value of $\rho_{MZ} - \rho_{DZ}$
Loss Aversion	.348	.837	0	3	.340***	10981	.178***	.022
Short Term Time Preference	2.671	.751	0	3	.246***	11121	.164***	0.128
Procrastination	4.390	.906	0	5	.428***	11299	.172***	<0.01
Default Bias	1.095	.890	0	3	.250***	10336	.101**	<0.01
Illusion of Control	.767	.422	0	1	.264***	11182	.125**	0.032
Ambiguity Aversion	.378	.485	0	1	.214***	10887	.128**	0.100
Fungibility of Money	.946	.226	0	1	.416***	11188	.174*	.061
Conjunction Fallacy	.163	.369	0	1	.252***	11060	.048	<0.01
Base Rate Fallacy	.120	.325	0	1	.289***	10987	.175**	0.142
Insensitivity to Sample Size	.489	.450	0	1	.479***	10759	.202***	<0.01
Representativeness	.770	.786	0	3	.379***	10573	.194***	<0.01
Cognitive Reflection (CRT)	.813	1.131	0	3	.590***	5323	.302***	<0.01

Variable definitions are in the text. Variables are coded so that a higher value corresponds to less susceptibility to the anomaly.All variables are categorical, integer-valued and a higher number corresponds to less "bias". All correlations are polychoric. ρ_{MZ}: polychoric correlations in MZ twins. ρ_{DZ}: polychoric correlation in same sex DZ twins. ρ_{DZO}: polychoric correlation in opposite sex twins. Three stars (***) denote statistical significance at the one percent level, two stars (**) denote statistical significance at the five percent level and one star (*) denotes statistical significance at the ten percent level. All results are bootstrapped. The reported p-values are one-sided. Variables are coded so that a higher value corresponds to less susceptibility to the anomaly.

Table III. ACE Estimates for Behavioral Anomalies

	Genetic (a^2)	Common (c^2)	Non-shared (e^2)	-2·$ln(L)$
Loss Aversion	0.23*** (0.13-0.45)	0.11 (0.00-0.33)	0.65*** (0.55-0.76)	5949.25
Short Term Time Preference	0.18 (0.00-0.35)	0.07 (0.00-0.26)	0.75*** (0.65-0.86)	6259.31
Procrastination	0.18** (0.05-0.24)	0.00 (0.00-0.10)	0.82*** (0.76-0.89)	10380.28
Default Bias	0.24*** (0.10-0.31)	0.00 (0.00-0.11)	0.76*** (0.69-0.82)	10652.72
Illusion of Control	0.24 (0.00-0.34)	0.00 (0.00-0.21)	0.76*** 9(0.66-0.86)	5022.15
Ambiguity Aversion	0.16 (0.00-0.29)	0.04 (0.00-0.22)	0.80*** (0.71-0.89)	6013.37
Fungibility of Money	0.39 (0.00-0.55)	0.00 (0.00-0.38)	0.61*** (0.45-0.78)	1929.90
Conjunction Fallacy	0.22** (0.01-0.33)	0.00 (0.00-0.16)	0.78*** (0.67-0.90)	4002.90
Base Rate Fallacy	0.27 (0.00-0.43)	0.03 (0.00-0.30)	0.71*** (0.57-0.86)	3183.68
Insensitivity to Sample Size	0.42*** (0.28-0.50)	0.00 (0.00-0.11)	0.58*** (0.50-0.66)	6018.48
Representativeness	0.36*** (0.21-0.42)	0.00 (0.00-0.11)	0.64*** (0.58-0.71)	9381.84

This table shows heritability estimates for the eleven variables defined in the text. A is the genetic factor; C is the common environmental factor; E is the unique environmental factor. All models are estimated allowing for different thresholds in in men and women, but the thresholds are constrained to be the same in MZ and DZ twins of the same sex. Variance components are constrained to be the same in men and women. The 95% confidence intervals shown within parentheses are constructed using likelihood ratio tests, as described in Neale and Miller (1997). Three stars (***) denote statistical significance at the one percent level, two stars (**) denote statistical significance at the five percent level and one star (*) denotes statistical significance at the ten percent level. Variables are coded so that a higher value corresponds to less susceptibility to the anomaly.

Table IV. Correlations Between Behavioral Anomalies and CRT and Bivariate ACE Estimates of Behavioral Anomalies and CRT

	ρ	ρ_A	ρ_C	ρ_E	$-2 \cdot ln(L)$
Loss Aversion	0.03	-0.14 (-1.00-0.33)	1.00 (-1.00-1.00)	0.02 (-0.14-0.18)	10817.15
Short Term Time Preference	0.17***	0.31 (-0.78-1.00)	1.00 (-1.00-1.00)	0.10 (-0.06-0.24)	11009.19
Procrastination	-0.13***	-0.26 (-0.51-0.08)	-1.00 (-1.00-1.00)	0.06 (-0.07-0.18)	14310.67
Default Bias	0.08***	0.10 (-0.52-0.43)	1.00 (-1.00-1.00)	-0.03 (-0.15-0.08)	15420.42
Illusion of Control	0.24***	0.83*** (0.31-1.00)	-1.00 (-1.00-1.00)	-0.03 (-0.18-0.13)	9750.75
Ambiguity Aversion	-0.19***	-0.20 (-1.00-1.00)	-1.00 (-1.00-1.00)	-0.09 (-0.22-0.05)	10762.44
Fungibility of Money	0.10	0.20 (-1.00-1.00)	-1.00 (-1.00-1.00)	0.15 (-0.10-0.39)	6700.89
Conjunction Fallacy	0.14	0.34* (-0.08-1.00)	-0.67 (-1.00-1.00)	0.05 (-0.11-0.21)	8760.65
Base Rate Fallacy	0.15**	0.41 (-1.00-1.00)	-1.00 (-1.00-1.00)	-0.01 (-0.20-0.17)	7951.56
Insensitivity to Sample Size	0.41***	0.88*** (0.62-1.00)	-1.00 (-1.00-0.68)	0.08 (-0.06-0.22)	10608.67
Representativeness	0.33***	0.80*** (0.51-1.00)	-1.00 (-1.00-1.00)	0.05 (-0.07-0.17)	14017.89

This table shows polychoric correlations and bivariate heritability estimates (Martin and Eaves 1977) between CRT scores and the eleven variables defined in the text. All models are estimated allowing for different thresholds in men and women, but the thresholds are constrained to be the same in MZ and DZ twins of the same sex. The first column shows the polychoric correlation between the behavioral anomaly and cognitive reflection. The remaining columns show the estimated correlations between the three variance components of cognitive reflection and the corresponding variance components for each behavioral anomaly. For example, the estimated correlation between the genetic endowment for cognitive reflection and each behavioral anomaly is ρ_A. The 95% confidence intervals shown within parentheses are constructed using likelihood ratio tests, as described in Neale and Miller (1997). Three stars (***) denote statistical significance at the one percent level, two stars (**) denote statistical significance at the five percent level and one star (*) denotes statistical significance at the ten percent level. Variables are coded so that a higher value corresponds to less susceptibility to the anomaly.

9 Appendix A

In this appendix, we present the English translations of the survey questions that were used in this paper.

9.1 Loss Aversion

Q1 Imagine that you could take part in a lottery where a coin toss determines if you win 2000 SEK ("heads" in the coin toss) or lose 1000 SEK ("tail" in the coin toss). Would you choose to participate in the lottery?

Yes

No

Q2 Imagine that you could take part in a lottery where a coin toss determines if you win 1500 SEK ("heads" in the coin toss) or lose 1000 SEK ("tail" in the coin toss). Would you choose to participate in the lottery?

Yes

No

Q3 Imagine that you could take part in a lottery where a coin toss determines if you win 2500 SEK ("heads" in the coin toss) or lose 1000 SEK ("tail" in the coin toss). Would you choose to participate in the lottery?

Yes

No

9.2 Self-Control

9.2.1 Short Term Time Preference

Q1 Imagine having to choose between receiving a sum of money today, or waiting to receive a larger sum in one week. Which would you choose?

5000 SEK today

6000 SEK in a week

Q2 Imagine having to choose between receiving a sum of money today, or waiting to receive a larger sum in one week. Which would you choose?

5000 SEK today

7000 SEK in a week

Q3 Imagine having to choose between receiving a sum of money today, or waiting to receive a larger sum in one week. Which would you choose?

5000 SEK today

5500 SEK in a week

9.2.2 Procrastination

How often does it happen that you do not pay bills on time?

Never

Once a year

Once every six months

Several times every six months

Once a month

Several times a month

9.3 Default Bias

Q1 A few years ago it became possible to switch electricity provider. Have you switched electricity provider after this possibility was introduced?

Yes

No

Q2 A few years ago it became possible to switch telephone operator from Telia. Have you switched telephone operator after this possibility was introduced?

Yes

No

Q3 Have you left the Church of Sweden since the separation from the state?

Yes

No, I am still in the Church of Sweden

No, I did not belong to the Church of Sweden at the separation from the state

9.4 Illusion of Control

Imagine that you could participate in one of the two lotteries below, where the chance of winning is the same.

Lottery 1: You are allocated a lottery ticket and every one in a thousand of the participants will win 10000 SEK

Lottery 2: You can pick a lottery ticket yourself and every one in a thousand of the participants will win 9000 SEK

Which of these two lotteries would you choose?

Lottery 1

Lottery 2

9.5 Ambiguity Aversion

Imagine that there is an urn with 30 red balls and 60 other balls which are either black or yellow. The number of balls of each color is determined in advance, but you do not know the exact number of balls that are black or yellow, only that the total number is 60. The balls are well mixed so that every ball has the same chance of being drawn. Imagine that you can draw one ball from this urn and that you have to choose between the following three lotteries. Which lottery would you choose?

Lottery A: You receive 900 SEK if a red ball is drawn.

Lottery B: You receive 1000 SEK if a black ball is drawn.

Lottery C: You receive 1000 SEK if a yellow ball is drawn.

9.6 Fungibility of Money

Q1 Imagine that you have decided to watch a play that costs 100.SEK When you enter the theatre to buy the ticket you discover that you have lost a 100 SEK bill. Will you still pay 100 SEK to watch the play?

Yes

No

Q2 Now imagine that you have decided to watch a play and that you have already bought a ticket for 100 SEK. When you enter the theatre you discover that you have lost the ticket. It is impossible to get a refund for the lost ticket. Would you buy a new ticket for 100 SEK?

Yes

No

9.7 The Representativeness Heuristic

9.7.1 Conjunction Fallacy

Linda is 31 years old, single, outspoken and very talented. She has a university degree in philosophy. As a student she was very involved in discrimination and social justice issues. She also participated in several anti nuclear demonstrations. Which of the following alternatives is the most likely?

A: Linda works in a bank

B: Linda works in a bank and is active in the feminist movement

Alternative A

Alternative B

9.7.2 Base Rate Fallacy

Kalle is attractive, athletic, drives a Mercedes and has a very attractive girlfriend. Which of the following alternatives is the most likely?

A: Kalle is a professional tennis player

B: Kalle works as a nurse

Alternative A

Alternative B

9.7.3 Insensitivity to Sample Size

There are two hospitals in a city. In the big hospital, 45 children are born every day, and in the small hospital 15 children are born every day. On average 50% of the children born are boys, but it varies from day to day. In which hospital do you think that it is most likely that more than 60% of the children born are boys in a specific day?

The big hospital

The small hospital

9.8 Cognitive Reflection

We used exactly the same three items as in Frederick (2005) and hence do not reproduce them here.

10 Appendix B

In this appendix, we sketch the assumptions needed to estimate bivariate heritability (Martin and Eaves 1977). Readers interested in a more comprehensive development are referred to Beauchamp et al. (2010). We write,

$$P_1 = a_1 A_1 + c_1 C_1 + e_1 E_1,$$

$$P_2 = a_2 A_2 + c_2 C_2 + e_2 E_2,$$

where P_1 and P_2 are the two traits of interest and all variables are be expressed as deviations from zero with unit variance. In matrix notation, we can write this as,

$$P = \tilde{a}\tilde{A} + \tilde{c}\tilde{C} + \tilde{e}\tilde{E},$$

where $\tilde{a}$ is a diagonal two-by-two matrix whose diagonal elements are a_1 and a_2 and $\tilde{A} = [A_1, A_2]'$. Here, $\tilde{c}, \tilde{C}$, $\tilde{e}$ and $\tilde{E}$ are defined similarly. We impose the same assumptions as in the univariate case. In addition, we assume that all elements of $\tilde{A}, \tilde{C}$ and $\tilde{E}$ are mutually uncorrelated. Stacking the observations in each family, $\mathbf{Y} = (P_1, P_2, P_1^*, P_2^*)'$, we have the following symmetric matrix of moment conditions:

$$E(YY') = \begin{bmatrix} a_1^2+c_1^2+e_1^2 & & & \\ \rho_A a_1 a_2+\rho_C c_1 c_2+e_1 e_2 \rho_E & a_2^2+c_2^2+e_2^2 & & \\ Ra_1^2+c_1^2 & R\rho_A a_1 a_2+\rho_C c_1 c_2 & a_1^2+c_1^2+e_1^2 & \\ R\rho_A a_1 a_2+\rho_C c_1 c_2 & Ra_2^2+c_2^2 & \rho_A a_1 a_2+\rho_C c_1 c_2+e_1 e_2 \rho_E & a_2^2+c_2^2+e_2^2 \end{bmatrix}$$

where $R = 0.5$ if the observation is from a DZ pair and 1 otherwise. Here, the parameter ρ_A is the correlation between the standardized latent genetic endowments A_1 and A_2 and ρ_C and ρ_E are analogously defined. Given the standardization, it is readily verified that there are nine independently informative equations and hence that there are exactly enough moments to identify the parameters of the model. The genetic correlation squared is the R^2 from a hypothetical regression of the genetic endowment of the first trait on the genetic endowment of the second trait. A high R^2 is consistent with the hypothesis that genetic variance in cognitive reflection mediates some of the heritable variation in the behavioral anomalies. However, whilst a high genetic correlation is suggestive, it does not prove mediation. For example two traits could be explained by entirely different sets of genes and yet be correlated because of linkage disequilibrium.[12]

[12] Linkage disequilibrium refers to the tendency for alleles which are located near each other on a chromosome to be inherited together.