On the Relationship Between Cognitive Ability and Risk Preference

Thomas Dohmen (University of Bonn and IZA)
Armin Falk (briq and University of Bonn)
David Huffman (University of Pittsburgh)
Uwe Sunde (LMU)

Discussion Paper No. 76

March 5, 2018

Collaborative Research Center Transregio 190 | www.rationality-and-competition.de
Ludwig-Maximilians-Universität München | Humboldt-Universität zu Berlin
Spokesperson: Prof. Dr. Klaus M. Schmidt, University of Munich, 80539 Munich, Germany
+49 (89) 2180 3405 | info@rationality-and-competition.de

On the Relationship Between Cognitive Ability and Risk Preference

Thomas Dohmen, Armin Falk, David Huffman and Uwe Sunde[1]

[1] The authors thank Dan Benjamin, Daniel Krähmer, Sven Rady and Philippe Tobler for helpful discussions. We are also grateful to Radost Holler for providing excellent research assistance. Financial support by Deutsche Forschungsgemeinschaft through CRC TR 190 (Sunde) and CRC TR 224 (Dohmen and Falk) is gratefully acknowledged.
Affiliations:

Thomas Dohmen: University of Bonn, IZA, Maastricht University, DIW, CESifo
Armin Falk: Behavior and Inequality Research Institute, University of Bonn, IZA, CEPR, CESifo
David Huffman:University of Pittsburgh, IZA
Uwe Sunde: University of Munich, IZA, CESifo, DIW, CEPR

Their email addresses are t.dohmen@uni-bonn.de, Armin.Falk@briq-institute.org, huffmand@pitt.edu, and uwe.sunde@econ.lmu.de.

Many decisions of individuals are a combination of internal preferences and mental processes related to cognitive ability. As Frederick (2005) argued in this journal, "there is no good reason for ignoring the possibility that general intelligence or various more specific cognitive abilities are important *causal* determinants of decision making." Since then, a number of empirical studies have focused on the relationship between cognitive ability and decision making in different contexts. This paper will focus on the relationship between cognitive ability and decision making under risk and uncertainty. Taken as a whole, this research indicates that cognitive ability is associated with risk-taking behavior in various contexts and life domains, including incentivized choices between lotteries in controlled environments, behavior in non-experimental settings, and self-reported tendency to take risks.

We begin by clarifying some important distinctions between concepts and measurement of risk preference and cognitive ability. In particular, complexity and possible confusions arise because observed measures of risk preference and cognitive ability are used to represent the latent characteristics of these concepts. We discuss the substantial (and somewhat implausible) range of assumptions that need to be satisfied in order to be able to interpret a correlation between measures of risk preference and cognitive ability as a relationship between latent risk preference and latent cognitive ability. Drawing causal inferences from such relationships raises additional challenges.

We go on to argue that it is nevertheless important and valuable to study whether cognitive ability is related to measured risk preference (see also Dohmen et al., 2010). Risk preference is typically measured by risky behavior (actual or self-reported). If risky behavior varies systematically with cognitive ability, this may reinforce or counteract the impact of cognitive ability on life outcomes, depending on the nature of the correlation. If there is a relationship it also becomes important to control for cognitive ability when relating life outcomes to standard revealed preference measures of risk preference. If cognitive ability has a causal impact on measured risk preference, it is important to understand the mechanism, and there are intriguing policy implications.

We then take stock of what is known empirically on the connections between cognitive ability and measured risk preferences, looking at studies using real-world risky behavior, experimental measures of risky choice, and self-reported measures of willingness to take risks. An example of one pattern that seems to emerge frequently in these studies is that cognitive ability tends to be positively correlated with avoidance of harmful risky situations, but it tends to be negatively correlated with risk aversion in advantageous situations. This suggests that the relationship between cognitive ability and risk taking has a reinforcing effect on economic outcomes. In light of age-related cognitive decline, another implication refers to age-related changes in decision making under risk, which has wide-ranging implications for aging societies. There is also intriguing emerging evidence on the way that measured risk preference relates in different ways to different facets of cognitive ability, with implications for understanding mechanisms and possibly for better targeting in policy interventions.

We conclude by discussing perspectives for future research, in particular the scope for the development of richer sets of elicitation instruments and measurement across a wider range of concepts. We also consider progress in neuroscience, but conclude that at present that field still seems relatively far from allowing definitive conclusions about latent risk preference and cognitive ability. Nevertheless, the existing empirical evidence suggests that interventions to influence cognitive ability, should they be possible, might have spillovers on risky choice.

A Conceptualization Risk Preference and Cognitive Ability: Measurement and Causality

In economic theory, risk preference has traditionally been conceptualized as a primitive of the decision model that affects the way in which individuals make risky trade-offs. This trait is general in the sense that it is relevant for risky choices in all contexts and domains, whether it be choices about financial assets, car driving, or health. Importantly, this concept of risk preference as a primitive is not directly observable, but rather is a latent trait. The typical way of obtaining empirical measures of this trait (referring to risk preferences, but equally other types of preferences) is to observe the decisions of individuals that face a particular, well-defined trade-off between choice options that are associated with different riskiness. Under the assumption that all other factors that affect the trade-off are controlled for and that the subject perceives the trade-off exactly as intended by the researcher, then the subject's choice reveals the latent risk preference. For example, risk preference is often measured in experiments based on a choice between two financial lotteries that differ with respect to risk. The key assumptions behind this setup are that the individual understands probabilities and the expected values of the options being offered, and that other factors that may affect risky choice besides the latent preference, e.g., wealth, can be adequately controlled for. Another crucial assumption is that the inferred preference ranking is invariant to the context or framing of the choice, so that it can be generalized to risky choice in other contexts. Similar assumptions are needed to infer latent risk preference from observing choices over risky life outcomes, or from self-reports of risk attitudes.

If latent risk preference were systematically related to what is often assumed to be another primitive of economic models – cognitive ability – this would have important implications for economics. While both are typically assumed (implicitly or explicitly) to be orthogonal, it is conceivable that these traits are in fact systematically related. If so, this would have important consequences for the appropriate specification of models, theoretical and empirical, that include both traits. Various mechanisms have been proposed through which a relationship might exist. In the context of a two-system model, if latent risk preference is partly driven by the emotional, impulsive system-one, but higher cognitive ability entails greater control of decisions by the deliberative, calculating system-two, then there might be a causal impact of cognitive ability on latent risk preference (Benjamin et al., 2013). In this case, latent risk preference would be, at least partly, endogenous to cognitive ability.

Alternatively, causality could potentially go the other direction, with latent risk preference playing a role in development of partly endogenous cognitive ability. For instance, Cunha et al. (2010) formulate and estimate a model of the accumulation of cognitive and noncognitive skills where the evolution of skills depends on family environment, genetic factors, parental skills, investments and shocks. In their dynamic model, changes in the vector of skills depend on the stock of skills at the beginning of a given period. Cognitive skills might thus be affected by noncognitive skills, and potentially preferences. They also emphasize that causality in early childhood development may be bi-directional due to feedback processes. Heckman, Pinto, and Savelyev (2013) show that skill formation is affected by the Perry Preschool program, in which children aged three and four were exposed to a learning environment that promotes social competency, planning, and organization. Likewise, Kosse et al. (2016) show that participation in a Mentor program affects the formation of prosociality. It is conceivable that individuals partly choose their environment by sorting into particular types of situations, and this sorting decision could be related to risk preference.

Latent risk preference could also play a role later in life in choices about investment in education, with the latter fostering improved cognitive ability. Another source for a relationship between cognitive ability and latent risk preference could be co-evolution, i.e., certain combinations of these two traits might be beneficial. For example, perhaps evolutionary pressures might have created a tendency for low cognitive ability to be paired with cautious tendencies (Dohmen et al., 2010). Likewise, intergenerational transmission of traits (see, e.g., Dohmen et al., 2012) might imply a correlation of these traits in the population (Boyer, 2006).

One challenge to investigating a potential relationship between latent risk preference and cognitive ability arises, however, precisely because risk preference is latent and the assumptions needed to infer this latent risk preference from risky behavior are fairly restrictive. If the choice situation is not held constant across individuals, and this introduces noise in measured risk preference, this may obscure any relationship between latent risk preference and cognitive ability. In addition, it could well be that cognitive ability systematically affects some of the factors that influence risky choice but are distinct from (latent) risk preference. After all, choices made on any particular task in settings of risk and uncertainty will be at least partly the outcome of a conscious process of mental deliberation, which in turn involves cognitive abilities such as processing of information related to probabilities and stakes, the calculation of expected values, and the valuation of different choice alternatives. Cognitive ability might also matter for the importance of other factors that may influence observed measures of risk preference, including aspects of the choice setting itself (e.g., the decision frame, the domain of possible choices, stake size associated with decisions) and personal characteristics (e.g., the level of pre-existing wealth or level of education).

Other challenges arise if the goal is to test *causal* relationships between latent risk preference and cognitive ability. A first challenge is developing an intervention that exogenously varies either latent risk preference, or cognitive ability. It is not trivial to do this, in particular as the formation and operation of these primitives is not fully understood. A second challenge is ensuring that such an intervention changes exclusively one of the traits without also affecting the other (see Heckman, 2005). For example, suppose that repeated exposure to risk in childhood affects latent risk preference. For this to be a valid source of exogenous variation, it is necessary that this repeated exposure does not also affect cognitive ability. It is unclear whether this will be the case. Likewise, interventions to affect cognitive ability might also influence latent risk preference. Without knowing more about the formation of latent risk preference and cognitive ability it is difficult to be sure that causality is being identified. Finally, identifying a causal effect requires the ability to measure changes in latent risk preference and cognitive ability, which is itself a challenge.

Yet an additional layer of complexity is added because cognitive ability is itself a latent trait, as well as multidimensional. Cognitive ability is typically measured by different types of achievement or performance tests. These tests only capture cognitive ability if other factors that might affect test performance are held constant. For example, distractions on the day of the test, and personality traits that determine task motivation could play a role in test performance. It may be possible to control for these factors, e.g., by measuring personality type (see, e.g., Dohmen et al., 2010). While some of these factors affecting test performance may be orthogonal to latent risk preference and just add noise, however, certain other factors such as risky or cautious test-taking strategy could conceivably be determined by latent risk preference. This raises the possibility that measured risk preference is related to performance on cognitive ability tests (with causality going from risk preference to test performance) but without indicating a relationship between latent risk preference and cognitive ability.

Moreover, cognitive ability is also multidimensional. One might think of different facets of cognitive ability as lying along a continuum, from being exogenous primitives of the model, to more endogenous and akin to acquired knowledge. This representation corresponds to the distinction between fluid and crystalized intelligence in psychology (Cattell 1971; 1987). Broadly speaking, crystallized intelligence represents knowledge and acquired skills (for example, verbal skills, numeracy, or financial literacy), whereas fluid intelligence captures the ability to solve novel problems and represents the outcome of biological factors in intellectual development, which includes capacities such as speed of processing, or memory. There are also other categorizations of cognitive abilities, which is one reason why there are many different types of tests for measuring cognitive ability (see, e.g., Ackermann and Heggestad, 1997). For example, the most frequently used tests include the Wechsler Adult Intelligence Scale (WAIS), which refers to a person's global capacity to act purposefully, to think rationally, and to deal effectively with his environment; different submodules capture different aspects of crystallized and fluid intelligence. Another test, Raven's Progressive Matrices, tries to measure abstract reasoning more closely related to fluid intelligence. Risk preference might be related to some facets of cognitive ability but not others, and the presence and direction of causality could depend on the facet.

For these reasons, finding a defensible way to extract a measure of latent risk preference that is distinct from cognitive ability, while understanding any potential causal relationship between the two, is very difficult. Adding the possibility that certain risky choices are structured in a way that is too fast for conscious calculation, and so subconscious processes may play a role we well, makes an exquisitely difficult problem even harder.

Evidence Concerning the Correlation between Cognitive Ability and Measured Risk Preference

As discussed in the introduction of this paper, studying the relationship between measured risk preference and cognitive ability is valuable, even without being able to shed light on relationships of latent traits. The empirical literature contains a considerable array of evidence on how observed measures of risky choice are related to various facets of measured cognitive ability. Broadly speaking, three measurement approaches prevail: 1) risk taking behavior observed in everyday life; 2) risk-taking observed from a menu of standardized choices (typically lottery choices) in a controlled environment, as in an incentivized laboratory experiment; and 3) risk preference as captured by self-reported willingness to take risk. Studies of risk preference also differ with respect to the measures of cognitive ability and the facets of cognition that are considered, as well as with respect to risk taking behavior across different contexts by respondents with different demographic and socio-economic characteristics.

Cognition and Risk Taking Behavior in Non-experimental Settings

While risk taking behavior in different contexts of life has been found to be correlated with various facets of cognition, the sign and magnitude of the correlation seems to vary across contexts and studies. In this variation, however, a systematic pattern emerges: Cognitive ability tends to be positively correlated with avoidance of harmful risky situations and to be negatively correlated with risk aversion in advantageous situations. Evidence on this theme emerges both from studies of behavior in risky situations, often done by psychologists and psychiatrists, and also from studies focused on economic decision-making.

Boyer (2006) reviews four strands of research in the developmental psychology literature on risk-taking behaviors in situations that involve undesirable "real-world" risks, such as substance use, alcohol consumption, unsafe sexual behavior or criminal behavior. Each of the four strands considers a different class of factors that potentially influence the development of risk-taking behavior. Cognitive developmental research focuses on changes in decision-making capacities during childhood and adolescence that potentially underlie risk perception, probability judgement and sensitivity to risk. Emotional development research studies the development of affective decision-making, psychobiological research analyzes the neurological and biochemical bases of risk-taking, while social development research investigates influences of the social environment on the emergence of risk-taking tendencies. The literature suggests that cognitive, emotional, and psychobiological development, as well as social factors, are correlated with changes in risk taking behavior. Empirical evidence by and large indicates that engagement in precarious risky behaviors is lower for individuals with higher cognitive capacity and emotional regulation skills. It is not clear, however, whether there is a direct link between cognitive skills and risk preference. For example, the correlation could potentially reflect an impact of cognitive ability on quality of decision making and therefore the ability to avoid harmful decisions.

Poor decision-making quality might also underlie the finding in epidemiological studies that low cognitive ability types are more likely to smoke, drink alcohol, or to commit a crime. Kubicka et al. (2001), for example, document that IQ, measured during childhood by Wechsler Intelligence Scale, Children (WISC) is correlated with a lower prevalence of smoking in adulthood. Using data for 330 individuals from 24-year-follow-up study, they estimate that the odds ratio of being smoker at age 28-31 (vs. being a non-smoker) is twice as high for a child with an IQ of 85 compared to a child with IQ of 115. Frisell, Pawitan, and Långström (2012) share this methodological approach and relate a measure of cognitive ability to risk taking behavior later in life, using administrative data and a much larger sample of more than 250,000 Swedish men born between 1961 and 1975. They link data on a measure of general cognitive ability, which is contained in the Conscript Register (1980–1993) and based on the Swedish Enlistment Battery (SEB80), to violent criminal convictions from the Crime Register, 1973–2009. The raw data indicate a negative relationship between the cognitive ability score and the proportion of individuals convicted for violent crime for all three sub-samples considered: half-brothers who grew up apart, half-brothers raised together and full brothers. Even in the group that has the smallest crime rate, i.e. brothers who were raised together, the proportion that had been convicted of violent crime is roughly 15 percentage points higher for those with the lowest SEB80 score of 1 compared to those with the highest score of 9. Regression results confirm a significant association between the cognitive ability score and crime rates for all sub-groups that is robust to familial characteristics that might confound the relationship between cognitive ability and risky criminal behavior.

A large strand of literature, reviewed by Hasting, Madrian and Skimmyhorn (2013) and Lusardi and Mitchell (2014), on financial literacy and financial decision-making also shows that a set of cognitive skills, such as numeracy and the ability to process economic information, and knowledge improve the quality of decision-making under risk in the sense that they lead to better financial planning and wealth accumulation. Agarwal and Mazumder (2013) relate a measure of cognitive skills that is based on the Armed Forces Qualifying Test (AFQT) score to the optimal use of credit cards for convenience transactions and to financial mistakes on a home equity loan application. They find that a one standard deviation increase in the AFQT score is associated with an 11 percentage point decrease in the likelihood of making a rate-changing mistake in the home loan application. Moreover, consumers that score one standard deviation higher on the AFQT are 24 percentage points more likely to discover the optimal balance transfer strategy in credit card use. These results are driven by arithmetic reasoning and math knowledge, two sub-parts of the AFQT test that assess math ability, but not by verbal ability (measured by paragraph comprehension and word knowledge in the AFQT).

Contrary to findings on risk taking in the context of harmful and undesirable risk, however, better cognitive functioning seems to be associated with more risky behavior in the financial context. Grinblatt, Keloharju, and Linnainmaa (2011) focus on the effect of cognitive ability on financial decision making in a context that involves risk. They study stock market participation in the year 2000 of 158,044 Finnish males between 1953 and 1982. Merging data from several administrative data sources, they relate men's test scores (ranging from 1 to 9, as in the SEB80) from the Finnish Armed Forces (FAF) Intelligence Assessment, which contains 120 questions to elicit mathematical, verbal, and logical skills, to Finish tax administration data and data on data on their daily portfolios and trades. Controlling for a large set of confounding factors, including wealth, income, marital status, children, age, asset ownership, and labor market status, they show that stock market participation monotonically increases with FAF Intelligence scores. These findings based on administrative data substantiate the results of a set of studies that higher cognitive ability is correlated with more risk taking in financial markets (e.g. Christelis, Jappelli and Padula, 2010; Cole, Paulson and Shastry, 2014).[2] One potential explanation for these findings may be that cognitive ability improves quality of decision making in the sense of being able to recognize when risk taking is beneficial financially, although higher cognitive ability might also improve decision-making quality in a way that reduces the riskiness of decisions. Grinblatt, Keloharju, and Linnainmaa (2011), for example, show that high IQ-investors tend hold less risky portfolios and earn higher risk-adjusted returns. In sum, the above discussed studies on cognitive ability, financial literacy and risky behavior in financial matters do not shed light on whether the relationship between cognitive skills and risk taking behavior reflects an impact of cognitive ability on the quality of decision making in non-financial context as well.

Lusardi and Mitchell (2014) discuss the difficulties in establishing whether such links are causal (as opposed to being related due to, e.g., endogeneity and measurement error), focusing on risk taking behavior in financial decisions and financial literacy. They review a set of studies that uses

[2] Christelis, Jappelli, and Padula (2010) analyze data almost 20,000 seniors who responded to the Survey of Health, Aging and Retirement in Europe (SHARE) and find that answers to three cognitive tests -- the number of animals one can name in one minute, the number of nouns (out of 10) one recalls, and a series of up to four numeracy questions – are significantly positively with self-reported stock market participation. Cole, Paulson and Shastry (2014) document that measures of cognition in the National Longitudinal Survey of Youth (NLSY) are related to self-reported ownership of stocks, bonds, or mutual funds.

instrumental variables (IV) estimation methods in order to deal with endogeneity of financial literacy, and do find support for a causal impact of financial literacy on financial decision making. An excellent example of this approach is the study by van Rooij, Lusardi and Alessie (2011) who instrument financial literacy with the financial experiences of siblings and parents and show that financial literacy has a significant positive effect on stock market participation.

Cognition and Experimental Measures of Risk Aversion

Compared to non-experimental settings, choice experiment settings have the advantage of greater control over the primary attributes of the risky choice options. A number of experimental studies have been conducted that use different measures of risk aversion and cognitive ability.

Experimental studies often use incentivized choices from menus of different monetary lotteries. Such menus are typically administered in the form of multiple price lists that confront subjects with a sequence of choices between lotteries. One prominent price list format proposed by Holt and Laury (2002) involves choices between two lotteries that differ in the spread between the high and the low payoff. From row to row, the potential outcomes of the lotteries are kept constant, but the probabilities of these outcomes are varied. A second, simpler, type of price list format involves choices between a lottery and a safe payment. Typically the outcomes and probabilities of the lottery are not varied across rows, but the size of the safe payment is changed. A potential advantage of the latter approach is its simplicity as perceived by the decision maker as it allows for a straightforward identification of an individual's certainty equivalent of the respective lottery.

Burks et al. (2009) use the latter approach to elicit certainty equivalents of different lotteries among a subject pool of trucker trainees, and studied the relationship of risky choice to cognitive ability. To measure cognitive ability, they use three different tests, a nonverbal IQ test (Raven's matrices), a test of the ability to plan (the Hit 15 game), and a quantitative literacy (or numeracy) test. From the lottery choices in the gain domain they compute the coefficient of relative risk aversion and relating it to the cognitive ability measures they find a strong negative association between the measure of cognitive performance and risk aversion. This result stems from the fact that truckers with lower performance on the cognitive tests switch earlier in the choice table from preferring the lottery to the safe payment, which increases which each choice while the lottery is constant. They speculate that the perceived utility of the lottery is noisy while the utility of the sure payment is perceived precisely. If the noise in perception is higher the lower cognitive ability is, and if individuals dislike what they do not perceive precisely, truckers with low cognitive ability should prefer the safe payment more frequently. Corroborating evidence for this conjecture comes from two findings: First, truckers with lower performance on the cognitive tests more frequently choose lotteries that have an expected value smaller than the safe payment alternative. Second, they are more likely to make inconsistent choices, by switching multiple times in the price list. Truckers in the lowest quartile of the cognitive score distribution have a 25 percent higher likelihood of being inconsistent compared to those in the highest quartile. Other studies also indicate that higher intelligence is associated with a stronger tendency for consistent choices (for example, Frederick 2005; Oechssler, Roider, and Schmitz 2009; Benjamin, Brown, and Shapiro 2013).

Analyzing a representative sample of adults in Germany, Dohmen et al. (2010) use a similar incentivized choice between a lottery and a safe payment to elicit risk preferences. To measure cognitive ability, they apply two different tests, a symbol-digit correspondence test that is similar to a submodule in the nonverbal section of the WAIS, and a word fluency test that is similar to a verbal submodule of the WAIS. While both tests are related to the speed of processing, they capture different dimensions of cognitive ability (in terms of fluid and crystallized intelligence). The results point to a significantly negative correlation between risk aversion and cognitive ability even when accounting for family background, education, test-taking strategy, and personality traits (as measured by the Big Five). The findings also show that both distinct types of cognitive ability tests have power for explaining risky choice.

Benjamin et al. (2013) consider the correlation between risk aversion and cognitive ability among a sample of Chilean high school students and went on to explore possible causal channels behind this correlation. In contrast to the previous papers, they use multiple price lists offering choices between a safe payment and a sequence of lotteries with a 50/50 chance of winning. Instead of varying the safe payment, their design varies the high outcome in the lottery across choice alternatives. In addition, they consider different lotteries with either a zero low outcome or a negative low outcome. Benjamin et al. have access to achievement test scores, taken from the quantitative and verbal sections of a national exam for university admission, as a measure of cognitive ability. Similar to the earlier studies, they find a negative correlation between risk-averse choices and cognitive ability as reflected by test scores. Their result appears not to be driven by errors in computing expected values. In order to shed light on channels and potential causality, they use two interventions to manipulate cognitive resources available for decision making, a distracting task and a requirement for explaining the reasons for decisions. Their evidence is consistent with behavior stipulated by two-system models as cognitive load induces more risk-averse choices. In the context of the conceptual discussion above, however, it is unclear that this can be interpreted as evidence for a causal relationship between latent risk preference and cognitive ability.

In a recent study, Andersson et al. (2016) re-investigate the tendency for individuals with low cognitive ability to be relatively more risk averse in choice experiments. They study a representative sample of Danish adults, and measure cognitive ability with a variation of Raven's Progressive Matrices, as well as a cognitive reflection test. They present members of the sample with one of two sets of risky choices (multiple price lists). In both multiple price lists, subjects make ten choices between a relatively safe lottery, which is held constant across choices within a price list, and a more risky lottery, of which the spread and expected value is increased from row to row. For example, in the first multiple price list, the first choice is between a lottery with a 50:50 chance of winning 30 or 50 Danish krone (DKK), and a lottery with a 50:50 chance of winning 5 or 60 DKK. In each subsequent row, the spread and expected value of the latter riskier lottery is increased by raising the high outcome of the lottery by 10 DKK (i.e. the risky lottery in the second row offers a 50:50 chance of winning 5 or 60 DKK), In both price lists, risk averse and risk neutral individuals initially prefer the safer lottery, but switch to preferring the riskier lottery later in the choice table.

The two multiple price lists differ in terms of how often a risk neutral person would prefer the safe lottery before switching to the riskier one. In the first set, a risk neutral individual would start preferring the riskier lottery in row 3 compared, and in the second set the same individual would switch to favoring the riskier lottery in row 7. Andersson et al. find that individuals with lower cognitive ability are relatively more risk averse in the first set (i.e. switch relatively late from preferring the low-spread lottery to preferring the high-spread lottery). By contrast, in the second set, low cognitive ability is associated with being relatively less risk averse. Andersson et al. argue that these findings reflect a tendency for those with low cognitive ability to make random choice errors. For example, a risk neutral person should prefer the safe lottery only in the first two choices of the first price list, but not in the other eight choices. Random choice errors could lead to risk seeking behavior in the first two choices, but would induce risk averse decisions in the other eight choices. In the second multiple price list, however, random choices will tend to introduce bias towards more risk seeking behavior.

Andersson et al. (2016) suggest that one interpretation is that the correlation between risky behavior and cognitive ability found in earlier work might be "spurious." In our view their results do nicely illustrate a type of noise in measuring latent risk preference, arising from how the choice architecture can systematically influence risky choice in such measures. The results also demonstrate, however, that cognitive ability is related systematically to risky choice, in a way that is mediated by the nature of the choice architecture. Indeed, they replicate previous findings about cognitive ability and risk aversion in the type of choice setting used in previous work, where there are relatively more opportunities to choose in a risk averse than a risk loving way. The interesting result is that this relationship flips when the choice setting changes. Their results raise questions about which type of non-experimental choice settings might foster systematic risk aversion, or risk seeking behavior, among those with low cognitive ability. As with the rest of this literature, the Andersson et al. (2016) findings do not in our view warrant conclusions about the relationship between latent traits of risk preference and cognitive ability, because it is not identified whether cognitive ability affects lottery choices solely through other channels than risk preference (e.g. through mistakes in decision-making) or whether cognitive ability impacts latent risk preference. Nevertheless, their results indicate the difficulties of identifying the nature of the relationship between (latent and measured) risk preference and cognitive ability.

These difficulties aside, several other patterns emerge from this branch of the literature. For one, when considering the results from studies with a range of different sample sizes, the findings indicate that measurement error may be an issue and effect sizes are potentially small. For example, no statistically significant relationship is observed in studies that involve small sample sizes of less than 200 observations (Sousa 2010; Mather et al. 2012; Tymula et al. 2012; Taylor, 2016; Pachur, Mata, and Hertwig 2017). While negative correlations between measures of risk aversion in the gain domain and measures of cognitive ability have been found in particular samples, such as trainee truckers (Burks et al. 2009), and college students (Benjamin, Brown, and Shapiro 2013), such correlations tend to be stronger in representative adult population samples (Dohmen et al. 2010; Andersson et al. 2016). A likely reason is that larger samples also tend to display more heterogeneity with respect to cognition, which makes it possible to find a stronger correlation.

A second pattern that emerges from the literature reveals differences in the correlation between risk taking in lotteries and cognitive ability depending on whether lotteries only entail gains or also potential losses. In particular, and similar to the findings in several non-experimental settings, experimental studies tend to find a negative correlation between risk aversion in lottery choice and various measures of cognitive ability when the lottery outcomes are in the gain domain, whereas the findings suggest a positive correlation between risk aversion and cognitive ability when the lottery outcomes involve potential losses (see, e.g., Rustichini et al. 2012, 2016, Burks et al., 2009, Oechssler et al., 2009, Frederick, 2005).

Statistically significant negative correlations between risk aversion and cognitive ability are found for cognition measures related to numeracy (for example, Benjamin, Brown, and Shapiro 2013; Rustichini et al. 2012; Rustichini et al. 2016)[3], but also for cognition measures such as the ability to solve Raven's Progressive Matrices (Andersson et al. 2016), the Hit 15 game (Burks et al. 2009), speed of recognition and word fluency (Dohmen et al. 2010), the Cognitive Reflection Test (Frederick 2005) as well as standardized achievement test scores (Benjamin, Brown, and Shapiro 2013). Some studies have access to different cognitive ability measures. For instance, Dohmen et al. (2010) find that two distinct types of cognitive ability tests both have power for explaining risky choice. Taken together, this evidence could indicate that risk aversion when measured in the gain domain is not linked to one narrow aspect of cognitive ability, but rather a broader trait that underlies the performance in a range of cognitive tasks.

Nevertheless, an interesting pattern emerges. The correlation between measured risk preferences and cognitive ability seems to be particularly strong when quantitative IQ tests are used for its elicitation rather than memory tests or grades. Statistically significant correlations are typically found for cognition measures or IQ tests that accentuate numeracy (for example, Beauchamp, Cesarini, and Johannesson, 2017, Benjamin, Brown, and Shapiro 2013; Rustichini et al. 2012; Rustichini et al. 2016). Weaker findings emerge for tasks involving memory or school grades (e.g., Booth and Katic, 2013, Angrisani and Casanova, 2011). This evidence might also suggest that different facets of cognitive ability play different roles. However, there are relatively few studies that run horseraces between different cognitive ability measures.

Evidence from Measures of Self-reported Willingness to Take Risks

Many survey studies include measures of cognitive ability and survey instruments to elicit self-reported willingness to take risks, including the National Longitudinal Study of Youth (NLSY), the German Socioeconomic Panel (SOEP), the Dutch DNB Household Survey, Understanding Society – The UK Household Longitudinal Study, and the Survey of Health, Aging and Retirement in Europe (SHARE). Typically, these surveys include a simple question asking individuals to rate their willingness to take risks on a Likert scale. The most widely used format is the question about the respondent's willingness to take risk in general. The simplicity of this general risk question or related formats has the advantage of being easy to understand, thereby limiting the problem of decision errors or noise, while delivering relevant information about risk preferences (Dohmen et al., 2011). Several studies using such self-reported measures of individuals' willingness to take risks find that the answers are positively related to measures of cognitive ability (for example, Dohmen et al. 2010; Beauchamp, Cesarini, and Johannesson 2017). Analyzing novel data from the Global Preference Survey, Falk et al. (2018) show that answers to the general risk question are positively related to self-reported math skills in representative population samples of 76 countries. In 55 countries, this relationship is significant at the 1 percent level, and only in 12 countries it is not statistically significant at the 10 percent level.

Own calculations show that average willingness to take risk of adults is also related significantly to average cognitive ability at the country level, as measured by the OECD Programme for the International Assessment of Adult Competencies (PIAAC). PIAAC is designed by the OECD to measure the competencies of adults in numeracy, literacy, and problem solving. Specifically, willingness to take risks is more pronounced in countries with higher average numeracy (rho=-0.598) and literacy (rho=-0.541) for the 16 countries surveyed in both the GPS and in PIAAC (own calculations).

In summary, the findings in this literature suggest that individuals with low cognitive ability view themselves as relatively unwilling to take risks. It is conceivable that this reflects errors in self-assessment, but it is not obvious that low cognitive ability should lead to errors that are systematically biased towards indicating greater risk aversion. If low cognitive ability just adds noise to self-assessments, this would work against finding a relationship of self-reported willingness to take risks with cognitive ability.

Changes in risk-taking behavior and cognition related to aging

A large body of evidence indicates that adults exhibit more risk-averse behavior as they grow older (as discussed by Schildberg-Hörisch in this issue). In an experimental study of 135 subjects ranging in age from 12-90, Tymula et al. (2013) supports the finding that older individuals are more risk-averse than their midlife counterparts, but also finds that find that adolescents are more risk-averse, too. Falk et al. (2018) and Mata et al. (2016) document that the relationship between age and risk attitudes is found across the globe. At the same time, a large body of psychology and neuroscience finds that performance on a wide variety of cognitive tasks declines over the life course, including processing speed (Salthouse 1996) and working memory (Van der Linden, Brédart, and Beerten 1994).

Some studies have investigated whether this pattern is related to cohort effects rather than an age profile in risk preferences. Studies based on cross-sectional data document that older cohorts are on average less willing to take risks than younger cohorts (Barsky et al. 1997; Donkers, Melenberg, and van Soest 2001; Dohmen et al. 2011). However, studies based on longitudinal data indicate that the difference in willingness to take risks is not solely driven by a cohort effect (for example Sahm 2012). Using data from two representative samples from Germany and the Netherlands, Dohmen et al. (2017) disentangle cohort, period and age effects to investigate how risk attitudes change over the life course, and provide evidence that individuals do become less willing to take risks as they grow older.

In light of this evidence, a recent strand of literature in economics and neuroscience has begun to relate changes in risk aversion and cognition over the life span. As one example, Bonsang and Dohmen (2015) use data from the Survey of Health, Aging and Retirement in Europe (SHARE) that includes both a measure of financial risk preference and measures of cognitive ability for a representative sample of individuals aged 50+ in 11 European countries. They document that the age-related cross-sectional variation in willingness to take risks is not statistically significantly different, once cognition is controlled for. Mata et al. (2011) conduct a meta-analysis and conclude that age-related differences in risk-taking vary across tasks and decision context. Decreased learning performance among older adults seems to contribute to age-related differences in risk taking, in particular when objective probability distributions are not known.

Taken as a whole, these findings indicate that the process of cognitive decline is connected with changes in risk taking over the life course. Yet the findings do not necessarily document a causal relationship between cognition and latent risk preferences. As an alternative hypothesis, cognition and risk preferences might both be affected by simultaneous and interrelated physiological processes. Neuropsychological evidence indicates that the human brain changes not only during early childhood but also at later stages (for example, Giedd et al. 1999; Best and Miller 2010), which is associated with executive control but also other abilities such as social cognition and empathy (Singer 2006) and potentially risk preference. One prominent example of how risky choice behavior varies with the development of the socio-emotional system in the brain is in the context of puberty (Steinberg 2008).

Perspectives for future research

In light of the previous discussion, two avenues for future research are conceivable. The first is to delve deeper into the physiological foundations of decision making. Given the challenges that arise from the revealed preference approach to measuring latent risk preference and cognitive ability, it appears natural to turn to alternative approaches to measuring such traits, applying recently developed methodologies from neuroscience. Research in brain science builds on the idea that both latent cognitive ability and latent risk preference are rooted in the brain, and seeks to use different regions of the brain as the unit of analysis. Ideally, it would be possible to infer from activity in a given brain region the degree of latent risk preference, and from another brain region the level of latent cognitive ability, and assess whether and how these are related. Even more ambitious, one could test causality by intervening directly in the brain in a way that influences exclusively either risk preference or cognitive ability (but not the respective other trait). Given the current state of knowledge in neuroscience about the function of different brain regions, and the available technology for measuring and intervening in the brain, however, we seem relatively far from being able to address the question of interest.

Neuro-economic studies have made some progress in identifying parts of the brain and neural circuits that are activated when individuals are making a choice related to risk or uncertainty in particular decision contexts. These studies typically use functional magnetic resonance imaging (fMRI) to observe changes in brain activity (as measured by oxygen saturation of blood in certain regions of the brain) when aspects of choice alternatives (like probabilities or reward size) are varied in order to identify brain regions that are associated with risky choice. This literature, as reviewed in Tobler and Weber (2014), indicates that risky choice is associated with activity in the valuation system, including dopamine neurons, striatum orbitofrontal cortex, medial prefrontal cortex, posterior cingulate and parietal cortex (see also D'Acremont and Bossaerts 2008; Platt and Huettel 2008; Rushworth and Behrens 2008; Schultz et al. 2008; 2011). Another approach (reviewed in Levasseur-Moreau and Fecteau, 2012) has been to use noninvasive brain stimulation such as transcranial direct current stimulation (tDCS) or transcranial magnetic stimulation (TMS) to investigate whether stimulating certain brain regions can influence risk taking behavior. However, even if a brain region is identified as being pivotal for risk-taking behavior*,* this brain region does not necessarily (or exclusively) represent the location of the underlying latent level of risk preference.[4]

There is also evidence that the brain regions involved in risky choice change when the study involves more complex risky choices rather than the very simple lotteries that are typically used in the literature, raising questions about the location of latent risk preference in the brain (Tobler and Weber, 2014). Studies with non-human primates and rats suggest that risk and probabilities are processed by single neurons that are distributed throughout the brain (for a review, see Burke and Tobler, 2011). Because these neurons are located in brain regions that are connected, it cannot be precluded that risk preference is encoded in a neural system distributed throughout the brain, complicating the study of factors that might affect this predisposition. Analogously, latent cognitive ability is also potentially determined in a distributed neural system.

It should be clear that analyzing the nature of the relationship between risk preference and cognition, given the limitations of the revealed preference approach, and the state of our current understanding of brain structure and brain functioning, is very challenging. However, this complexity is often not spelled out in empirical studies of these topics, where observed measures of risk preference are often treated as unbiased proxies for latent risk preference. It would be useful for researchers to formulate more tightly-focused questions that concern the relationship between measured risk preference and measures of cognition.

In light of this, the second avenue for future research is to extend the existing work using measures of risk preferences and cognitive ability and address the (many) open questions that the existing literature has raised. One aspect worthy of more work is the development and use of richer sets of measures and elicitation instruments and potentially applying more data intensive methodologies. Some recent studies have made progress in this direction and applied several of the various ways to measure risk preferences from non-experimental, experimental and survey approaches jointly in order to isolate a single factor that measures risk (see, e.g, Frey et al., 2017). This approach, which is akin to measuring a latent trait (or single manifold) of intelligence by a battery of different tests, seems to be useful in that the impact of idiosyncratic factors that confound single measures of risk preference are reduced. With equally rich information about cognitive abilities, it might be possible to gain further insights into the relation between the latent traits of risk preference and cognitive ability. This would also help reconciling the contradictory evidence about the correlation between risk preference and cognitive ability in choice situations in the gain or in the loss domain, as well as the issue of decision errors.

Along a similar line, there seems to be a value in exploring the relationship between measured risk preferences and cognitive ability across a wider range of contexts. For example, one can imagine a range of experiments that would vary how the risky scenario is described to subjects, to assess whether this influences risky choice in a manner consistent with cognitive differences.

[4] An alternative approach to manipulating cognitive ability is to use tasks which increase or decrease the overall cognitive load needed to make decisions. This approach does not require impinging upon the brain directly. However, higher cognitive load has been shown to dampen emotional responses along with performance on cognitive tasks (DeFraine 2016). Thus, when using cognitive load to measure changes in cognitive level, the researcher may be finding out how shifts of emotion influences *risk-taking*, rather than how cognitive ability does so.

Along these lines, Rabin and Weizsäcker (2009) show that difficulties with calculating expected value seem to be a factor underlying "narrow bracketing"—that is, evaluating choices separately in choices across different pairs of lotteries. In addition, it may be fruitful to study whether individuals with low cognitive ability might be more likely to violate the transitivity assumption when choosing among different lotteries (Rustichini 2015) and whether they are less likely to act upon concepts such as stochastic dominance. Indeed, one strand of this literature documents that findings of such violations and inconsistent choice behavior are more prevalent among low-cognitive-ability types (for example, Burks et al. 2009; Eckel 1999; Huck and Weizsäcker 1999; Dave et al. 2010).

Experiments along these lines might be linked to a public policy context, as well. For example, varying the presentation of retirement or benefit options offered by a firm to its employees, or the sequence of benefit options being offered by a government, might influence choice among individuals with lower cognitive ability. A researcher might also study interventions to improve numeracy or other cognitive abilities, and whether they lead to differences in risky lottery choices.

To sum up, there clearly are connections between cognitive ability and revealed (measured) risk preference. This article has argued that economists and psychologists should increase their awareness about these connections. Using the concept of revealed risk preference without also including the concept of cognitive ability runs a risk of leading to confusions, both in the theory that is used to analyze decision-making in conditions of risk and in the interpretation of empirical work on risk preference. As these connections are gradually uncovered in future research, the answers are likely to have widespread applications to economic analysis and public policy.

The following are some examples. If it were established that cognitive ability does cause risky choice*,* at least in a given setting, then under relatively mild assumptions about the function relating the two (like monotonicity and independence) one would be able to generalize the relationship to many different choice settings. However, it may turn out that the relationship between cognition and risk preference is different depending on the setting—and in particular, on the specific task that is being carried out in a risky environment. If this is true, it will be harder to extrapolate results from one study to another. Looking at connections between cognition and different kinds of tasks may well illuminate the specific mechanisms connecting the two. Thus, this research area should seek to map out the relationship of these constructs across a broader range of settings than has been studied so far. It may also turn out that while risk preference and cognitive ability are related, they have meaningfully distinct effects on choices and outcomes. Then, the nature of the correlation between these traits in different settings can have implications for mitigating or exacerbating inequality. We know that there is considerable individual heterogeneity in risk preferences and in behavior in risky settings. Looking at variation in measures of cognitive ability, and relating it to measures of risk preference in different decision environments, may help to explain this heterogeneity.

Finally, delving into the relationship between cognitive ability and risky choice seems likely to have implications for both making policy and testing policy. For example, it may become possible to point to specific facets of cognition which are most strongly related to risk taking behavior. If these specific cognitive tasks can be influenced by training, or by gaining practice in that setting, the respective interventions could alter risky behaviors. Similarly, changing choice architectures or frames could affect risky choice, in different ways depending on variations in cognitive ability. To the extent that risk choices are correlated with other outcomes of interest, the connections between cognitive ability and risk preference could be used to target policy interventions.

References

Ackermann, Phillip L., and Eric D. Heggestad. 1997. "Intelligence, personality, and interests: Evidence for overlapping traits." *Psychological Bulletin* 121(2): 219-245.

Agarwal, Sumit, and Bhashkar Mazumder. 2013. "Cognitive Abilities and Household Financial Decision Making." *American Economic Journal: Applied Economics* 5(1): 193–207.

Angrisani, Marco, and Maria Casanova. 2011. "Understanding Heterogeneity in Household Portfolios: The Role of Cognitive Ability and Preference Parameters." http://www.webmeets.com/files/papers/SAEe/2011/54/Angrisani_Casanova_2011.pdf

Andersson, Ola, Hakan J. Holm, Jean-Robert Tyran, and Erik Wengström. 2016. "Risk Aversion Relates to Cognitive Ability: Preferences or Noise?" *Journal of the European Economic Association* 4(5): 1129–1154.

Barsky, Robert B., F. Thomas Juster, Miles S. Kimball, and Mathew D. Shapiro. 1997. "Preference Parameters and Behavioral Heterogeneity: An Experimental Approach in the Health and Retirement Study." *Quarterly Journal of Economics* 112(2): 537-579.

Beauchamp, Jonathan P., David Cesarini, and Magnus Johannesson. 2017. "The Psychometric Properties of Measures of Economic Risk Preferences." *Journal of Risk and Uncertainty* 54(3):203-267.

Benjamin, Daniel J., Sebastian A. Brown, and Jesse M. Shapiro. 2013. "Who Is 'Behavioral'? Cognitive Ability and Anomalous Preferences." *Journal of the European Economic Association* 11(6): 1231–1255.

Best, John R. and Patricia H. Miller. 2010. "A Developmental Perspective on Executive Function." *Child Development* 81(6): 1641–1660.

Bonsang, Eric, and Thomas Dohmen. 2015. "Risk Attitude and Cognitive Aging." *Journal of Economic Behavior & Organization* 112: 112–126.

Booth, Alison L., and Pamela Katic. 2013. "Cognitive Skills, Gender and Risk Preferences." *Economic Record* 89(284): 19–30.

Boyer, Ty W. 2006. "The Development of Risk-taking: A Multi-Perspective Review." *Developmental Review* 26(3): 291–345.

Burke, Christopher J., and Philippe C. Tobler. 2011. "Coding of Reward Probability and Risk by Single Neurons in Animals". *Frontiers in Neuroscience* 5(121).

Burks, Stephen V., Jeffrey P. Carpenter, Lorenz Goette, and Aldo Rustichini. 2009. "Cognitive Skills Affect Economic Preferences, Strategic Behavior, and Job Attachment." *Proceedings of the National Academy of Science (PNAS)* 106(19): 7745–7750.

Cattell, Raymond B. 1971. *Abilities: Their Structure, Growth, and Action.* Boston: Houghton Mifflin.

Cattell, Raymond B. 1987. *Intelligence: Its structure, growth and action*. Amsterdam: North-Holland.

Christelis, Dimitris, Tullio Jappelli, and Mario Padula. 2010. "Cognitive Abilities and Portfolio Choice." *European Economic Review* 54(1): 18–39.

Cole, Shawn, Anna Paulson Gauri K. Shastry. 2014. "Smart Money? The Effect of Education on Financial Outcomes." *The Review of Financial Studies* 27(7): 2022–2051.

Cunha, Flavio, James J. Heckman, and Susanne M. Schennach. 2010. "Estimating the Technology of Cognitive and Noncognitive Skill Formation." *Econometrica* 78(3): 883–931.

D'Acremont, Mathieu, and Peter Bossaerts. 2008. "Neurobiological Studies of Risk Assessment: A Comparison of Expected Utility and Mean-Variance Approaches." *Cognitive, Affective, & Behavioral Neuroscience* 8(4): 363–374.

Dave, Chetan, Catherine C. Eckel, Cathleen A. Johnson, and Christian Rojas. 2010. "Eliciting Risk Preferences: When is Simple Better?" *Journal of Risk and Uncertainty* 41(3): 219–43.

DeFraine, William C. 2016 "Differential Effects of Cognitive Load on Emotion: Emotion Maintenance Versus Passive Experience." *Emotion* 16(4): 459–467.

Dohmen, Thomas, Armin Falk, David Huffman, and Uwe Sunde. 2010. "Are Risk Aversion and Impatience Related to Cognitive Ability?" *American Economic Review* 100(3): 1238–1260.

Dohmen, Thomas, Armin Falk, David Huffman, and Uwe Sunde. 2012. "The Intergenerational Transmission of Risk and Trust Attitudes." *Review of Economic Studies* 79(2), 645-677.

Dohmen, Thomas, Armin Falk, David Huffman, Uwe Sunde, Jürgen Schupp, and Gert G. Wagner. 2011. "Individual Risk Attitudes: Measurement, Determinants and Behavioral Consequences." *Journal of the European Economic Association* 9(3): 522–550.

Dohmen, Thomas, Armin Falk, Bart Golsteyn, David Huffman, and Uwe Sunde. 2017. "Risk Attitudes Across the Life Course." *Economic Journal*, 127(605): F95-F116.

Donkers, Bas, Bertrand Melenberg, and Arthur Van Soest. 2001. "Estimating Risk Attitudes Using Lotteries: A Large Sample Approach." *Journal of Risk and Uncertainty* 22(2): 165–195.

Eckel, Catherine C. 1999. "Commentary on "The Effects of Financial Incentives in Experiments: A Review and Capital-Labor Production Framework." *Journal of Risk and Uncertainty* 19(1–3): 47–8.

Falk, Armin, Anke Becker, Thomas J. Dohmen, Benjamin Enke, David Huffman, and Uwe Sunde. 2018. "Global Evidence on Economic Preferences." forthcoming in Quarterly Journal of Economics.

Frederick, Shane. 2005. "Cognitive Reflection and Decision Making." *Journal of Economic Perspectives* 19(4): 25–42.

Frey, Renato, Andreas Pedroni, Rui Mata, Jörg Rieskamp, and Ralph Hertwig. 2017. " Risk preference shares the psychometric structure of major psychological traits. *Science Advances* 3(10), e1701381, DOI: 10.1126/sciadv.1701381.

Frisell, Thomas, Yudi Pawitan, and Niklas N. Långström. 2012. "Is the Association Between General Cognitive Ability and Violent Crime Caused by Family-Level Confounders?" *PloS ONE* 7(7): e41783.

Giedd, Jay N., Jonathan Blumenthal, Neal O. Jeffries, F Castellanos, Hong Liu, Alex Zijdenbos, Tomáš Paus**, Alan C. Evans, and Judith L. Rapoport.** 1999. "Brain Development during Childhood and Adolescence: A Longitudinal MRI Study." *Nature Neuroscience* 2(10): 861–863.

Grinblatt, Mark, Matti Keloharju, and Juhani Linnainmaa. 2011. "IQ and Stock Market Participation." *Journal of Finance* 66(6): 2121–2164.

Hasting, Justine S., Brigitte C. Madrian, and William L. Skimmyhorn. 2013. "Financial Literacy, Financial Education, and Economic Outcomes." *Annual Review of Economics* 5: 5: 347-373.

Heckman, James J. 2005. "The Scientific Model of Causality." *Sociological Methodology* 35(1): 1–97.

Heckman, James J., Rodrigo Pinto, and Peter Savelyev. 2013. "Understanding the Mechanisms Through Which an Influential Early Childhood Program Boosted Adult Outcomes." *American Economic Review* 106(6): 2052-2086.

Holt, Charles A., and Susan K. Laury. 2002. "Risk Aversion and Incentive Effects." *American Economic Review* 92(5): 1644–1655.

Huck, Steffen, and Georg Weizsäcker. 1999. "Risk, Complexity, and Deviations from Expected-Value Maximization: Results of a Lottery Choice Experiment." *Journal of Economic Psychology* 20(6): 699–715.

Kosse, Fabian, Thomas Deckers, Hannah Schildberg-Hörisch, and Armin Falk. 2016. "The Formation of Prosociality: Causal Evidence on the Role of Social Environment", IZA Discussion Paper 9861.

Kubicka, Ludek, Zdenek Matejcek, Zdenek Dytrych, and Zdenek Roth . 2001. "IQ and Personality Traits Assessed in Childhood as Predictors of Drinking and Smoking Behaviour in Middle-aged Adults: a 24-Year Follow-up Study." *Addiction* 96: 1615–1628.

Levasseur-Moreau, Jean, and Shirley Fecteau. 2012. "Translational Application of Neuromodulation of Decision-making." *Brain Stimulation* 5: 77–83.

Lusardi, Annamaria, and Olivia S. Mitchell. 2014. "The Economic Importance of Financial Literacy: Theory and Evidence." *Journal of Economic Literature* 52(1): 5–44.

Participants: The Effect of Age and Cognitive Skills." *Economica* 81: 522–543.

Mata, Rui, Anika K. Josef, Gregory R. Samanez-Larkin, and Ralph Hertwig. 2011. "Age Differences in Risky Choice: A Meta-Analysis." *Annals of the New York Academy of Sciences* 1235(1): 18–29.

Mata, Rui, Anika K. Josef, and Ralph Hertwig. 2016. "Propensity for Risk Taking Across the Life Span and Around The Globe." *Psychological Science* 27(2): 231–243.

Mather, Mara, Nina, Mazar, Marissa A. Gorlick, Nicole R. Lighthall, Jessica Burgeno, Andrej Schoeke, and Dan Ariely. 2012. "Risk Preferences and Aging: The "Certainty Effect" in Older Adults' Decision Making." *Psychology and Aging* 27(4): 801–816.

Oechssler, Jörg, Andreas Roider, and Patrick W. Schmitz. 2009. "Cognitive Abilities and Behavioral Biases." *Journal Economic Behavior & Organization* 72: 147–152.

Pachur, Thorsten, Rui Mata, and Ralph Hertwig. 2017. "Who Dares, Who Errs? Disentangling Cognitive and Motivational Roots of Age Differences in Decisions Under Risk." *Psychological Science* 28(4): 504–518.

Platt, Micheal L., and Scott A. Huettel. 2008. „Risky Business: the Neuroeconomics of Decision Making under Uncertainty." *Nature Neuroscience* 11: 398 – 403.

Rabin, Mathew, and Georg Weizsäcker. 2009. "Narrow Bracketing and Dominated Choices." *American Economic Review* 99(4): 1508–43.

Rushworth, Matthew F.S., and Timothy E.J. Behrens. 2008. "Choice, Uncertainty and Value in Prefrontal and Cingulate Cortex." *Nature Neuroscience* 11(4): 389–397.

Rustichini, Aldo. 2015. "The Role of Intelligence in Economic Decision Making." *Current Opinion in Behavioral Sciences* 5: 32–36.

Rustichini, Aldo, Colin G. DeYoung, Jon Anderson, and Stephen V. Burks. 2012. "Toward the Integration of Personality Theory and Decision Theory in Explaining of Economic and Health Behavior." IZA Discussion Paper 6750.

Rustichini, Aldo, Colin G. DeYoung, Jon Anderson, and Stephen V. Burks. 2016. "Toward the Integration of Personality Theory and Decision Theory in Explaining Economic Behavior: An Experimental Investigation." *Journal of Behavioral and Experimental Economics* 64: 122–137.

Sahm, Claudia R. 2012. "How Much Does Risk Tolerance Change?" *Quarterly Journal of Finance* 2(4): 1–33.

Salthouse, Timothy A. 1996. "The Processing-speed Theory of Adult Age Differences in Cognition." *Psychological Review* 103(3): 403–428.

Schildberg-Hörisch, Hannah. "Stability of Risk Preferences." *Journal of Economic Perspectives*, this issue.

Schultz, Wolfram, Kerstin Preuschoff, Colin Camerer, Ming Hsu, Christopher D. Fiorillo, Philippe N. Tobler, and Peter Bossaerts. 2008. "Explicit Neural Signals Reflecting Reward *Uncertainty*." *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 363: 3801–3811.

Schultz, Wolfram, Martin O'Neill, Philippe N. Tobler, and Shunsuke Kobayashi. 2011."Neural Signals for Reward Risk in Frontal Cortex." *Annals of the New York Academy of Sciences* 1239: 109–117.

Singer, Tania. 2006. "The Neuronal Basis and Ontogeny of Empathy and Mind Reading: Review of Literature and Implications for Future Research." *Neuroscience and Behavioral Reviews* 30: 855–863.

Sousa, Sergio. 2010. "Are Smarter People Really Less Risk Averse?" CeDEx Discussion Paper Series 2010-17.

Steinberg, Laurence. 2008. "A Social Neuroscience Perspective on Adolescent Risk-Taking." *Development Review* 28(1): 78–106.

Taylor, Matthew P. 2016. “Are High-Ability Individuals Really More Tolerant of Risk? A Test of the Relationship Between Risk Aversion and Cognitive Ability.” *Journal of Behavioral and Experimental Economics* 63: 136–147.

Tobler, Philipe N., and Elke U. Weber. 2014. “Valuation for Risky and Uncertain Choices.” In *Neuroeconomics: Decision Making and the Brain* (2nd ed.), edited by Paul W. Fehr and Ernst Fehr, 149–172. London: Academic Press.

Tymula, Agnieszka, **Lior A. Rosenberg Belmaker, Amy K. Roy, Lital Ruderman, Kirk Manson, Paul W. Glimcher, and Ifat Levy.** 2012. “Adolescents’ Risk-taking Behavior Is Driven by Tolerance to Ambiguity.” *Proceedings of the National Academy of Sciences (PNAS)* 109(42): 17135-17140.

Tymula, Agnieszka, Lior A. Rosenberg Belmaker, Lital Ruderman, Paul W. Glimcher, and Ifat Levy. 2013. “Like Cognitive Function, Decision Making Across the Life Span Shows Profound Age-related Changes.” *Proceedings of the National Academy of Sciences (PNAS)* 110(42): 17143–17148.

Van der Linden, Martial, Serge Brédart, and Annick Beerten. 1994. “Age-related Differences in Updating Working Memory.” *British Journal Psychology* 85(1): 145–152.

Van Rooij, Maarten, Annamaria Lusardi, and Rob Alessie. 2011. “Financial Literacy and Stock Market Participation.” *Journal of Financial Economics* 101(2): 449–72.