On the Relationship between Cognitive Ability and Risk Preference

Thomas Dohmen, Armin Falk, David Huffman, and Uwe Sunde

Many decisions of individuals involve 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 nonexperimental 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

■ *Thomas Dohmen is Professor of Applied Microeconomics and Armin Falk is Director of the Behavior and Inequality Research Institute, both at the University of Bonn, Bonn, Germany. David Huffman is Professor of Economics at the University of Pittsburgh, Pittsburgh, Pennsylvania. Uwe Sunde is Professor of Economics at the University of Munich, Munich, Germany. Their email addresses are t.dohmen@uni-bonn.de, Armin.Falk@briq-institute.org, huffmand@pitt.edu, and uwe.sunde@econ.lmu.de.*

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, Falk, Huffman, and Sunde 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 some intriguing policy implications arise.

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. One pattern that emerges 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. There is also intriguing emerging evidence that measured risk preference is particularly strongly related to certain facets of cognitive ability, those that facilitate quantitative problem solving, with implications for understanding mechanisms and possibly for better targeting 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 of 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 the choices are 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 is to observe the decisions of individuals who 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, the subject's choice reveals 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 set-up 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 (for example, wealth), can be controlled for adequately. 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 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, Brown, and Shapiro 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, Heckman, and Schennach (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, Deckers, Schildberg-Hörisch, and Falk (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 coevolution: that is, 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 (for example, Dohmen, Falk, Huffman, and Sunde 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 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, it may obscure any relationship between latent risk preference and cognitive ability. In addition, cognitive ability might systematically affect 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 (for example, the decision frame, the domain of possible choices, stake size associated with decisions) and personal characteristics (like 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 another 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 some of these factors—for example, by measuring personality type, as we do in Dohmen, Falk, Huffman, and Sunde (2010). While some of these factors affecting test performance may be orthogonal to latent risk preference and just add noise, certain other factors such as risky or cautious test-taking strategy could conceivably be affected 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 multidimensional. One might think of different facets of cognitive ability as lying along a continuum, ranging from 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 (for example, Ackermann and Heggestad 1997). One test, the Wechsler Adult Intelligence Scale (WAIS), 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. Add in the possibility that certain risky choices are structured in a way that is too fast for conscious calculation so that subconscious processes play a role, and an exquisitely difficult problem becomes even harder.

Evidence Concerning the Correlation between Cognitive Ability and Measured Risk Preference

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) observing risk-taking behavior in everyday life; 2) observing risk-taking 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 Nonexperimental 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. With a closer look at this variation, however, a 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 judgment, and sensitivity to risk. Emotional development research examines the development of affective decision-making. Psychobiological research analyzes the neurological and biochemical bases of risk taking. 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 effect 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. Kubička, Matějček, Dytrych, and Roth (2001), for example, document that IQ (as measured during childhood by Wechsler Intelligence Scale, Children) is correlated with a lower prevalence of smoking in adulthood. Using data for 330 individuals from a 24-year-follow-up study, they estimate that the odds ratio of being a smoker at age 28–31 (versus being a nonsmoker) 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—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 subgroups that is robust to familial characteristics that might confound the relationship between cognitive ability and risky criminal behavior.

A large strand of literature on financial literacy and financial decision-making shows that a set of cognitive skills—such as numeracy, 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 (reviewed by Hasting, Madrian, and Skimmyhorn 2013; Lusardi and Mitchell 2014). 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 subparts of the AFQT test that assess math ability, but not by verbal ability (which is measured by paragraph comprehension and word knowledge in the AFQT).

In the context of desirable risk, better cognitive functioning seems to be associated with more risky behavior. 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 from the Finnish Armed Forces (FAF) Intelligence Assessment, which contains 120 questions to elicit mathematical, verbal, and logical skills, to Finnish tax administration data and 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 intelligence scores. These findings substantiate the results of a set of studies that higher cognitive ability is correlated with more risk taking in financial markets (for

example, Christelis, Jappelli, and Padula 2010; Cole, Paulson and Shastry 2014).[1] One potential explanation for these findings may be that cognitive ability improves the 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 to hold less-risky portfolios and earn higher risk-adjusted returns. However, these studies on cognitive ability, financial literacy, and risky behavior in financial matters cannot tell us whether the relationship between cognitive skills and risk-taking behavior in a nonfinancial context also works through the quality of decision-making.

Focusing on risk-taking behavior in financial decisions and financial literacy, Lusardi and Mitchell (2014) discuss the difficulties in establishing whether such links are causal—as opposed to being related due to, say, endogeneity and measurement error. They review a set of studies that use instrumental variables estimation methods to address endogeneity of financial literacy, and 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 use the financial experiences of siblings and parents as an instrumental variable to show that financial literacy has a significant positive effect on stock market participation.

Cognition and Experimental Measures of Risk Aversion

Compared to nonexperimental 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 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

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[1] Christelis, Jappelli, and Padula (2010) analyze data from 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 related 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.

perceived by the decision maker, as it allows for a straightforward identification of an individual's certainty equivalent of the respective lottery.

Burks, Carpenter, Goette, and Rustichini (2009) use the latter approach to elicit certainty equivalents of different lotteries among a subject pool of trucker trainees and to study 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. 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 with 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 when cognitive ability is lower, 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, truckers with lower performance on the cognitive tests 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, in Dohmen, Falk, Huffman, and Sunde (2010), we use a similar incentivized choice between a lottery and a safe payment to elicit risk preferences. To measure cognitive ability, we apply two different tests: a symbol–digit correspondence test and a word fluency test (which are similar to submodules in the Wechsler Adult Intelligence Scale). 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. The findings also show that both distinct types of cognitive ability tests have power for explaining risky choice.

Benjamin, Brown, and Shapiro (2013) consider the correlation between risk aversion and cognitive ability among a sample of Chilean high school students, and they go 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 a low outcome that is zero or negative. 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 does not appear to be driven by errors in computing expected values. 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 mentioned earlier, an emotional/impulsive system and a deliberative/calculating system) as cognitive load induces more risk-averse choices. In the context of the conceptual discussion above, however, it is unclear whether this can be interpreted as evidence for a causal relationship between latent risk preference and cognitive ability.

In a recent study, Andersson, Holm, Tyran, and Wengström (2016) reinvestigate 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, for 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 (that is, 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, whereas 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 (that is, they 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 risk aversion 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 and risk aversion, in a way that is mediated by the nature of the choice architecture. Indeed, they replicate previous findings about the relationship between 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 can flip when the choice setting changes. Their results raise interesting questions about which type of nonexperimental 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 (for example, 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. First, 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 a number of 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, Carpenter, Goette, and Rustichini 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.[2] In particular, and similar

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[2]An example of a lottery with outcomes in the gain domain is: you win 100 with 50 percent chance or you win 900 with 50 percent chance. An example of a lottery in the loss domain is: you lose 100 with 50 percent chance or you lose 900 with 50 percent chance. A risk-neutral person is indifferent between the first lottery and a sure payment of 500, and indifferent between the second lottery and a sure loss of −500.

to the findings in several nonexperimental 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 (for example, Rustichini, DeYoung, Anderson, and Burks 2012, 2016; Burks et al. 2009; Oechssler, Roider, and Schmitz 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, 2016), 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, in Dohmen et al. (2010), we 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.

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, 2016). Weaker findings emerge for tasks involving memory or school grades (for example, Booth and Katic 2013; Angrisani and Casanova 2011). This evidence might also suggest that different facets of cognitive ability play different roles. However, relatively few studies have 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" that offers a range of possible answers. 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, Falk, Huffman, Sunde, Schupp, and Wagner 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, in Falk, Becker, Dohmen, Enke, Huffman, and Sunde (forthcoming), we 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 in only 12 countries is it not statistically significant at the 10 percent level.

Own calculations show that average willingness to take risks 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. In our calculations, willingness to take risks is more pronounced in countries with higher average numeracy (correlation of −0.598) and literacy (correlation of −0.541) for the 16 countries surveyed in both the Global Preference Survey and in PIAAC.

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 between self-reported willingness to take risks and 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 to 90, Tymula, Belmaker, Ruderman, Glimcher, and Levy (2013) support the finding that older individuals are more risk averse than their midlife counterparts but also find that adolescents are more risk averse too. Two papers, Falk, Becker, Dohmen, Enke, Huffman, and Sunde (forthcoming) and Mata, Josef, and Hertwig (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, Juster, Kimball, and Shapiro 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, in Dohmen, Falk, Golsteyn, Huffman, and Sunde

(2017), we disentangle cohort, period, and age effects to investigate how risk attitudes change over the life course, and we 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 lifespan. 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, Josef, Samanez-Larkin, and Hertwig (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), and this 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

Our discussion suggests two main avenues for future research. 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 both). 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.

Neuroeconomic 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 orbito-frontal cortex, medial prefrontal cortex, and posterior cingulate and parietal cortex (see also d'Acremont and Bossaerts 2008; Platt and Huettel 2008; Rushworth and Behrens 2008; Schultz et al. 2008; Schultz, O'Neill, Tobler, and Kobayashi 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.[3]

There is also evidence that the brain regions involved in risky choice change when the study involves more complex risky choices rather than the 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 nonhuman 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, a possibility exists 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.

Clearly, 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

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[3] An alternative approach to manipulating cognitive ability is to use tasks that 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 influence *risk taking*, rather than how cognitive ability does so.

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.

Thus, a 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 nonexperimental, experimental, and survey approaches jointly in order to isolate a single factor that measures risk (for example, Frey, Pedroni, Mata, Rieskamp, and Hertwig 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 is 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 with reconciling the contradictory evidence about the correlation between risk preference and cognitive ability in choice situations in the gain or in the loss domain, and it would help with the issue of decision errors.

Similarly, it could prove valuable to explore 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. 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. 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, Eckel, Johnson, and Rojas 2010).

These kinds of experiments might be linked to a public policy context. 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, this article has argued that economists and psychologists should increase their awareness about the connections between cognitive ability and revealed (measured) risk preference. Using the concept of revealed risk preference

without also including the concept of cognitive ability runs the risk of confusion, 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. For example, if it was 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 differs 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 making and testing public policy. For example, it may become possible to point to specific facets of cognition that 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, appropriate 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 risky choices are correlated with other outcomes of interest, the connections between cognitive ability and risk preference could be used to target policy interventions.

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