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On the relationship between numeracy and wealth

Estrada Mejia, Catalina

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Catalina Estrada-Mejia

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On the relationship between numeracy and wealth

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CHAPTER 1

General introduction

The term “wealth” refers to the total capital accumulated over a lifetime, and it is usually estimated as the net worth of people’s savings, investments and loans. Households need wealth to be economically secure, stable and independent, and to create opportunities for the next generation (Shapiro, Meschede, & Osoro, 2013). Wealth allows people to move forward by moving to better neighborhoods, investing in business, investing in the education of their children, and saving for retirement. Wealth can also buffer the effects of temporary income loss such in the case of illness or unemployment. Therefore, not accumulating enough wealth can profoundly hurt the well-being of individuals and their families. A major concern in the current economic climate is the persistent differences in wealth, even among households with the same income and socioeconomic characteristics (Agarwal & Mazumder, 2013; Bernheim, Skinner, & Weinberg, 2001). To discover the major drivers behind this heterogeneity a wide range of possible explanations, including demographic variables, economic preferences, and individual differences have been studied (Agarwal & Mazumder, 2013; Ameriks, Caplin, & Leahy, 2003; Bernheim et al., 2001; Lusardi & Mitchell, 2007; Rindermann & Thompson, 2011). However, the extent to which wealth heterogeneity can be explained by these factors is still subject of debate (Ameriks, et al., 2003; Bernheim et al., 2001).

Given the important role of wealth in people’s well-being, it is important to obtain greater understanding of the major drivers behind wealth accumulation. I believe one psychological factor that can help us to understand differences in wealth accumulation is individuals’ numeracy. Although different definitions are available in the literature, numeracy mainly refers to an individual’s ability to use mathematical knowledge in reflective and insight-based ways. Researchers in this field have suggested that numeracy is a key determinant of financial outcomes (Banks, O’Dea, & Oldfield, 2011; Lusardi, 2012; Smith, McArdle, & Willis, 2010), and a sizeable and growing literature has established a correlation between numeracy and several different financial behaviors (see an overview in Lusardi, 2012). For instance, it has been found that individuals with greater numeracy are more likely to participate in financial markets and to invest in stocks (Almenber & Widmark, 2011; Christelis, Jappelli, & Padua, 2010;), more likely to plan for retirement (Lusardi & Mitchell, 2007, 2011), more knowledgeable when choosing a mortgage (Disney & Gathergood, 2011), less likely to default (Gerardi, Goette, & Meier, 2010), and more likely to avoid predatory loans, pay loans on time, and pay credit cards in full (Sinayev & Peters, 2015). In this thesis, I aim to extend prior research by investigating the relationship between numeracy and wealth.

The study of the psychology of numeracy and, specifically, of the relationship between numeracy and wealth is important because it will further our understanding of the forces behind wealth differences, but also, because it will further our understanding of the scope of numeracy effects. Specifically, we will obtain greater understanding of the extent to which numeracy affects people's financial decisions and financial outcomes. Ultimately, research that integrates findings from both psychology and economics will help design policies to help people make better financial decisions.

In this thesis, in order to better understand the relationship between numeracy and wealth, I first explored whether this relationship was robust, statistically significant and economically relevant (Chapter 2 and Chapter 3). Then, to better understand why numeracy and wealth were related, I investigated a possible mechanism (Chapter 4). Precisely, I examined the relationship between numeracy and willingness to take financial risks. In my attempt to answer these questions I built on economic and psychological literature, and use data from the Netherlands and Peru. The remainder of this introductory chapter is organized as follows. In the next section I present a more comprehensive definition of the concept of numeracy, as well as research documenting how numeracy is related to demographic characteristics, to intelligence and to other individual factors. Subsequently, I describe how the construct of numeracy has been measured in past research and describe the measures used in my studies. Next, I define wealth and explain how wealth can be measured. Lastly, I present an overview of the three empirical chapters and the concluding chapter.

What is numeracy?

The word numeracy first appeared in a report of the Central Advisory Council for Education of England (Lloyd, 1959) in the context of educating schoolchildren. In its original sense, numeracy refers to mathematical abilities that go beyond arithmetic calculations (Lloyd, 1959). In line with this proposition, numeracy has been commonly defined in the literature as “the ability to comprehend, use and attach meaning to numbers” (Nelson, Reyna, Fagerlin, Lipkus, & Peters, 2008, p.261). Within this broad definition, however, numeracy is understood as a complex concept that encompasses several functional components (Lipkus & Peters, 2009; Reyna, Nelson, Han, & Dieckmann, 2009). As I see it, on the one hand, numeracy captures an individual’s understanding of mathematical terminology (e.g., numbers, numbers line, fractions, proportions, percentages, and probabilities) and mathematical procedures (e.g., counting, sorting, calculating, comparing numerical magnitudes). On the other hand, numeracy comprises the ability to use numerical information in a meaningful and informative way. Therefore, numeracy also includes the ability to determine whether or not to use mathematics in a particular situation and if so, to determine what mathematics to use, how to do it, and what the answer means in relation to the situation. Other similar definitions from the literature are summarized in Table 1.

In this thesis, I conceptualize numeracy as an individual’s ability to use mathematical knowledge in a reflective and insight-based way. Consequently, I adhere to the idea that numeracy extends beyond calculation abilities to color the way people perceive their world, how they understand the problems around them and the strategies they use to solve those problems. For instance, the findings obtained in Chapter 4 strongly suggests that numeracy also influences the specific cognitive processes underlying individual decision making, and not only the handling of numbers.

Table 1. Definitions of numeracy

Source	Definition
Lloyd, 1959, para.398	A word to represent the mirror image of literacy.
Cockroft, 1982, para.39	We would wish the word “numerate” to imply the possession of two attributes. The first of these is an “at-homeness” with numbers and an ability to make use of mathematical skills which enables an individual to cope with the practical mathematical demands of his everyday life. The second is an ability to have some appreciation and understanding of information which is presented in mathematical terms, for instance in graphs, charts or tables or by reference to percentage increase or decrease.
Gal, 1995, para.9	The term numeracy describes the aggregate of skills, knowledge, beliefs, dispositions, and habits of mind-as well as the general communicative and problem-solving skills-that people need in order to effectively handle real-world situations or interpretative tasks with embedded mathematical or quantifiable elements.
Adelswärd & Sachs, 1996, p.1186	Numeracy, in the sense of knowledge and mastery of systems for quantification, measurement and calculation, is a practice-driven competence rather than abstract academic knowledge of “mathematics.” Proficiency in numeracy varies with people’s backgrounds and experience.
Montori & Rothman, 2005, p. 1071	Numeracy skills include understanding basic calculations, time and money, measurement, estimation, logic, and performing multistep operations. Most importantly, numeracy also involves the ability to infer what mathematic concepts need to be applied when interpreting specific situations.
Nelson et al., 2008, p.261	The ability to comprehend, use and attach meaning to numbers.

How is numeracy related to demographic characteristics?

Studies using representative national samples have shown that low numeracy is widespread even in developed countries such as Germany, the Netherlands, Sweden and Japan (Galesic, & García-Retamero, 2010; Organisation for Economic Co-operation and

Development [OECD], 2013; Peters, Hibbard, Slovic, & Dieckmann, 2007). Thus, observed low levels of numeracy are prevalent worldwide, rather than specific to any given country or stage of economic development. Moreover, these studies have documented persistent differences by population subgroups (Lusardi & Mitchell, 2011; Schaie, 1993; Wood et al., 2011). First, age patterns are notable, proficiency in numeracy follows an inverted U-shaped pattern, peaking in middle age (around 30 years of age) and then declining steadily thereafter, being lowest for the younger and the older groups. However, there are some notable cohort differences, with older cohorts demonstrating stronger numeric abilities than younger cohorts (Wood et al., 2011).

Second, there are persistent sex differences (Lusardi & Mitchell, 2011; Schaie, 1993; Wood et al., 2011). On average, men have higher numeracy scores than women. However, the latest data from the OECD's Programme for the International Assessment of Adult Competencies (PIAAC; OECD, 2013), which measures numeracy skills among adults aged 16-65 from 24 countries, highlighted that in half the countries surveyed, there was no difference between young men and young women. This indicates that among younger adults, the gender gap in numeracy is negligible. Lastly, these studies have found an association between numeracy and education (Lusardi & Mitchell, 2011; Schaie, 1993; OECD, 2013; Wood et al., 2011). Higher educational attainment is correlated with higher numeracy, but numeracy levels vary considerable among individuals with similar qualifications (OECD, 2013). This implies that formal education plays a key role in developing numeracy skills, but that more education does not automatically translate into higher numeracy.

Given that there are stables differences in numeracy in the population, numeracy researchers need to cautiously consider the selection of the sample. Specifically, it is important to examine when it is appropriate to use a college student sample, and when it is not. There are two major disadvantages of using a student sample for the type of studies reported in this thesis. First, student samples tend to be more numerate than the general population (Cokely, Galesic, Schulz, Ghazal, & García-Retamero, 2012; Weller, Dieckmann, Tusler, Mertz, Burns, & Peters, 2013) and, therefore, it might not be possible to observe potential effects of being innumerate or moderately numerated on wealth accumulation. Second, the limited variation in numeracy within the student sample may cause some numeracy effects to be underappreciated. It is possible that the restriction in the range of numeracy scores, common in student samples, resulted in a lower observed correlation than it would have if data from the entire possible range were analyzed. Taking these reasons into consideration, I did not use student samples in my studies. In Chapter 3, I used a sample from an agrarian population in Peru, which includes participants with zero years of formal education. In Chapter 2, I used a large and diverse sample from the Dutch population. However, student samples can provide great insights to other research questions such as the effect of numeracy on cognitive biases (Liberali, Reyna, Furlan, Stein, & Pardo, 2012; Peters & Levin, 2008) or the relationship between numeracy and other individual differences (Liberali et al., 2012). Taking this into consideration, in the section about how is numeracy related to thinking styles and personality, I used a sample of psychology students.

How is numeracy related to intelligence?

Numeracy is related, but separable, from general intelligence. At least three sources of evidence support the validity of numeracy as a separate construct from intelligence. First, neuroimaging studies of healthy individuals, as well as neuropsychological analyses of brain-damaged patients, have documented the existence of specialized neuronal circuits dedicated to numerical processing (see a meta-analysis in Dehaene, Piazza, Pinel, & Cohen, 2003). Specifically, neuroimaging studies have recorded the activity of several single neurons in the human parietal cortex and have found that neurons in this region fired for numeric tasks but not for linguistic tasks (Abdullaev & Melnichuk, 1996). In addition, studies with brain-damaged patients revealed that lesions to the inferior-parietal region of the brain can destroy numerical knowledge without impairing nonnumerical knowledge (Dehaene, 1997). In a similar vein, a study with older adults reported that individuals with vast experience on numerical processing, such as retired accountants, present age-related declines in nonnumerical memory while preserving numerical memory similar to young adults (Castel, 2007).

A second line of evidence comes from studies documenting that different cognitive skills such as mathematical computation, working memory, and fluid reasoning have different patterns of change throughout the course of maturation (Baker, Salinas, & Eslinger, 2012; Eslinger et al., 2008), which implies that numerical ability can be developed independent of other cognitive abilities. Finally, substantive research has shown that numeracy's effects on judgment and decision-making tasks are robust after controlling for different measures of intelligence (Liberali et al., 2011; Peters, Västfjäll, Slovic, Mertz, Mazzocco, & Dickert, 2006; Reyna & Brainerd, 2007).

Altogether, these findings support the validity of numeracy as a separate construct from intelligence. This is important because it indicates that numeracy and intelligence can have different effects on people's judgments and decisions. Then, it is valuable to obtain greater understanding of when and how each of these cognitive abilities plays a role. Such knowledge about the psychology of numeracy will add precision to our understanding of how different cognitive abilities affect individuals' decision making. Results in Chapter 2 and Chapter 3 add to this debate and reveal that numeracy has an effect on wealth that is independent of participants' intelligence.

How is numeracy related to thinking styles and personality measures?

In order to further explore the validity of the construct of numeracy, it is important to understand how numeracy is associated to (or differs from) other characteristics of the individual. Unfortunately, there has been relatively little systematic examination of the relationship between numeracy and other individual differences (exemptions are Cokely et al., 2012; Liberali et al., 2011). To explore this question, I conducted a preliminary exploratory study. Specifically, I investigated the association between numeracy, thinking styles and personality traits. Participants were 163 first-year psychology students at Tilburg University (133 women, 30 men) ranging in age from 16 to 27 years (M = 18.9, SD = 1.8). Numeracy was measured with the 4-item Berlin Numeracy Test (Cokely et al., 2012). Participants also completed the 40-item Rational-Experiential Inventory (REI-40; Pacini & Epstein, 1999) that measures rational (e.g., "I enjoy solving problems that require hard thinking") and experiential (e.g., "I trust my initial feelings about people") thinking styles and the 10-item Personality Inventory (TIPI; Gosling, Rentfrow, & Swann, 2003) assessing the Big Five personality traits. Partial and full correlations are presented in Table 2.

Table 2. Partial and full correlation between numeracy, personality and thinking styles

Variable	Full correlation	Partial correlation
Personality measures		
Openness	.057	.056
Conscientiousness	-.080	-.048
Extraversion	-.112	-.100
Agreeableness	.134	.133
Neuroticism	-.124	-.095
Thinking styles		
Rational thinking style	.175*	.199*
Experiential thinking style	.100	.109

Note: Entries in table are correlation coefficients between numeracy and the other measures in the analysis. *p < .05, **p < .01. Partial correlations are estimated controlling for gender and age.

Partial correlations, controlling for gender and age, revealed that numeracy correlated positively with the factor measuring rational thinking style (r = .199, p = .012). However, numeracy was not correlated with the experiential thinking style factor (r = .109, p = .168) or personality traits (all *p values* > .093*)*. These exploratory findings provide tentative evidence for construct validity. In other words, numeracy was found to have a significant positive relationship with a construct that should theoretically be related (i.e., rational thinking), but not to be correlated to unrelated constructs like personality or experiential thinking.

How can we measure an individual's numeracy?

Objective and subjective measures of numeracy are available in the literature. Objective scales measure the ability to perform mathematical operations, to solve problems involving numerical information, and to interpret information. In contrast, subjective scales measure how confident and comfortable people feel about their numerical ability. In Chapter 2 and Chapter 4, numeracy was assessed with the 11-item Numeracy Scale developed by Lipkus, Samsa and Rimer (2001). It is an objective scale that measures respondents' ability to perform basic arithmetic operations, and to solve problems involving frequency, probability, and percentages. An example question is: "Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls how many times do you think the die would come up even (2, 4, or 6)?" (Correct answer: 500 out of 1,000). This scale is the most commonly used measured in empirical studies. In Chapter 3, a 3-item scale was developed based on the Lipkus, Samsa and Rimer (2001) scale but adapted to the rural agrarian population. This scale is presented and discussed in Chapter 3. For the sake of completeness, at the end of this chapter, I provide an overview of the most often used scales that are available in the literature.

Comparison of subjective and objective measures

Although some studies have found a significant correlation between the subjective numeracy scale (SNS) and objective measures (Fagerlin, Zikmund-Fisher, Ubel, Jankovic, Derry, & Smith, 2007; Galesic & García-Retamero, 2010), researchers have stated that subjective and objective numeracy did not correlate well enough with each other to be interchangeable (Liberali et al., 2012; Cokely et al. 2012). For instance, in two studies Liberali and colleagues (2012) showed that the correlation between the SNS and the Lipkus scale (Lipkus et al., 2001) was about .45 and .47 (.20 lower than the .68 reported by Fagerlin et al., 2007). With a correlation of .47, the shared variance is only 22%. Liberali and colleagues (2012) also showed that the test items of the SNS did not load on the same factors as the objective measures. For all these concerns about subjective measures not measuring the same construct as the objective measures, I did not use subjective scale in my studies.

Finally, since this thesis focuses on studying the relationship between numeracy and wealth, let me next explain what wealth is and how it can be measured.

What is and how can we measure wealth?

Wealth is usually understood as the value of all financial assets, nonfinancial assets and liabilities accrued over the lifetime. The most comprehensive wealth measures, like the one designed by the Survey of Consumer Finances in The United States, include the value of financial assets such as (i) checking, saving, money market, and call accounts; (ii) IRA and Keogh accounts; (iii) certificates of deposit; (iv) stocks, bonds, mutual funds, savings bonds; (v) trusts, annuities and other managed assets; and (v) cash value life insurance. It also contains the value of nonfinancial assets such as the respondent’s principal residence, investment real estate, vehicles, business interests, and other valuable assets such as art and precious metals. Finally, it includes the value of debt and liabilities such as mortgages, home equity loans and lines of credit, loans for investment real estate, vehicle loans, student loans, consumer installment loans, and debt on credit cards (Fries, Starr-McCluer, & Sundén, 1998). However, there are no standard measures of wealth available in the literature, since the pool of assets that are included depends on the availability of information on an individual level. In Chapter 2 and Chapter 4 wealth was measured using information on assets and liabilities. The inventory covers checking and saving accounts, stocks, bonds and other financial assets, real estate, mortgages, loans, and lines of credit.

The measurement of wealth has shown to be particularly challenging in developing countries where individuals have little or no access to financial services (Sahn & Stifel, 2000, 2003). In response, alternative measures based on indicators of ownership of durable goods such as radios, TVs, sewing machines, stoves, or bicycles, and housing characteristics such as the number of rooms, or the type of toilet facilities have been developed (Filmer & Pritchett, 2001; Sahn & Stifel, 2003; Smits & Steendijk, 2014). These alternative measures have shown to be as reliable as more conventional measures like the one described above (Filmer & Pritchett, 2001; Montgomery, Gragnolati, Burke, & Paredes, 2000). In Chapter 3 wealth was estimated using this alternative type of measures.

Overview of the chapters

In this thesis I investigated whether the relationship between numeracy and wealth was robust, statistically significant and economically relevant. In addition, to better understand why numeracy and wealth were related, I investigated a possible mechanism. Precisely, I examined the relationship between numeracy and willingness to take financial risks. The empirical chapters are based on individual papers that have been submitted for publication. All chapters are designed in such a way that they can be read individually, which explains the partial overlap between the introductions for each chapter. Since the original papers were all coauthored with my supervisors and other researchers, I decided to use a "we-form" instead of an "I-form" in those. Below, I summarize the chapters to show the reader what can be expected in the remainder of this book.

Chapter 2: This chapter examines the relationship between numeracy and wealth using a cross-sectional and a longitudinal study. For a sample of approximately 1,000 Dutch adults, we found an economically relevant and statistically significant correlation between numeracy and wealth, even after controlling for differences in education, intelligence, risk preferences, beliefs about future income, financial knowledge, need for cognition or seeking financial advice. Conditional on socio-demographic characteristics, our estimates suggest that on average a one-point increase in the numeracy score of the respondent is associated with 5 percent more personal wealth. Additionally, we found that numeracy is a key determinant of the wealth accumulation trajectories that people follow over time. Over a 5-year period, while participants with low numeracy decumulate wealth, participants with high numeracy maintain a constant positive level of wealth.

Chapter 3: In this paper, we investigate whether numeracy also has a positive influence on wealth in an agrarian population from the Highlands of Peru, a simpler financial environment where wealth is acquired through monetary exchanges, barter and reciprocal labor. Wealth was measured using data on asset ownership (e.g., owning a bicycle or radio) and housing characteristics (e.g., type of toilet facilities). Result from regression analysis and SEM models revealed that the positive relationship between numeracy and wealth was substantial and statistically significant even after accounting for differences in fluid intelligence and crystallized intelligence, potential demographic confounders, and the direct effects of education. These findings contribute to the growing research in numeracy by documenting the positive effect of numeracy on wealth in a population with a less sophisticated financial market where mathematical abilities are presumably less imperative for wealth accumulation.

Chapter 4: This chapter examines the relationship between numeracy and willingness to take risks for a representative sample of the Dutch population, controlling for potential confounding factors (e.g., age, gender, education, and income). We also modeled the decision strategies underlying the choices and tested whether strategy selection was conditional upon participant's numeracy, payoffs, or both. Specifically, we considered an expected value strategy (EV), as well as three heuristic strategies: least-likely, maximin, and maximax. Our findings revealed no significant differences on the willingness to take risk between individuals with low and high numeracy for low payoffs. However, for high payoffs, high numeracy individuals were significantly *less* willing to take risk than low numeracy individuals. In terms of the decision strategies, as participants' numeracy increased, the likelihood of using EV increased when payoffs were low, but decreased when payoffs were high. The opposite was observed for the maximin strategy. Independently of the payoffs, as numeracy increased the likelihood of choosing the least-likely or the maximax strategy decreased.

To conclude, in **Chapter 5** the empirical findings from the previous chapters are combined into a parsimonious view of the relationship between numeracy and wealth. General conclusions are drawn regarding the association between numeracy and wealth. Finally, implications for numeracy research are discussed and promising research topics for future research are identified.

Overview of objective and subjective numeracy scales

Next I provide an overview of the most often used scales that are available in the literature. Table 3 summarizes the items from all the measures described below.

Objective Numeracy Scales

11-item Numeracy Scale. This scale is based on three questions developed by Schwartz, Woloshin, Black and Welch (1997) and expanded later by Lipkus, Samsa and Rimer (2001). The scale assesses respondents' basic arithmetic and statistical skills. An example question is: "Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls how many times do you think the die would come up even (2, 4, or 6)?" (Correct answer: 500 out of 1,000). The total resulting numeracy score reflects the sum of correct answers, with higher scores indicating higher levels of numeracy. Possible scores range from 0-11.

Berlin Numeracy Test. The scale was designed by Cokely and colleagues (2012) as an instrument to quickly assess statistical numeracy. It is based on 4 questions. It is available in a traditional paper and pencil format and a computer adaptive test format. An example question is: "Out of 1,000 people in a small town 500 are members of a choir. Out of these 500 members in the choir 100 are men. Out of the 500 inhabitants that are not in the choir 300 are men. What is the probability that a randomly drawn man is a member of the choir? Please indicate the probability in percent" (Correct answer: 25%). The total resulting numeracy score reflects the sum of correct answers, with higher scores indicating higher levels of numeracy. Possible scores range from 0-4.

8-item Numeracy Scale. The scale was developed by Weller and colleagues (2013). It is based on 8 questions extracted from existing scales: Lipkus et al. (2001), Peters et al., (2007), and Frederick's (2005; CRT). An example question is: "A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?” The total resulting numeracy score reflects the sum of correct answers, with higher scores indicating higher levels of numeracy. Possible scores range from 0-8.

Subjective Numeracy Scales

The Subjective Numeracy Scale *(SNS)*. The SNS was developed by Fagerlin and colleagues (2007) to distinguish between low- and high- numerate individuals, on the basis of respondents’ self-assessment of their quantitative ability. The SNS contains four items that measure respondents’ perception of their numerical ability (e.g., “How good are you at working with fractions”) and four items that pertain to preferences for numeric information presentation (e.g., “When reading the newspaper, how helpful do you find tables and graphs that are parts of a story”). Respondents evaluate each item using a 6-point Likert Scale, with higher scores indicating higher levels of numeracy or higher preference for numerical information. Possible scores range from 0-6.

Table 3. Items from the objective and subjective numeracy scales

	Objective Numeracy Scales			Subjective
	11-item Numeracy Scale Lipkus et al., 2001	**Berlin Numeracy Test Cokely et al., 2012**	**8-item Numeracy Scale Weller et al., 2013**	**Numeracy Scale Fagerlin et al., 2007**
1	Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls, how many times do you think the die would come up even (2, 4, or 6)?	Imagine we are throwing a five-sided die 50 times. On average, out of these 50 throws how many times would this five-sided die show an odd number (1, 3 or 5)?	Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls, how many times do you think the die would come up even (2, 4, or 6)?	How good are you at working with fractions?
2	In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize is 1%.What is your best guess about how many people would win a $10.00 prize if 1,000 people each buy a single ticket to BIG BUCKS?	Out of 1,000 people in a small town 500 are members of a choir. Out of these 500 members in the choir 100 are men. Out of the 500 inhabitants that are not in the choir 300 are men. What is the probability that a randomly drawn man is a member of the choir? Please indicate the probability in percent.	In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize is 1%.What is your best guess about how many people would win a $10.00 prize if 1,000 people each buy a single ticket to BIG BUCKS?	How good are you at working with percentages?
3	In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets to ACME PUBLISHINGSWEEPSTAKES win a car?	Imagine we are throwing a loaded die (6 sides). The probability that the die shows a 6 is twice as high as the probability of each of the other numbers. On average, out of these 70 throws, how many times would the die show the number 6?	In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets to ACME PUBLISHINGSWEEPSTAKES win a car?	How good are you at calculating a 15% tip?
4	Which of the following numbers represents the biggest risk of getting a disease? 1 in 100, 1 in 1000, 1 in 10	In a forest 20% of mushrooms are red, 50% brown and 30% white. A red mushroom is poisonous with a probability of 20%. A mushroom that is not red is poisonous with a probability of 5%. What is the probability that a poisonous mushroom in the forest is red?	If the chance of getting a disease is 10%, how many people would be expected to get the disease: Out of 1000?	How good are you at figuring out how much a shirt will cost if it is 25% off?
5	Which of the following numbers represents the biggest risk of getting a disease? 1%, 10%, 5%		If the chance of getting a disease is 20 out of 100, this would be the same as having a ____% chance of getting the disease	When reading the newspaper, how helpful do you find tables and graphs that are parts of a story? (Not at all helpful – Extremely helpful)

(Continued)

Table 3. Items from the objective and subjective numeracy scales (Continued)

	Objective Numeracy Scales			Subjective Numeracy Scale
	11-item Numeracy Scale Lipkus et al., 2001	**Berlin Numeracy Test Cokely et al., 2012**	**8-item Numeracy Scale Weller et al., 2013**	**Fagerlin et al., 2007**
6	If Person A's risk of getting a disease is 1% in ten years, and person B's risk is double that of A's, what is B's risk?		A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?	When people tell you the chance of something happening, do you prefer that they use words ("it rarely happens") or numbers ("there's a 1% chance")?
7	If Person A's chance of getting a disease is 1 in 100 in ten years, and person B's risk is double that of A's, what is B's risk?		In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?	How often do you find numerical information to be useful? (Never – Very often)
8	If the chance of getting a disease is 10%, how many people would be expected to get the disease: Out of 100?		Suppose you have a close friend who has a lump in her breast and must have a mammography. The table below summarizes all of this information. Imagine that your friend tests positive (as if she had a tumor), what is the likelihood that she actually has a tumor?	When you hear a weather forecast, do you prefer predictions using percentages (e.g., "there will be a 20% chance of rain today") or predictions using only words (e.g., "there is a small chance of rain today")?
9	If the chance of getting a disease is 10%, how many people would be expected to get the disease: Out of 1000?			
10	If the chance of getting a disease is 20 out of 100, this would be the same as having a ____% chance of getting the disease			
11	The chance of getting a viral infection is .0005. Out of 10,000 people, about how many of them are expected to get infected?			

CHAPTER 2

Numeracy and wealth

This chapter is based on: Estrada-Mejia, C., De Vries, M., & Zeelenberg, M. (2015). Numeracy and wealth. *Working paper*.

Abstract

Numeracy is defined as the ability to understand and use numerical information. We examined the relationship between numeracy and wealth using a cross-sectional and a longitudinal study. For a sample of approximately 1,000 Dutch adults, we found an economically relevant and statistically significant correlation between numeracy and wealth, even after controlling for differences in education, intelligence, risk preferences, beliefs about future income, financial knowledge, need for cognition or seeking financial advice. Conditional on socio-demographic characteristics, our estimates suggest that on average a one-point increase in the numeracy score of the respondent is associated with 5 percent more personal wealth. Additionally, we find that numeracy is a key determinant of the wealth accumulation trajectories that people follow over time. Over a 5-year period, while participants with low numeracy decumulate wealth, participants with high numeracy maintain a constant positive level of wealth.

Recent economic trends have made individuals increasingly responsible for their own financial security upon retirement. Financial security greatly depends on the ability to accumulate adequate wealth (Wolff, 1998; 2006), since wealth can be a significant source of retirement income. One concern in the current economic climate is the persistent differences in wealth and savings, even among households with the same income and socioeconomic characteristics (Bernheim, Skinner, & Weinberg, 2001). Economists and policy makers have devoted great efforts in understanding this heterogeneity in wealth, and numerous determinants have been proposed. However, the extent to which this heterogeneity can be explained by demographic variables or by economic preferences is still subject of debate (Ameriks, Caplin, & Leahy, 2003; Bernheim et al., 2001). Lately, psychologists have also developed an interest in the problem and have provided evidence that individual differences in personality, motivation, and intelligence are predictors of wealth differentials (Agarwal & Mazumder, 2013; Brown & Taylor, 2014; Lusardi & Mitchell, 2007; Rindermann & Thompson, 2011). In the current article, we extend that literature by studying the role of numeracy in personal wealth accumulation. Numeracy is defined as the ability to understand and use probabilistic and mathematical concepts. Specifically, we address the question of whether differences in numeracy contribute to differences in the accumulation of wealth. We examine this using a cross-sectional and longitudinal model, while controlling for other demographic, socio-economic and individual characteristics. The underlying premise is that people with high numeracy accumulate more wealth than people with low numeracy.

Previous findings are consistent with the hypothesis that numeracy is related to wealth and wealth growth. In one of the first studies in this vein, Banks and Oldfield (2007) document a strong positive relationship between numeracy and financial wealth, even when controlling for other dimensions of cognitive ability as well as educational attainment. Subsequent research has found tentative evidence for differences in wealth accumulation among groups with different numerical ability. That is, in the years leading up to retirement those who are more numerate accumulate financial assets faster than those who are less numerate (Banks, O'Dea, & Oldfield, 2011; Smith, McArdle, & Willis, 2010). Although the results presented above are in line with our predictions, they are limited in the sense that it remains unclear whether numeracy is directly correlated with wealth or whether numeracy is correlated with a third factor, so far unobserved, that is correlated with financial outcomes. For example, people low in numeracy might have different risk or time preferences, face different incentives and constraints, have different information, or hold different beliefs. Consequentially, it is possible that the observed correlation of numeracy and wealth does not exist in the population but is the result of omitting a third key variable as predictor. If this was the case, it would indicate that numeracy does not have a direct effect on people's wealth but an indirect effect through its relation with this third factor. Moreover, it would imply that numeracy has a weak or no effect on people's financial decisions and that it cannot explain differences in people's wealth.

The current article builds on this previous research to investigate whether there is an economically relevant and statistically significant correlation between numeracy and wealth. We aim to test whether this correlation is robust to the inclusion of controls for other possible factors affecting wealth. We restrict this analysis to factors that, a-priori, have shown to be related with numeracy and financial outcomes. These factors are risk preferences (Cokely & Kelley, 2009; Dohmen, Falk, Huffman, Sunde, Schupp, & Wagner, 2011; Donkers & Van Soest, 1999; Reyna, Nelson, Han, & Dieckmann, 2009), seeking financial advice (Hackethal, Haliassos, & Jappelli, 2012; Hung & Yoong, 2010), beliefs about future income (Carroll, 1994), financial knowledge (Behrman, Mitchell, Soo, & Bravo, 2012; Van Rooij, Lusardi, & Alessie, 2012), and need for cognition (Simon, Fagley, & Halleran, 2004). We examine whether the estimated correlation between numeracy and wealth is much affected by the inclusion of these additional controls. Moreover, we explore whether numeracy is related to the wealth accumulation trajectories that people follow over time. We study how the processes unfold and whether numeracy has an effect on the rate of change in wealth across a 5-year time period. Let us first explain why we might expect wealth to vary with numeracy.

Relationship between numeracy and wealth: three sources of influence

Numeracy concerns comprehending, processing, and using numerical information appropriately (Peters, 2012; Peters et al., 2006; Reyna et al., 2009). Findings from decision-making research suggest a number of reasons why we might expect numeracy and wealth to be related. First, there is substantive evidence that an individual’s numeracy can predict mistakes in probability judgment that have been shown to have pervasive effects on people’s financial outcomes. Specifically, compared to people low in numeracy, people high in numeracy are less sensitive to framing effects (Peters et al., 2006), less likely to fall prey of conjunction and disjunction fallacies, and less susceptible to the ratio-bias phenomena (Liberali, Reyna, Furlan, Stein, & Pardo, 2012). These biases and fallacies distort risk perceptions and may lead to misunderstandings of the decision options and suboptimal decisions. We expect that individuals with low numeracy, who are more likely to fall prey of these biases and fallacies, would be more likely to make suboptimal financial decisions (e.g., maintaining credit cards debts and mortgages when cheaper forms of credit are available) and end up accumulating less wealth.

Second, numeracy appears to have an effect on individuals’ risk and time preferences that are likely to affect financial behavior. People with higher numerical ability are more likely to take strategic risks (Jasper, Bhattacharya, Levin, Jones, & Bossard, 2013; Pachur & Galesic, 2013). In a series of studies participants high in numeracy preferred a risky alternative when it was advantageous to do so and avoided it when it was not (Jasper et al., 2013). Moreover, this “strategic” risk management strategy increased their final outcome in the game. Numeracy has also shown to be related with time preferences. Chilean high-school students with higher numeracy were less impatient; they chose larger delayed rewards over smaller immediate rewards (Benjamin, Brown, & Schapiro, 2013). This is relevant because impatient people persistently report less wealth by the time of retirement (Hasting & Mitchell, 2011). Taken together, these findings suggest that numeracy systematically affects economic preferences and choices in ways that favor wealth accumulation.

Finally, people high in numeracy appear to be more able to process information and to distinguish between relevant and irrelevant information. In a series of studies participants were asked to choose among different hospital and insurance plans; the options were described using multiple numerical and non-numerical attributes (Peters, Dieckman, Dixon, Hibbard, & Mertz, 2007; Peters, Dieckmann, Västfjäll, Mertz, Slovic, & Hibbard, 2009). People high in numeracy made more “optimal” decisions, choosing the option with the best numerical quality indicators. This suggests that participants high in numeracy were better able to integrate multiple types of mathematical information, draw inferences, develop mathematical arguments and justify their choices. Given the complexity of saving and portfolio choices individuals in modern financial markets face, it is likely that those with higher ability to understand the different alternatives would make better decisions. Let us now turn to our study.

Method

Participants

We used data from the LISS panel (Longitudinal Internet Studies for the Social sciences), an organization affiliated with Tilburg University. The panel is designed to be a representative sample of the Dutch population and consists of approximately 8,000 individuals. Panel members complete a questionnaire over the Internet each month and are paid for each completed questionnaire. We recovered demographic variables and financial information from three measurement waves across 5 years, namely 2007, 2009 and 2011. Additionally, we matched this information with the numeracy score of each respondent, which was measured in 2008 (see Appendix A for an overview of the different questionnaires). Since not all respondents in the Panel have information in all background and financial variables, our sample consists of 1,019 panel members. Descriptive statistics of all variables are presented in Table 1.

Table 1. Summary table of variables used in the study (year 2009)

Variable	Explanation	Mean	SD	N
Wealth	Wealth in euros	€66,876	€204,313	1,019
Numeracy	Numeracy scores. Range (0-11), 11 items, Cronbach's alpha = .78. Higher scores indicate higher level of numeracy	8.79	2.41	1,019
CRT	Cognitive Reflection Test scores. Range (0-3), 3 items, Cronbach's alpha = .65. Higher scores indicate higher level of cognitive ability	1.19	1.11	212
Risk preferences	Answer to the question “How would you rate your willingness to take risk” (0=highly risk averse, 10=fully prepared to take risks)	3.67	2.38	468
Financial advisor	The respondent seeks financial advice (coded 1=yes, 0=no). Percentage of respondents who answered “yes”	26.7%		954
Sufficient income	Net monthly income necessarily to maintain their lifestyle in euros	€3,235	€4,462	1,006
Financial knowledge	Answer to the question “How would you score your understanding of financial matters” (1= very poor, 7=very good)	5.13	1.16	965
Need for cognition	Need for cognition scores. Range (0-7), 18 items, Cronbach's alpha = .88. Higher scores indicate higher need for cognition	4.51	0.94	1,007
Female	Female dummy (coded 1=female, 0=male). Percentage of female	42.2%		1,019
Age	Age of the respondent	53.62	15.21	1,019

(Continued)

Table 1. Summary table of variables used in the study (Continued)

Variable	Explanation	Mean	SD	N
Partnered	The respondent lives together with a partner (coded 1=yes, 0=no). Percentage of respondents who answered “yes”	73%		1,019
Children	Number of living-at-home children	0.64	1.03	1,019
High Education	The respondent achieved higher education (coded 1=yes, 0=no). Percentage of respondents who answered “yes”	39.5%		1,019
Income	Personal net annual income in euros	€23,168	€61,074	1,019
Paid work	The respondent’s primary occupation is paid employment (coded 1=yes, 0=no). Percentage of respondents who answered “yes”	49.8%		1,019
Retired	The respondent’s primary occupation is retired (coded 1=yes, 0=no). Percentage of respondents who answered “yes”	28.3%		1,019

Measures

Independent variables.

Demographic. Gender, age, education and work status were retrieved for all participants for 2007, 2009 and 2011. Participants who reported finishing higher vocational education or university received a score of 1 and 0 otherwise. Work status was collapsed in three categories: Paid work, retired or other.

Numeracy. Numeracy was measured using an 11-item scale (Lipkus, Samsa, & Rimmer, 2001) which tests for basic arithmetic and statistical skills. An example question is: “Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls how many times do you think the die would come up even (2, 4, or 6)?” (Correct answer: 500 out of 1,000). Total scores were computed counting the number of correct answers, with higher scores indicating higher levels of numeracy. Possible scores range from 0-11. Cronbach's alpha =.78.

Appendix B gives a complete overview of the questions, including the percentages of correct answers and a graph of the distribution of numeracy in our sample.

Cognitive Reflection Test (CRT). Panel members completed a three-item Cognitive Reflection Test (Frederick, 2005) to measure one type of cognitive ability—the ability or disposition to reflect on a question and resist reporting the first response that comes to mind. An example of a question is: “A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?” (Correct answer: 5 cents). Test scores were calculated by counting the number of correct answers, with higher scores reflecting higher levels of cognitive ability. Possible scores range from 0-3. Cronbach's alpha = .65.

Risk preferences. Risk preferences were measure by the following question: “People can behave differently in different situations. How would you rate your willingness to take risks in the following areas? Your willingness to take risks…[in financial matters]” on a scale of 0 to 10, where 0 means “highly risk averse” and 10 means “fully prepared to take risks”.

Need for cognition. The Need for Cognition Scale is an assessment instrument that quantitatively measures “the tendency for an individual to engage in and enjoy thinking” (Cacioppo & Petty, 1982, p. 116). Respondents were asked to rate the extent to which they agree with each of 18 statements (nine reverse coded) about the satisfaction they gain from thinking. Sample statements include "I find satisfaction in deliberating hard and for long hours" and "Thinking is not my idea of fun". Participants responded to the statements using a 7-point Likert scale (1=strongly agree to 7=strongly disagree). We calculated an average such that higher numbers reflected higher need for cognition. Possible scores range from 0-7. Cronbach's alpha = .88.

Financial knowledge. The LISS panel survey contains only one question to assess self-perception of financial knowledge. Respondents are asked to answer to the question

“How would you score your understanding of financial matters” on a scale of 1 to 7, where 1 means “very poor” and 7 means “very good”.

Financial advisor. Panel members reported whether or not they generally asked for financial advice. Responders were asked to answer yes or no to the question “In deciding what financial product to purchase, I would let myself be influenced by an independent financial adviser” (dummy-coded: 1= yes, 0= no).

Beliefs about minimum sufficient income. Panel members indicated the amount of income necessary to maintain their lifestyle. They were asked to consider the current circumstances of their household and to indicate, for their household, in their current circumstances, what amount of net income per month they would consider sufficient to live. Log-transformed scores were used in the analyses that follow.

Income. LISS Panel members indicated their personal net monthly income in Euros for 2007, 2009 and 2011. Net annual income was obtained by multiplying the raw score by 12. Log-transformed scores were used for analyses.

Dependent variable.

Wealth. The LISS Panel has collected information about wealth every second year starting from 2007. All panel members age 16 and older respond to questions about the assets and liabilities that they hold alone. The inventory covers checking and saving accounts, stocks, bonds and other financial assets, real estate, mortgages, loans, and lines of credit. Wealth was measured as shown in equation 1, which is similar to the measures typically used in studies of precautionary saving and wealth (Choi, Kariv, Müller, & Silverman, 2014; Noussair, Trautmann, & Van de Kuile, 2013). Total wealth scores were log-transformed before undergoing statistical analyses.

$$Wealth = saving\ balance + long\ term\ insurance\ balance + risky\ investments + real\ estate\ investments - mortgage\ liabilities - other\ loans \quad (1)$$

Procedure

Our analysis proceeds in four steps. We first establish the correlation between numeracy and wealth by estimating regressions of the log of wealth on the log of income, demographic variables and the numeracy score of the responder. Second, we show that cognitive ability cannot be used as a substitute for numeracy. Third, we demonstrate that the correlation between numeracy and wealth is quantitatively robust to the inclusion of additional controls. We show that including these factors in the regression does not reduce (or eliminate) the correlation between numeracy and wealth. Last, we estimate a multilevel model to show that numeracy is related to the wealth accumulation trajectories that people follow over time.

Results

Cross-sectional estimation of the relationship between wealth and numeracy

Our first step was to test whether numeracy has an effect on wealth that is economically important and that cannot be explained by other socioeconomic characteristics. Table 2, column A, presents the estimated correlation between numeracy and wealth when no controls are included. Numeracy had a significant positive effect on wealth ($p < .001$) and the point estimate for the marginal effect was 0.069. Next, we tested whether this correlation was quantitatively robust to the inclusion of controls for differences in demographic characteristics. In column B, we repeated the estimation reported in column A adding a set of socioeconomic variables. The point estimate of the marginal effect of numeracy declined slightly from 0.069 to 0.052, but the coefficient remained statistically significant ($p < .001$)[1]. The stability of the numeracy effect is remarkable, especially given the fact that the control variables in column B are powerful. The Adjusted-R^2 of the regression model increased from .038 to .217 as we added the set of controls. These covariates are powerful predictors of wealth but lead to only a small change in the estimated numeracy effect. Hereafter we will refer to this model as the baseline specification. Next, to evaluate the sensitivity of the results to changes in the wealth and numeracy specification, we estimated the baseline model with levels of wealth and numeracy. We again see that numeracy has a positive and statistically significant effect on wealth. The results of these estimations are reported in Appendix C.

These results suggest that there is a statistically significant and economically relevant correlation between numeracy and wealth. The point estimates indicate that, conditional on measures of income, age, education, occupation, and basic demographic characteristics, a one point increase in the numeracy score of the respondent is associated with 5.2 percent more personal wealth.

Evaluating alternative measures for numeracy

We next evaluated whether numeracy was important over and above intelligence when it comes to the relationship with wealth. The LISS panel has not implemented any of the well-known intelligent tests. However, they asked a sample of panel members to complete the CRT that, in other samples, is well correlated with measures of cognitive ability (Frederick 2005; Obrecht, Chapman, & Gelman, 2009). Among the 212 subjects who completed both tests, the correlation between numeracy and the CRT was positive ($r = .420$, $p < .001$), but the variables were not collinear in the regression analysis (Model column C, *VIF* for the CRT = 1.08). To assess the predictive content of cognitive ability, we added the CRT scores to the

[1] Consistent with previous literature we find that demographic characteristics such as having more income, having a university degree, being older or living with a partner are associated with having more wealth on average (Bomberger, 1993; Greenwood, 1987; Keister, 2000)

baseline specification. To preserve sample size and allow the comparability with the baseline model, we also included a variable to indicate whether a CRT score was available for the respondent. For those who had no score, we substituted the mean of the rest of the sample. This strategy to handle missing data is known as single-value imputation or mean imputation (Arminger, Clogg, & Sobel, 1995; Cohen & Cohen, 1975). Estimations are presented in Table 2 in column C.

Table 2. Regression analyses examining the relationship between numeracy and wealth, alternative measures of numeracy and control variables

	A	**B-Baseline**	**C**	**1D**	**2D**
Numeracy Scores	0.069**	0.052**	0.050**	0.069**	0.060*
	(0.011)	(0.011)	(0.011)	(0.025)	(0.026)
CRT			0.063		0.057
			(0.047)		(0.051)
M-CRT			0.116*		
			(0.057)		
Female		0.001	0.007	-0.087	-0.067
		(0.054)	(0.054)	(0.119)	(0.120)
Age		0.015**	0.014**	0.021**	0.020**
		(0.002)	(0.002)	(0.005)	(0.005)
Partnered		0.212**	0.212**	0.028	0.027
		(0.056)	(0.056)	(0.118)	(0.118)
# Children		-0.026	-0.024	0.014	0.015
		(0.026)	(0.026)	(0.061)	(0.061)
Higher Education		0.217**	0.209**	0.186	0.161
		(0.054)	(0.054)	(0.123)	(0.125)
Log Income		0.658**	0.674**	0.601*	0.608*
		(0.110)	(0.110)	(0.240)	(0.240)
Occupation					
Paid work		0.016	0.009	0.384*	0.381*
		(0.069)	(0.069)	(0.163)	(0.163)
Retired		-0.020	-0.018	0.141	0.144
		(0.078)	(0.078)	(0.177)	(0.177)
Constant	4.151	0.348	0.239	0.279	0.198
	(0.027)	(0.441)	(0.448)	(0.950)	(0.953)
Adj. R-Square	0.038	0.218	0.220	.275	.276
# of obs	1019	1019	1019	212	212

Note. Entries are regression coefficients. Standard errors in parentheses. $^*p < .05$, $^{**}p < .01$. Omitted categories: male, not having a partner, low education (primary and lower secondary education), and other occupations. *M-CRT* functions as a missing-indicator coded 1 if a CRT score was available for the respondent, 0 otherwise. Missing-indicators compares whether observations with missing values differ from observations with non-missing values on variables where information is not missing.

The point estimate of the coefficient on the CRT was economically large — correctly answering one more of the three questions on the CRT is associated with 6.3% more wealth – but was not statistically significant (*p* = .184). Adding this measure reduced the estimated coefficient on numeracy by 0.002. As a robustness check, in column 1D, we repeated the baseline specification restricting attention to the 212 (20.8%) panel members who completed the numeracy and the CRT test. In this smaller sample, the point estimate on numeracy remained statistically different from zero ($b = 0.069$, $SE = 0.025$, $t = 2.501$, $p < .013$). In column 2D, we added the CRT scores to the baseline specification. As a result, the magnitude of the coefficient on numeracy declined (by 0.009) but it was statistically significant.

These results suggest that the observed correlation between numeracy and wealth is not explained by the correlation between numeracy and the CRT. Numeracy has a unique effect on the accumulation of wealth that is not explained by the respondents' general cognitive ability. The findings also indicate that numeracy is not acting as a proxy of the respondents' cognitive ability and that the CRT cannot be used as a simple substitute for numeracy for the purposes of explaining wealth.

Evaluating alternative explanations for the correlation

We found an economically relevant and statistically significant correlation between numeracy and wealth. Additionally, we showed that intelligence (measured with the CRT) was not a substitute for numeracy. This lends a basic level of support to the idea that numeracy robustly and independently explains differences in wealth. However, the correlation between numeracy and wealth may be due to a correlation between numeracy and other factors, so far unexamined. We next studied whether the positive effects of numeracy may be due to spurious correlations between numeracy and unexamined preferences, constraints or beliefs. We started with the baseline model estimated above (Table 2, column B) and introduced a third variable that may account for this observed correlation. If these third factors were important sources of the observed correlation between numeracy and wealth, then adding them in the regression should have a substantial effect on the estimated numeracy coefficients. Results are presented in Table 3.

Risk preferences. We began by investigating whether the correlation between numeracy and wealth was spurious, being a joint effect caused by the variation in risk preferences. In column A of Table 3, we repeated the baseline specification reported in Column B of Table 2. In column B of Table 3, we added the control for risk preferences. To preserve sample size, we also included a variable to indicate whether the respondent completed the question about risk preferences (45.9% of the respondents did). If not, we set their score to the sample mean. The point estimate on this measure indicates that risk preference was negatively associated with wealth but the coefficient was not statistically significant (b = -0.007, SE = 0.015, t = -0.445, p = .656). Moreover, the inclusion of a measure of risk preferences leaves the estimated coefficient on numeracy unchanged. We thus find no evidence that this measure of risk preferences explains the relationship between numeracy and wealth. Numeracy has an effect on wealth that it is not explained by individual’s attitudes toward risk.

Table 3. The robustness of the relation between numeracy and wealth to the inclusion of controls in a series of regression analyses.

	A	**B**	**C**	**D**	**E**	**1F**	**2F**	**G**
Numeracy Scores	0.052**	0.053**	0.051**	0.051**	0.051**	0.056**	0.056**	0.055**
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Risk preferences		-0.007						-0.006
		(0.015)						(0.015)
M-Risk preferences		-0.071						-0.066
		(0.047)						(0.048)
Sufficient income			0.073					0.025
			(0.103)					(0.108)
M-Sufficient income			0.145					0.283
			(0.208)					(0.238)
Financial knowledge				0.053*				0.066**
				(0.021)				(0.022)
M-Fin. knowledge				0.012				0.107
				(0.105)				(0.122)
Need for cognition					0.011			-0.002
					(0.028)			(0.029)
M-Need for cog.					-0.185			-0.180
					(0.217)			(0.238)
Financial advisor							0.137*	0.146*
							(0.056)	(0.056)
Female	0.001	-0.006	0.001	0.011	0.002	-0.004	-0.007	0.004
	(0.054)	(0.054)	(0.054)	(0.054)	(0.054)	(0.056)	(0.056)	(0.056)
Age	0.015**	0.015**	0.015**	0.015**	0.015**	0.016**	0.017**	0.017**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Partnered	0.212**	0.210**	0.200**	0.218**	0.211**	0.197**	0.194**	0.186**
	(0.056)	(0.056)	(0.058)	(0.056)	(0.056)	(0.057)	(0.057)	(0.059)
# Children	-0.026	-0.027	-0.026	-0.029	-0.027	-0.021	-0.022	-0.025
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.028)	(0.028)	(0.028)
High Education	0.217**	0.219**	0.213**	0.218**	0.215**	0.211**	0.211**	0.215**
	(0.054)	(0.054)	(0.054)	(0.054)	(0.056)	(0.057)	(0.057)	(0.059)
Log Income	0.658**	0.656**	0.647**	0.631**	0.655**	0.652**	0.633**	0.589**
	(0.110)	(0.110)	(0.111)	(0.110)	(0.110)	(0.113)	(0.113)	(0.115)
Occupation								
Paid work	0.016	0.015	0.016	0.021	0.014	0.023	0.010	0.023
	(0.069)	(0.069)	(0.069)	(0.069)	(0.069)	(0.072)	(0.072)	(0.072)
Retired	-0.020	-0.017	-0.018	-0.011	-0.020	-0.037	-0.045	-0.028
	(0.078)	(0.078)	(0.078)	(0.078)	(0.078)	(0.080)	(0.080)	(0.080)
Constant	0.348	0.418	0.015	0.177	0.496	0.313	0.326	-0.055
	(0.441)	(0.446)	(0.553)	(0.454)	(0.503)	(0.453)	(0.452)	(0.644)
Adj. R-Square	0.218	0.218	0.217	0.221	0.217	0.223	0.227	0.232
# of obs	1019	1019	1019	1019	1019	954	954	954

Note. Entries are regression coefficients. Standard errors in parentheses. *$p < .05$, **$p < .01$. Omitted categories: male, not having a partner, low education (primary and lower secondary education), and other occupations. M-Risk preferences, M-Future income, M-Financial knowledge and M-Need for cognition function as missing-indicators coded 1 if the score was available for the respondent, 0 otherwise.

Beliefs about minimum sufficient income. Standard lifecycle models predict that beliefs about future income may affect household wealth levels (Salm, 2006; Carroll, 1994; for an example of savings and expectations see Lindqvist, 1981). The LISS panel collects limited information about respondents' beliefs, but the survey does ask questions about the amount of income respondents think would be necessary to maintain their lifestyle. We can therefore use these data to evaluate the extent to which the correlation between numeracy and wealth is attributable to a correlation between numeracy and some beliefs about income that influence wealth. In Column C we report the estimates after adding the control for beliefs about minimum income. To preserve sample size, we also included a variable to indicate whether the respondent completed the question assessing the beliefs about income (98.7% of the respondents did). If not, we set their score to the sample mean. The coefficient on beliefs about income was positive, suggesting that a higher expectation of the minimum income necessary to live is associated with higher wealth, however was not statistically significant ($b = 0.073$, $SE = 0.103$, $t = 0.704$, $p = .482$). The estimated coefficient on numeracy decreased very slightly (by 0.001). We find no evidence that a relationship between numeracy and unobserved beliefs about income drives the correlation between numeracy and wealth.

Financial Knowledge. The purpose of financial education is to acquire the knowledge and skills necessary to manage financial resources effectively (Lusardi & Mitchell, 2007). It seems likely that the understanding of financial matters and numeracy would draw on the same skills of analysis. Hence, numeracy might be a proxy measure for financial knowledge. In column D we report the estimates after we added the control for financial knowledge. Again, to preserve sample size, we included a variable to indicate whether the respondent completed the questions about financial knowledge (94.7% completed). Comparing the estimates from this model specification with the baseline model, we see that adding participants' financial understanding decreased the estimated coefficient on numeracy only modestly (by 0.001). In this way, we find little evidence that people's perception of their efficacy to deal with financial knowledge is driving the correlation between numeracy and wealth. Financial knowledge has an effect on wealth that is statistically significant and economically relevant ($b = 0.053$, $SE = 0.021$, $t = 2.501$, $p = .013$) but that is independent of the effect of numeracy. Numeracy is correlated with wealth independent of the individual's perception of his or her financial knowledge.

Need for cognition. It is possible that wealth accumulation requires not only having the skills to understand the different financial alternatives but also the motivation to engage in an active search and understanding, which is assessed by NFC. If this is the case, numeracy will be a necessary but not sufficient condition for wealth accumulation. For example, it is possible that a person high in numeracy but low in need for cognition would not necessarily ask questions about interest rates (numerical information), and might end up accepting a credit with a very high interest rate. If the effect of numeracy depends on people's NFC, adding this factor to the regression should reduce the observed effect of numeracy.

In column E we added the NFC measure to the baseline specification. To preserve sample size, we included a variable to indicate whether the respondent completed the NFC questions (98.8% completed). If not, we set their score to the sample mean. This measure, itself, had little power to predict wealth levels and including it has virtually no effect on the coefficient on numeracy (decreased by 0.001). Thus, we find no evidence that a relationship between numeracy and need for cognition qualifies the correlation between numeracy and wealth.

Financial advisor. Some people consult an expert advisor before making financial decisions. Presumably, financial advisors have more information and more experience than a lay person and therefore their clients should obtain better financial outcomes. We next studied whether the positive correlation between numeracy and wealth could be explained by people high in numeracy seeking for more financial advice than people low in numeracy. This would mean that numeracy is correlated with the probability of seeking financial advice and having financial advice is correlated with accumulating more wealth. If this is the case, the observed correlation between numeracy and wealth should be economically irrelevant or statistically non-significant if we controlled for receiving financial advice when making important decisions. In Table 3, column 1F and column 2F, we report the estimates of this analysis.

In column 1F we repeated the baseline specification restricting attention to the 954 (93.6%) panel members who report whether or not they have looked for financial advice (Participants are asked to answer yes or no to the question “In deciding what financial product to purchase, I would let myself be influenced by an independent financial adviser”). In this smaller sample, the point estimate on numeracy remained economically relevant and statistically different from zero ($b = 0.056$, $SE = 0.011$, $t = 5.009$, $p < .001$). In column 2F, we added controls for having financial advice, which leaves the estimated coefficient on numeracy unchanged. We interpret this to indicate that the correlation between numeracy and wealth cannot be attributed to people with high numeracy obtaining more financial advice than people with low numeracy.

Finally, in column G, we added all control variables together. The point estimate on numeracy remained economically relevant and statistically different from zero ($b = 0.055$, $SE = 0.011$, $t = 4.841$, $p < .001$), and decreased very slightly (by 0.001) as compared to the base model in column 1F. We thus find no evidence that measures of risk preferences, beliefs about future income, financial knowledge, need for cognition or seeking financial advice explained the relationship between numeracy and wealth.

Evaluating the effect of numeracy on wealth accumulation over time

We found an economically relevant and statistically significant correlation between numeracy and wealth. We demonstrated that this correlation is robust to the inclusion of controls for risk preferences, beliefs about future income, financial knowledge, need for cognition or seeking financial advice, and that general measures of cognitive ability were not substitutes for numeracy. We now turn to explore whether numeracy is related to the wealth accumulation trajectories that people follow over time. To examine individual changes in wealth, we used the latent growth-curve methodology. The analysis was carried out in two steps. First, we modeled the trajectory of each individual using two parameters: a person-specific intercept (the initial wealth status) and a person-specific slope (rate of change in wealth), and tested whether these parameters varied between individuals. Second, we tested whether numeracy has a significant effect on the rate of change. We used standard statistical methods that have been developed for estimating individual growth curve parameters using multilevel model of change, and followed the notation and procedure proposed by Singer and Willett (2003). We first describe the models and then present the results.

Growth Model A: unconditional growth model.

Growth Model A models wealth only as a function of initial wealth and rate of change. The basic statistical model can be represented as follows.

$$Wealth_{ij} = \gamma_{00} + \gamma_{10} Rate_{ij} + (\varepsilon_{ij} + \zeta_{0i} + \zeta_{1i} Rate_{ij}) \quad (2)$$

Where we assume that $\varepsilon_{ij} \sim N\,(0, \sigma_{\varepsilon}^2)$ and $\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_0^2 & \sigma_{01} \\ \sigma_{10} & \sigma_1^2 \end{bmatrix}\right)$

In equation 2, Wealth_{ij} refers to the wealth (log-transformed) of an individual *i* at time *j*. γ_{00} is the intercept, which is defined as an individual's wealth when time equals zero (year 2007) or the individual's initial status. γ_{10} is the rate of change in wealth for individual *i* with increasing time. The residuals ζ_{0i} and ζ_{1i} represent the portion of initial status and rate of change that remains unexplained. ε_{ij} represents variations in estimating growth within individuals.

Growth Model B: adding the between-subjects predictors.

In Growth Model B we add a number of predictors: age, living with a partner (coded 1=yes, 0=no), achieved higher education (coded 1=yes, 0=no), net annual income (log-transformed), female (coded 1=female, 0=male), numeracy and the cross level interaction between numeracy and the growth rate. This model can be formulated as follows.

$$Wealth_{ij} = \gamma_{00} + \gamma_{01}Numeracy_i + \gamma_{02}Age_{ij} + \gamma_{03}Female_i + \gamma_{04}Partnered_{ij} + \gamma_{05}HighEducation_{ij} + \gamma_{06}LogIncome_{ij} + \gamma_{10}Rate_{ij} + \gamma_{11}Numeracy_i * Rate_{ij} + \left(\varepsilon_{ij} + \zeta_{0i} + \zeta_{1i}Rate_{ij}\right) \quad (3)$$

Where we assume that $\varepsilon_{ij} \sim N\,(0, \sigma_\varepsilon^2)$ and $\begin{bmatrix}\zeta_{0i}\\ \zeta_{1i}\end{bmatrix} \sim N\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}\sigma_0^2 & \sigma_{01}\\ \sigma_{10} & \sigma_1^2\end{bmatrix}\right)$

Results of fitting the multilevel models for change to data.

We started our analysis by examining whether a change took place in respondents' wealth over time. This first analysis focuses on determining whether there is statistically significant variation in individuals' initial wealth status (wealth in 2007) or in the rate of change in wealth to justify further investigation. Therefore, we concentrate the attention on examining the variance components or random effects of Growth Model A represented in equation 2. The lower part of Table 4 presents these results. The random effects from both the intercept (σ_0^2 = 0.646, p < .001) and linear growth rate (σ_1^2 = 0.032, p < .001) were significantly different from zero, indicating that there are substantial individual differences with respect to both the initial level and rate of change of wealth over this 5-year period. This result gave us confidence to continue with further investigation.

Table 4. Multilevel models examining the relationship between numeracy and the change of wealth over a 5-year period.

			Growth Model A	**Growth Model B**	**Low Numeracy**	**High Numeracy**
Fixed effects						
Composite model	Intercept (initial status)	γ_{00}	4.064** (0.024)	1.466** (0.277)	1.687** (0.260)	1.869** (0.256)
	Rate (rate of change)	γ_{10}	0.033** (0.011)	-0.135** (0.049)	-0.055** (0.021)	0.012 (0.015)
	Numeracy	γ_{01}		0.038** (0.010)	0.038** (0.010)	0.038** (0.010)
	Female	γ_{02}		0.066 (0.041)	0.066 (0.041)	0.066 (0.041)
	Age	γ_{03}		0.015** (0.001)	0.015** (0.001)	0.015** (0.001)
	Partnered	γ_{04}		-0.165** (0.039)	-0.165** (0.039)	-0.165** (0.039)
	High Education	γ_{05}		-0.235** (0.040)	-0.235** (0.040)	-0.235** (0.040)
	Log Income	γ_{06}		0.408** (0.062)	0.408** (0.062)	0.408** (0.062)
	Numeracy by Rate	γ_{11}		0.014** (0.005)	0.014** (0.005)	0.014** (0.005)
Random effects						
Level-1	Within-person	σ_{ε}^2	0.125** (0.008)	0.122** (0.008)	0.122** (0.008)	0.122** (0.008)
Level-2	In initial status	σ_0^2	0.646** (0.034)	0.441** (0.029)	0.441** (0.029)	0.441** (0.029)
	In rate of change	σ_1^2	0.032** (0.008)	0.033** (0.009)	0.033** (0.009)	0.033** (0.009)
	Covariance	σ_{01}	-0.023 (0.013)	-0.021 (0.013)	-0.022 (0.013)	-0.022 (0.013)

Note. Entries are regression coefficients. Standard errors in parentheses. **p* < .05, ***p* < .01. Omitted categories: male, not having a partner, low education (primary and lower secondary education), and other occupations. Low numeracy: 1 SD below the mean, High numeracy: 1 SD above the mean. Model A: SPSS procedure MIXED models, REML. Model B: SPSS procedure MIXED models, ML.

We added a set of predictors to explain the observed differences in respondents' initial status and growth trajectories; we are principally interested in the effect of numeracy on the growth rate. Growth Model B of table 4 presents the estimates of the enriched model described by equation 3. The interaction between numeracy and the rate of change was statically significant (γ_{11} = 0.014, $p < .001$), indicating that the rate of change vary as a function of numeracy. To understand the nature of this relation, we calculated the simple slopes between wealth and rate of change at high and low values of numeracy (defined as plus and minus one standard deviation around the mean of numeracy). Results from these analysis revealed that, for this time period, wealth tends to decrease over time for individuals with low numeracy (1 SD below the mean; γ_{10} = -0.055, $p < .001$) but stays constant for individuals with high numeracy (1 SD above the mean; γ_{10} = 0.012, $p = .427$). Results are presented in the last two columns of Table 4. Growth Model B is the most parsimonious model of a sequence of exploratory models that were fitted to the data; parameter estimates, their associated tests and model fit statistics are presented in Appendix D.

Discussion

This article contributes evidence relevant for several important questions regarding the relationship between numeracy and wealth. Using data from a large representative sample of the Dutch population, we find an economically significant correlation between numeracy and wealth, even after the inclusion of controls for differences in preferences, constraints, and beliefs. Including these factors in the regression analysis only slightly reduced the observed correlation (maximum reduction in the point estimate was of 0.002 going from 0.052 to 0.050). In addition, we present tentative evidence that cognitive ability is not a substitute for numeracy for the purpose of explaining wealth. Numeracy explains differences in wealth that cannot be explained by differences in participants’ intelligence. Finally, we demonstrate that numeracy is a key determinant of the wealth accumulation trajectories that people follow over time. Over a 5-year period, while participants with low numeracy tend to decumulate wealth, participants with high numeracy tend to maintain a constant level of wealth.

These findings extend previous studies in different ways. First, they demonstrate that the effect of numeracy on wealth is not sensitive to the inclusion of controls for risk preferences, beliefs about future income, financial knowledge, need for cognition or seeking financial advice. Although previous studies documented the existence of this correlation, these were limited due to an identification problem. It was unclear whether numeracy was directly correlated with wealth or whether numeracy was correlated with a third factor, so far unobserved, that was correlated with financial outcomes. Whereas it is not feasible to control for all possible factors affecting wealth, and that other unobserved variables are missing in our analysis, we considered factors that have been recognized as strong determinants in the wealth literature. We found clear indications that differences in individuals' numerical abilities, rather than more standard sources of heterogeneity, explain important variation in wealth.

Second, we estimate the economic value of the correlation. Numeracy is ultimately of importance to economics to the extent that it could meaningfully impact economic outcomes. Our estimates suggest that a one-point increase in the numeracy score of the respondent is associated with 5 percent more wealth on average. Relative to other wealth determinants this effect is not trivial. For example, in standard deviation terms, the effect of numeracy (Beta = 0.15) is of similar magnitude as the effect of income (Beta = 0.22) or the effect of having a university degree (Beta = 0.13). Overall, we think this result highlights the economic importance of the relationship between numeracy and wealth.

Finally, we reveal that the relationship between numeracy and wealth is robust for both younger and older adults. Previous studies only looked at populations closer to retirement and it was unknown whether similar effects would be observed in younger populations. Older and younger adults face different consumption and saving incentives. Younger adults generally discount the importance of saving with the idea that they will have more opportunities in the future. However, we found that also in this population, participants with higher numeracy on average have more wealth -they save more- than participants with low numeracy.

Final remarks and conclusion

Numeracy has been shown to be significantly related with financial decisions and financial outcomes. However, the causal mechanisms at work are still under investigation. The direct path between numeracy and wealth may arise through a variety of mechanisms. First, numeracy might capture aspects of decision-making ability that are very well correlated with the economic choices that lead to wealth accumulation. People with high numeracy might for example be more consistent or prudent on their financial decisions. Both of these factors have shown to be related with wealth accumulation (Noussair et al., 2013; Choi et al., 2014). Second, it is possible that people with high numeracy are more successful in their education, and therefore stay at school longer and achieve more educational qualifications, which can give access to higher-paying occupations. Third, people with high numeracy might auto select themselves into employments were they acquire superior financial knowledge. Financial expertise can help one to make more optimal financial decisions, resulting in better financial outcomes. However, these interpretations are tentative until future research allows a more concrete investigation into some of the causal mechanisms at work.

In summary, we provide empirical evidence on the economic significance of numeracy on wealth. We revealed that the correlation between numeracy and wealth is statistically significant and economically relevant even after controlling for differences in risk preferences, beliefs about future income, financial knowledge, need for cognition or seeking financial advice. Additionally, we demonstrate that numeracy is a key determinant of the wealth accumulation (or decumulation) trajectory that people follow over a 5-year period.

Appendix A

LISS panel data: studies and variables used

Study No	Name of the study	Variables
1	Background variables (December 2007, December 2009, and December 2011)	Gender, age, education, work status, income, and education
9	Assets: LISS Core Study (wave 1, wave 2, and wave 3)	Total balance in checking and saving accounts, stocks, bonds and other financial assets, real estate, mortgages, and loans
33	Disease prevention	Numeracy scale
49	Commercial opportunities	Risk attitude (financial)
81	Testing mechanisms for identifying true risk preferences	Cognitive Reflection Test
52	Are effective emotion regulation strategies associated with financial capability?	Financial advisor
68	Financial literacy	Financial knowledge
10	Income: LISS Core Study (wave 1)	Future income
7	Personality: LISS Core Study (wave 1)	Need for cognition

All LISS data sets used in this study are freely available for academic researchers, and may be obtained from the LISS data archive: http://www.lissdata.nl/dataarchive/. The first author can provide information about the elaborations on the data sets.

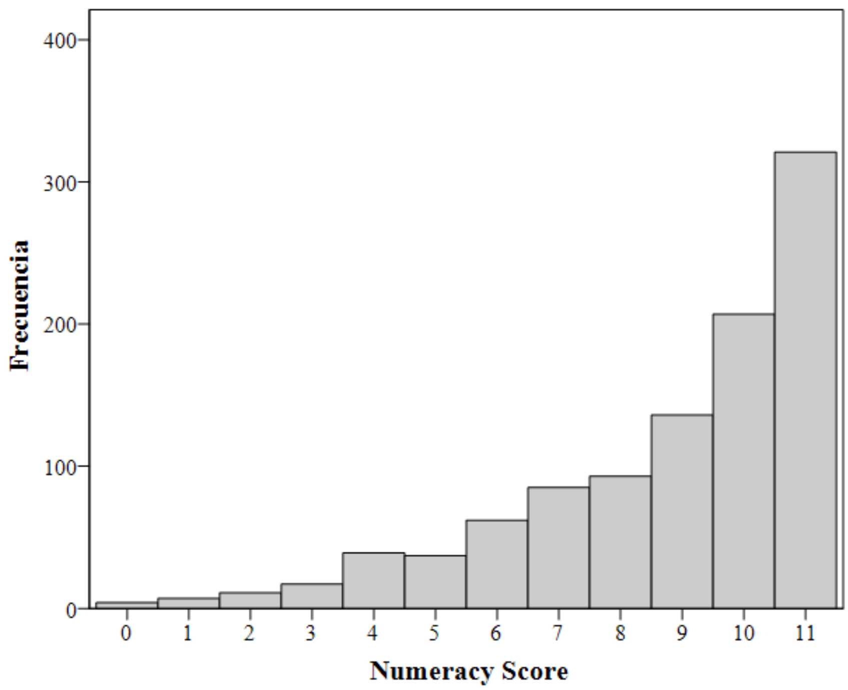
Appendix B

Distribution of numeracy scores in the sample

Table B.1. Percentage of correct answers for each item of the numeracy scale (*N*=1019)

	Question	Correct answer	% Correct
1	Imagine that we roll a fair, six-sided die 1,000 times. Out of 1,000 rolls, how many times do you think the die would come up even (2, 4, or 6)? In ... out of 1000 times.	500	70.2
2	In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize are 1%. What is your best guess about how many people would win a $10.00 prize if 1,000 people each buy a single ticket from BIG BUCKS?	10	82.2
3	In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets of ACME PUBLISHING SWEEPSTAKES win a car? ...% of the tickets	0.1	61.7
4	Which of the following numbers represents the biggest risk of getting a disease? (1:1 in 100, 2:1 in 1000, 3:1 in 10)	3	79.5
5	Which of the following represents the biggest risk of getting a disease? (1:1%, 2:10%, 3:5%)	2	82.6
6	If Person A's risk of getting a disease is 1% in ten years, and Person B's risk is double that of A's, what is B's risk?	2%	87.2
7	If Person A's chance of getting a disease is 1 in 100 in ten years, and Person B's risk is double that of A, what is B's risk?	2%	84.7
8	If the chance of getting a disease is 10%, how many people would be expected to get the disease? Out of 100...people will get the disease	10	93
9	If the chance of getting a disease is 10%, how many people would be expected to get the disease? Out of 1000...people will get the disease	100	92.2
10	If the chance of getting a disease is 20 out of 100, this would be the same as having a ... % chance of getting the disease.	20	78.3
11	The chance of getting a viral infection is .0005. Out of 10,000 people, about how many of them are expected to get infected? ... out of 10,000 people	5	67.2

Figure B.1. Distribution of numeracy scores in the sample



Appendix C

Robustness checks of the baseline model

In order to test the robustness of results to changes in the functional form of wealth and numeracy, we estimated the baseline model (defined in the main article in Column B Table 2) with different model specifications. In all specifications we find evidence that numeracy is positively and statistically significantly correlated with wealth, while controlling for other demographic, socio-economic and individual characteristics. Table C.1 below presents the results of these estimations.

First, to reduce the importance of extreme outliers, we drop twenty respondents that represent the top and bottom half of one percent of the wealth distribution. Results are presented in column A. In column B we restrict our sample to individuals who report being the main financial decision maker. Next, to evaluate the sensitivity of the results to the numeracy continuous specification, in Column C we estimate the regression in levels of numeracy. The sample was divided into two groups based on a median split of the numeracy scores. In addition, two models examine the effect of changes in the specification of the wealth function. In column D we restrict the function of wealth to financial wealth and thus real estate investments and mortgages liabilities were not included. Financial wealth is a more liquid concept than total wealth, since an individual’s home is difficult to convert into cash in the short term. It reflects the resources that may be immediately available for consumption or various forms of investments. To evaluate the sensitivity of the results to the log specification, in Column E we estimate the regression in levels of wealth. The sample was divided into three quartiles based on the raw scores of wealth. Participants that score in the bottom 25 percent were placed in the low category, those that score in the top 25 percent were classified in the high category and those that score in the middle 50 percent correspond to the moderate category. Order logistic regression was performed to take into account the ordinal data structure.

Table C.1. Baseline model estimated with different specifications for numeracy or wealth, interaction terms and subsamples

	A	**B**	**C**	**D**	**E**
Numeracy Scores	0.046**	0.052**		0.050**	0.133**
	(0.010)	(0.013)		(0.011)	(0.029)
High Numeracy			0.240**		
			(0.054)		
Female	-0.010	0.055	0.001	0.023	-0.014
	(0.051)	(0.065)	(0.054)	(0.054)	(0.142)
Age	0.015**	0.015**	0.015**	0.013**	0.035**
	(0.002)	(0.002)	(0.022)	(0.002)	(0.006)
Partnered	0.165**	0.302**	0.225**	0.188**	0.484**
	(0.052)	(0.062)	(0.055)	(0.055)	(0.146)
# Children	0.008	-0.020	-0.027	-0.041	-0.040
	(0.024)	(0.032)	(0.026)	(0.026)	(0.068)
High Education	0.212**	0.276**	0.230**	0.188**	0.607**
	(0.051)	(0.063)	(0.054)	(0.054)	(0.143)
Log Income	0.566**	0.636**	0.678**	0.615**	1.508**
	(0.105)	(0.140)	(0.110)	(0.109)	(0.309)
Occupation					
Paid work	0.016	-0.005	0.006	0.011	-0.177
	(0.066)	(0.085)	(0.069)	(0.069)	(0.182)
Retired	-0.035	-0.059	-0.029	0.028	-0.207
	(0.074)	(0.092)	(0.078)	(0.078)	(0.205)
Constant	0.770	0.770	0.138	0.561	
	(0.422)	(0.422)	(0.441)	(0.438)	
Adjusted R-Square	0.201	0.217	0.215	0.200	NA
# of obs	999	713	1019	1005	1019
Description of the model	Extreme outliers excluded	Only main financial decision maker	Numeracy scores: median split	Dependent variable: financial wealth	Dependent variable: quartiles of wealth

Note. Entries in Column A, B, C and D are regression coefficients. Entries in Column E are ordered log-odds regression coefficients. Standard errors in parentheses. *p < .05, **p < .01.

Appendix D

Sequence of exploratory multilevel models examining the relationship between numeracy and the change of wealth

Singer and Willett (2003) recommend fitting a systematic sequence of models in which each model extends or reduces a prior model in some sensible way. Inspection and comparison of its elements are used to determine the most parsimonious model that can address the research question. Two models were fitted in addition to Growth-Model B reported in the main article. Below we compare these two models against each other and against Growth-Model B. Estimated parameters, model fit statistics and deviance tests are presented below in Table D.1. Our strategy was to first fit an extended model where all predictors were included and test whether reducing the model by excluding non-significant predictors significantly worsens the fit of the model. We use the deviance test to examine whether the reduced model fit is significantly “worse” than the more complex model.

Growth-Model D includes numeracy, age, living with a partner (coded 1=yes, 0=no), achieved higher education (coded 1=yes, 0=no), net annual income (log-transformed), and female (coded 1=female, 0=male) as predictors of both initial status and change. Growth-Model C includes the same predictors of initial status but only numeracy and age as predictors for change. Growth-Model B includes the same predictors of initial status but only numeracy as a predictor for change; it is the same model reported in the main article (Table 4). Model comparison showed that the more parsimonious Growth-Model B does not fit significantly worse than more complex model (Growth-Model D and Growth-Model C).

Table D.1. Comparison of fitting alternative multilevel models for the change in wealth

		Growth-Model D	Growth-Model C	Growth-Model B
Fixed effects				
Composite model	Intercept (initial status)	1.636** (0.317)	1.398** (0.279)	1.466** (0.277)
	Rate (rate of change)	-0.349 (0.203)	-0.034 (0.070)	-0.135** (0.049)
	Numeracy	0.040** (0.011)	0.041** (0.010)	0.038** (0.010)
	Female	0.104* (0.049)	0.068 (0.041)	0.066 (0.041)
	Age	0.017** (0.002)	0.016** (0.002)	0.015** (0.001)
	Partnered	-0.128** (0.049)	-0.165** (0.039)	-0.165** (0.039)
	High Education	-0.251** (0.048)	-0.231** (0.040)	-0.235** (0.040)
	Log Income	0.335** (0.072)	0.398** (0.062)	0.408** (0.062)
	Numeracy by Rate	0.012* (0.006)	0.012* (0.005)	0.014** (0.005)
	Female by Rate	-0.039 (0.026)		
	Age by Rate	-0.002* (0.001)	-0.002* (0.001)	
	Partnered by Rate	-0.037 (0.028)		
	High Education by Rate	0.021 (0.027)		
	Log Income by Rate	0.083* (0.047)		
Random effects				
Level-1	Within-person	0.121** (0.008)	0.121** (0.008)	0.122** (0.008)
Level-2	In initial status	0.439** (0.029)	0.439** (0.029)	0.441** (0.029)
	In rate of change	0.033** (0.009)	0.033** (0.009)	0.033** (0.009)
	Covariance	-0.021 (0.013)	-0.021 (0.013)	-0.022 (0.013)
Goodness-of-fit				
Deviance (*df*)		5142.258 (18)	5147.333 (14)	5151.226 (13)
Comparison model: ΔDeviance (*df*)			D: 5.07(*4*)	C: 3.89*(*1*)

Note. Entries are regression coefficients. Standard errors in parentheses. *p < .05, **p < .01. Omitted categories: male, not having a partner, low education (primary and lower secondary education), and other occupations. Model A: SPSS procedure MIXED models, REML. Model B: SPSS procedure MIXED models, ML.

CHAPTER 3

Numeracy and wealth: A study from the Quechua population of Peru

This chapter is based on: Estrada-Mejia, C., Peters, E., Zeelenberg, M., De Vries, M., Baker, D.P., & Dieckmann, N. (2015). Numeracy and wealth: A study from the Quechua population of Peru. *Working paper*.

Abstract

Studies conducted in North America and Western Europe have documented a positive correlation between numeracy and wealth accumulation. However, little research has examined whether this relation extends to simpler financial environments where mathematical abilities are presumably less imperative for wealth accumulation. In this paper, we investigate whether numeracy also has a positive influence on wealth in an agrarian population from the Highlands of Peru, a simpler financial environment where wealth is acquired through monetary exchanges, barter and reciprocal labor. Wealth was measured using data on asset ownership (e.g., owning a bicycle or radio) and housing characteristics (e.g., type of toilet facilities). Result from regression analysis and SEM models revealed that the positive correlation between numeracy and wealth was substantial and statistically significant even after accounting for differences in fluid intelligence and crystallized intelligence, potential demographic confounders, and the direct effects of education. These findings contribute to the growing research in numeracy by documenting the positive effect of numeracy on wealth in a population with a less sophisticated financial market.

The expanding field of research on numeracy has documented the relationship between numeracy and a set of behaviors related to saving, portfolio choice, and wealth. For example, individuals with greater numeracy are more likely to participate in financial markets and to invest in stocks (Almenber & Widmark, 2011; Christelis, Jappelli, & Padua, 2010), more likely to plan for retirement (Lusardi & Mitchell, 2007, 2011), more knowledgeable when choosing a mortgage (Disney & Gathergood, 2011), less likely to default on loans (Gerardi, Goette, & Meier, 2010), and more likely to avoid predatory loans, pay loans on time, and pay credit cards in full (Sinayev & Peters, 2015). Furthermore, research has shown that numeracy is positively correlated with wealth, after controlling for a variety of cognitive abilities and socioeconomic factors (Banks, O'Dea, & Oldfield, 2011; Banks & Oldfield, 2007; Estrada-Mejia, de Vries, & Zeelenberg, in preparation; Lusardi, 2012; Smith, McArdle, & Willis, 2010). Although very informative, previous studies were all conducted with North American and Western European populations, where the financial environment is highly complex and changing rapidly. In this paper, we test whether numeracy is also associated with wealth in an agrarian population, where financial transactions are carried out not only in cash but also by barter, reciprocity, and payment in kind, and therefore are presumable less mathematically demanding.

Populations in developed countries face a relatively complex financial world, characterized by increasingly sophisticated financial products and services, and growing opportunities to personally interact with financial markets. Individuals in these contexts often have to deal with numerical information in the form of interest rates, exchange rates, risk incidence, base rates, and probabilities. Moreover, to make informed decisions in this complex financial context, it is essential for individuals to understand and use this numerical information. Objective numeracy refers to the ability to understand and use numeric concepts, to perform basic mathematical operations, compare magnitudes, and comprehend ratio concepts such as fractions, proportions, percentages and probabilities (Lipkus, Samsa, & Rimer, 2001; Peters, 2012; Nelson, Reyna, Fagerlin, Lipkus, & Peters, 2008). Thus, it is not surprising in this context that individuals with higher objective numeracy (called numeracy from hereon) make better financial decisions and accumulate higher wealth.

On the contrary, communities in the so-called underdeveloped countries face a substantially different financial context, with very limited access to financial alternatives and very limited contact with financial markets (World Bank, 2015). Therefore, one might wonder whether numeracy is also important in these contexts where the difficulty of the financial transactions is relatively low. Specifically, in this study we investigate the question of whether numeracy is uniquely associated with wealth in an agrarian population: the Quechua people from the highland of Peru. This population can be described as having a self-sufficient economy where financial transactions are carried out, not only in cash, but also by barter, reciprocity, and payment in kind (Mayer, 2002; Figueroa, 2008).

It could be argued that, since the complexity of the financial operations is relatively low and the economic exchanges are not monetary but based on relationships (e.g., goods acquired through barter or reciprocal exchanges), numeracy should be a weaker predictor than other factors, such as verbal fluency. Alternatively, it could be argued that numeracy still would have an effect on farmers' wealth through other channels such as influencing farmers' economic preferences, or influencing their reasoning and decision-making processes, in ways that favor (or detract from) wealth accumulation.

The question of whether the relationship between numeracy and wealth extends to simpler financial environments, where economic decisions are presumably less mathematically demanding, is important because it will further our understanding of the determinants of wealth in these less developed economies. In addition, it will inform us about the scope of the effects of numeracy. If numeracy is also related to wealth in this context, it may indicate that the effect of numeracy on financial behaviors goes beyond facilitating calculations and extends to how people reason (see, for example, Peters, Baker, Dieckmann, Leon, & Collins, 2010 for a similar argument in a health context). In the General Discussion we return to this proposition and address it in light of the results of our studies. Below, we describe the financial environments of these small, relatively isolated, agrarian Quechua-speaking communities in Peru's Andean highlands.

Financial environments in the Peruvian Andes and in developed countries

The highlands of Peru are mainly populated by small farming communities (Figueroa, 2008). Households get their family income mostly from the exchange of agricultural production, livestock production, and labor services. These goods or services are paid to them in different ways: food (e.g., potatoes, milk), non-food goods (e.g., handicrafts), other types of productive services (e.g., reciprocal labor exchanges), and money. Part of this income is consumed in the form of food, clothes, cleaning products, and education; and part is *saved* or *invested* by acquiring material assets in the form of household durables (e.g., fridge or stove), house construction, increasing the stock of animals, or buying fertilizers and pesticides (Figueroa, 2008; Mayer & Glave, 1999). They also take *loans* principally for emergencies, such as illnesses or burials. However, interest is normally not charged directly in cash, but mostly in services (Figueroa, 2008). For instance, the borrower agrees to help the lender to farm his plot with two days of work in a not very distant time period. Credit functions as an advance payment of future work. Credit for agricultural working capital (the cash available for day-to-day operations of the business) or other purposes is less common (Figueroa, 2008).

These communities have little or no access to traditional financial services such as bank accounts, bank loans, and investment opportunities. For instance, The Global Findex report (World Bank, 2015) documented that, during the year 2014, only 23% of the Peruvian population (aged 15 years or older and living in rural areas) had a savings account at a bank, credit union, or another financial institution (e.g., cooperative, microfinance institution); about 7% had saved money in a bank or other type of financial institution; only 10% had borrowed any money from a financial institution; and about 3% had used a credit card. Although modernization is slowly permeating these communities and new generations are more integrated to the modern financial markets, it has been argued that capitalist development has had little effect on their economic behavior (Figueroa, 2008; Mayer, 2002). We examine the possibility that numeracy nonetheless will be associated with wealth in the present study.

The present study

In an attempt to provide insight into the association and possible contribution of numeracy to wealth, we investigate this question in a convenience sample of an agrarian population in Peru. The Quechua population living in the highlands of Peru offered an ideal opportunity for carrying out the research. The data were collected in 2009 by a group of researchers studying the relationship between health behavior, education, numeracy, and intelligence. Although the study was designed to test a different research question, the characteristics of the population and the selection of the sample provided us with a unique opportunity to test for the relative effect of numeracy on wealth. Previous findings from the study have been reported by Dieckmann and colleagues (in press) and Baker and colleagues (2015).

Although the Quechuan adults who were included in the study have similar lifestyles, similar post-schooling work experience, and similar parental background, they vary considerably in their numeracy skills (see descriptive analyses in the Results section). Our primary question is whether numeracy has a unique effect on wealth, over and above the potential confounders of intelligence, schooling and social background.

Method

Sample. Participants were from the Ancash region of the Peruvian Andes. The sample was selected using a two-stage stratified sampling procedure. First, Peru's National Census 2007 was used to develop a list of all small agrarian communities within the Carhuaz district in the Ancash region. Fourteen communities were selected based on high levels of within-community variation in educational attainment and, conversely, high levels of homogeneity of occupational structure (approximately 50% of the populations in these areas were subsistence-level farmers or employed in the local agrarian economy). Second, a door-to-door survey was conducted to recruit subjects, stratified by education attainment. Only heads of households or their partners were included in the present study. We excluded 9 participants who did not complete the numeracy test. The final sample consisted of 225 adults. Descriptive statistics of the sample are presented in Table 1.

Table 1. Sample demographics (*N* = 225)

Characteristic	*N* (%)
Age Cohort	
30-39	70 (31.1)
40-49	81 (36.0)
50+	74 (32.8)
Gender	
Female	117 (52.0)
Male	108 (48.0)
Mother Tongue	
Spanish	67 (29.8)
Quechua	158 (70.2)
Residence	
Urban (Small town)	132 (58.7)
Rural	93 (41.3)
Married or cohabitating	178 (79.1)

Procedure. Materials were translated from English to Spanish and Quechua (participants' native language) and translated back into English. Interviews were conducted one-on-one, in Spanish or Quechua, in private homes or at village school buildings. The study instruments were completed in two three-hour sessions spread across two separate days. Half of the cognitive ability instruments were completed in each session (along with several unrelated tasks and questionnaires). Participants were compensated with household goods (e.g., sugar or pasta) and schools in participating villages were given educational materials.

Measures.

***Wealth*.** Wealth was assessed using participants' household durables and housing quality. Similar measures were adopted to assess wealth in similar populations (Peters et al., 2010; Sahn & Stifel, 2000, 2003; Filmer & Pritchett, 2001). The household durables consist of indicators of ownership of stereos, TVs, computers, stoves, refrigerators, bicycles, and communication devices (cell phone and/or landline). The housing quality includes indicator variables for source of drinking water (piped water relative to other sources), toilet facilities (flush toilet inside the house relative to no toilet or latrine inside the house), and household construction material (indicators for quality of floors). Hereafter, we will refer to both household durables and housing characteristics as participants' assets.

To construct a wealth index, a factor analysis was conducted on the 14 different assets. Three assets (car, motorcycle and radio) had factor loadings below the conventional level of 0.3, and therefore were excluded. A second factor analysis on the remaining 11 assets showed that only one component had an eigenvalue over Kaiser's criterion of 1. The scree plot also suggested retaining only one factor. Given the convergence of the scree plot and Kaiser's criterion, only one factor was retained in the final analysis. Lastly, total wealth scores were computed using a regression scoring method. Table 2 presents the factor loadings (only for the assets included in the final analysis) and the percentage of participants who owned each of the assets.

Table 2. Factor loadings and prevalence of assets included in the wealth index

Assets	Factor loading	Prevalence %
Housing quality		
Floor made of cement relative to made of earth	.718	34.6
Toilet facilities relative to no toilet inside the house	.569	68.7
Piped water relative to other sources of water	.344	86.6
Household durables		
Stove	.811	46.8
Fridge	.651	28.6
Computer	.622	18.2
TV	.661	62.3
Stereo	.628	28.6
Landline	.451	15.0
Cellphone	.436	65.5
Bike	.377	25.9

Note. Entries are factor loadings and percentage of participants who own the asset.

***Numeracy*.** Numeracy was assessed using three questions targeting probabilistic reasoning. Psychometric analyses using item response theory (IRT) methods revealed that only two items had acceptable discrimination and, therefore, only these two items were retained. More details of the IRT model are reported in Appendix A. The items retained read as follows:

1. Imagine you were going to buy a raffle ticket and you had three different raffles to choose from? In the first raffle, 1 out of every 100 people wins. In the second raffle, 1 out of every 1000 people wins. In the third raffle, 1 out of every 10 people wins. Which raffle would you rather play? a. 1 in 100; b. 1 in 1000; c. 1 in 10.

2. If the chance of winning a raffle is 10%, how many people would you expect to win out of 1000? __people.

The total resulting numeracy score was calculated using the difficulty and discrimination parameters estimated from the IRT and rescaled to have a minimum value of zero. Higher scores indicate higher levels of numeracy (*M* = 0.79, *SD* = 0.62, range from 0 to 1.63).

Education. Participants reported their educational attainment by indicating the last year of schooling completed (*M* = 7.33, *SD* = 4.89, range from 0 to 16). Twelve percent (12.4%) of the sample had no formal education.

Crystallized intelligence. Crystallized verbal abilities and long-term memory was assessed with the Peabody Picture of Vocabulary Test (PPVT; Dunn, Padilla, Lugo, & Dunn, 1986). For each item, the facilitator presents a page with four pictures and then speaks a word describing one of the pictures. The participant is asked to point or to say the number of the picture that corresponds to the word (*M* = 73.38, *SD* = 13.05, range from 11 to 89).

Fluid intelligence. Fluid intelligence was assessed with four different instruments. All four instruments are psychometrically validated and commonly employed in studies of cognitive ability. Scores for each independent measure were standardized and added together into a compound measure (*M standardized score* = -0.02, *SD* = 2.84, range from -6.54 to 9.81).

Verbal fluency. Verbal fluency was assessed with the COWAT (Controlled oral word association test; Loonstra, Tarlow, & Sellers, 2001), which requires participants to generate words within a category (e.g., animals) in a specified amount of time (60 seconds) (*M* = 16.46, *SD* = 4.82, range from 6 to 31).

Working memory. Working memory capacity was assessed with the backward digits task (Wechsler, 1981). In it, participants are presented with a series of numeric digits and are asked to repeat them back in reverse order (*M* = 3.42, *SD* = 2.05, range from 0 to 10).

Planning. The Delis-Kaplan Executive-Function System Tower test was used to measure participants' planning, strategy, working memory, and attention shifting abilities (Delis, Kaplan, & Kramer, 2001). Using a board with three vertical pegs and five colored disks varying in size from small to large, the participants were asked to move the disks from a predetermined starting position to a specified ending position, where better solutions involve the most direct and fewest moves (*M* = 3.61, *SD* = 1.92, range from 1 to 9).

Non-verbal reasoning. The Raven Colored Progressive Matrices test was used to assess nonverbal reasoning about complexity (Raven, Raven, & Court, 2000). In this task, the subject is presented with a series of pattern matrices (2x2, 3x3, or 4x4) and asked to identify the missing element that completes each pattern (*M* = 5.57, *SD* = 1.97, range from 0 to 9).

Control variables. Controls included gender, age, residence (small town, defined as 100 or more households clustered together, versus rural), marital status (living with a partner versus not), and mother tongue (Quechua versus Spanish). Table 3 shows the basic descriptive statistics for all measures.

Table 3. Descriptive statistics for all measures included in the analysis

Characteristic	Mean	SD	Min	Max	*N*
Wealth	0	0.93	-1.28	1.76	219
Numeracy IRT scores	0.79	0.62	0	1.63	224
Numeracy raw scores	0.97	0.76	0	2	224
Years of schooling	7.33	4.89	0	16	225
Fluid intelligence					
Verbal fluency	16.46	4.82	6	31	224
Working memory	3.42	2.05	0	10	225
Planning	3.61	1.92	1	9	224
Non-verbal reasoning	5.57	1.97	0	9	226
Fluid intelligence index	-0.02	2.84	-6.54	9.81	223
Crystallized intelligence	73.38	13.05	11	89	225

Analytic approach

First a two-parameter logistic IRT model was used to examine the psychometric properties of the numeracy scale. Details about this model are reported in Appendix A. Second, we examined correlations between wealth and each of the potential predictors. Next, we estimated a series of regression models to provide an initial test of the relationship between numeracy and wealth, controlling for several potential confounders. The baseline model used numeracy, fluid intelligence, and crystallized intelligence as predictors of wealth. The demographic model added gender, age, residence, marital status, and mother tongue to the baseline model. The full model added education to the demographic model. After, as an additional illustration of the effect of numeracy on wealth, we estimated the probability of holding each of the assets from the wealth index (i.e., house durables and housing characteristics) using a mixed-effects logistic regression model. Details of the mixed-effects model are presented in Appendix B. Finally, structural equation models (SEMs) were used to test the effect of educational attainment, numeracy and intelligence measures on wealth. Unlike a regression analysis, the SEM approach allows us to model latent constructs that explicitly account for measurement error (e.g., Fluid intelligence) and to include educational attainment as a simultaneous predictor of numeracy, fluid intelligence, crystallized intelligence, and wealth. SEMs were estimated using Stata 14.

Results

Descriptive analyses

Half of the participants were female (52%), 79.1% were married or cohabitating, with a mean age of 44.8 years (*SD* = 8.46, range = 30–60 years); 58.7% lived in a small town, and 70.2% spoke Quechua as their first language. Participants had completed, on average, an elementary school education (*M* = 7.33 years, *SD* = 4.89, *Range* = 0–16 years). Twelve percent (12.4%) had no formal schooling, 34.7% had completed all or some primary education (6th grade or less), 34.7% had completed some or all of high school, and 18.2% had more than a high school education. An inspection of the pairwise correlations showed that more years of formal education, greater numeracy, and greater fluid and crystallized intelligence were associated with higher wealth (see Table 4).

Table 4. Correlations between study variables

Variable	1	2	3	4	5	6	7	8	9
1. Wealth									
2. Numeracy	.47**								
3. Years of schooling	.65**	.51**							
4. Fluid intelligence	.46**	.51**	.61**						
5. Crystallized intelligence	.50**	.38**	.64**	.57**					
6. Age	.07	-.02	-.11	-.14*	-.03				
7. Gender	.01	.01	-.07	-.09	-.16*	-.06			
8. Mother tongue	-.42**	-.13*	-.27**	-.12	-.25**	-.02	.02		
9. Residence	-.63**	-.28**	-.43**	-.28**	-.33**	-.06	.01	.51**	
10. Married	.09	.06	.07	.15*	.13	-.18**	-.21**	.05	.12

Note. **p* < .05, ***p* < .01. Dichotomous variables were coded as follow. Gender (Male = 0, Female = 1), Mother Tongue (Spanish = 0, Quechua = 1), Residence (Small Town = 0, Rural = 1), Married or cohabitating (No = 0, Yes = 1).

Regression analyses

Table 5 shows the results of a set of regression analyses modeling wealth. Model 1 showed that higher scores on numeracy (b = 0.40, SD = 0.10, t = 4.10, p < .001) and other cognitive ability measures were significant predictors of greater wealth (b_{FI} = 0.05, SD = 0.02, t = 1.99, p = .048; b_{CI} = 0.02, SD = 0.01, t = 4.54, p < .001). In Model 2, six control variables were included. Living in a small town as opposed to a rural area, speaking Spanish as opposed to Quechua, and being married or cohabiting as opposed to being single were all associated with higher wealth after controlling for numeracy, fluid intelligence and crystallized intelligence. This model also revealed that numeracy (b = 0.27, SD = 0.08, t = 3.34, p = .001) and the other cognitive ability measures (b_{FI} = 0.05, SD = 0.02, t = 2.40, p =

.017; b_{CI} = 0.01, *SD* = 0.005, *t* = 2.55, *p* = .012) remained as significant predictors of wealth after controlling for these demographic controls. In Model 3, education (years of schooling) was included as a predictor. From the cognitive ability measures, only numeracy ($b_{numeracy}$ = 0.18, *SD* = 0.08, *t* = 2.26, *p* = .025; b_{FI} = 0.02, *SD* = 0.02, *t* = 0.86, *p* = .392; b_{CI} = 0.002, *SD* = 0.005, *t* = 0.55, *p* = .585) remained a significant predictor of wealth after controlling for education. One additional model including the interactions of the control variables and numeracy revealed no significant interactions (all *p* > .210).

Table 5. Linear regression analysis

	Model 1	**Model 2**	**Model 3**
Numeracy	0.40**	0.28**	0.18*
	(0.10)	(0.08)	(0.08)
Fluid intelligence	0.05**	0.05*	0.02
	(0.02)	(0.02)	(0.02)
Crystalized intelligence	0.02**	0.01*	0.002
	(0.01)	(0.005)	(0.005)
Age		0.01	0.01**
		(0.01)	(0.005)
Gender (Male = 0, Female = 1)		0.15	0.15
		(0.09)	(0.08)
Mother Tongue (Spanish = 0, Quechua = 1)		-0.26*	-0.24*
		(0.11)	(0.10)
Residence (Small Town = 0, Rural = 1)		-0.80**	-0.67**
		(0.11)	(0.10)
Married or cohabitating (No = 0, Yes = 1)		0.28*	0.30**
		(0.11)	(0.10)
Education			0.07**
			(0.01)
Constant	-2.07	-1.31	-1.29
R^2	.35	.56	.62
N	216	216	216

Note. Entries in table are unstandardized betas (SD); ***p* < .05, ***< .01. DV = Wealth.

As an additional illustration, the probability of holding each of the assets (house durables and housing characteristics) from the wealth index was estimated using a mixed-effects logistic regression model (see Table 6). Probabilities were estimated for a typical sample responder: a 44-year-old female, living in a rural area, married, whose mother tongue is Quechua, and with average scores for fluid intelligence and crystalized intelligence. With the exception of owning a bike, the probability of holding each of the assets increases as numeracy increases. For instance, whereas the probability of having a stove is 48% for a participant with lower numeracy (1 SD below the mean), it is 89% for a highly numerate participant (1 SD above the mean). Likewise, whereas the probability of having a toilet facility inside the house is 87% for participants with lower numeracy, it is 96% for participants with higher numeracy (Probabilities were estimated with the model reported in Appendix B).

Table 6. Predicted probability of holding household durables and housing quality indicators per numeracy level

Characteristics	**-1SD numeracy**	**Mean numeracy**	**+1SD numeracy**
Housing quality			
Floor made of cement vs. earth	33.8	53.4	72.1
Toilet facilities vs. no toilet	87.1	92.4	95.7
Piped water vs. other	97.2	98.1	98.8
Household durables			
Stove	48.5	73.0	88.6
Fridge	23.0	40.9	61.6
Computer	15.8	24.1	35.1
TV	81.9	88.6	93.0
Stereo	31.0	43.9	57.7
Landline	16.0	19.9	24.6
Cellphone	88.1	90.4	92.3
Bike	48.5	41.9	35.7

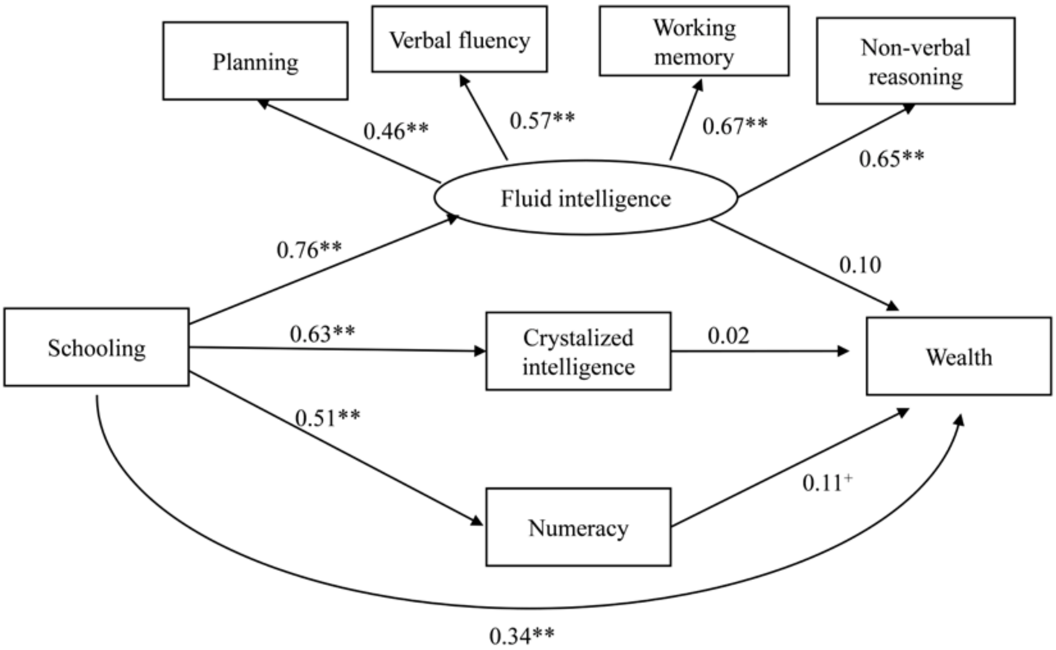
Note. Entries are estimated probabilities of holding the asset for a 44-years-old female, living in a rural area, married, whose mother tongue is Quechua, and with averages scores for fluid intelligence and crystalized intelligence.

Structural equation models (SEMs)

We then tested different models using an SEM framework that explored whether numeracy can be modeled independent of a general fluid intelligence latent variable. The first model included the four fluid intelligence factors and numeracy as indicators of a single latent cognitive ability factor. In a second model, we explored whether separating numeracy from the four fluid intelligence measures resulted in better overall fit. A comparison of the fit indexes revealed that the second model, which treated numeracy as an independent construct from fluid intelligence, fits better ($CFI_{Model2} = 1.000 > CFI_{Model1} = 0.987$; $TLI_{Model2} = 1.002 > TLI_{Model1} = 0.975$; $RMSEA_{Model2} = 0.000 < RMSEA_{Model1} = 0.047$). As a result, we modeled numeracy as a factor independent of fluid intelligence.

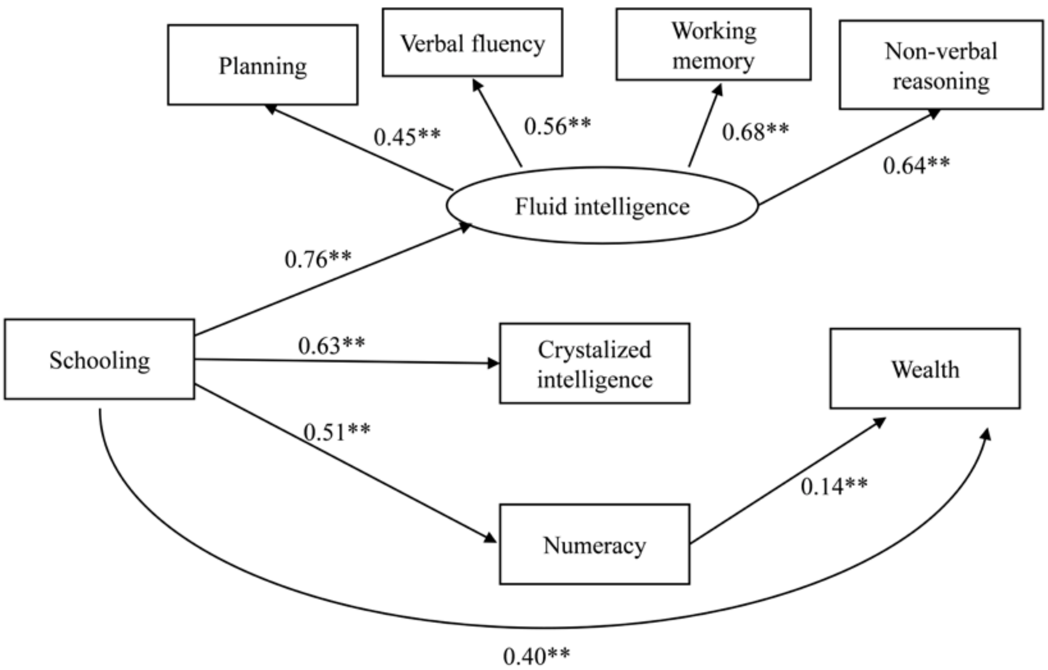
Figure 1 presents the initial model used to explore the simultaneous effect of education, fluid intelligence, crystallized intelligence and numeracy on wealth. The model provided an acceptable fit to the data (CFI = 0.979; TLI = 0.970; RMSEA = 0.038). With the aim of finding the most parsimonious model, non-significant pathways between predictors, control variables, and wealth were removed sequentially based on their respective significance levels. The final model (see Figure 2) provided a good fit to the data (CFI = 0.973; TLI = 0.965; RMSEA = 0.041). Moreover, a likelihood-ratio test comparing the initial model and the final model (χ^2 (4) = 7.82, p = .098) revealed that our final model (see Figure 2) is a more parsimonious model that fits as well as our initial model (see Figure 1). Our final model revealed that numeracy remained a significant predictor of wealth after accounting for all other model effects. In this final model, fluid intelligence and crystallized intelligence were no longer statistically significant predictors.

Figure 1. SEM initial model



Note. * p<.05, **p<.01. The following control variables were included as predictors of wealth (not displayed in figure): Age, gender, residence, mother tongue and married. All parameter estimates are standardized regression coefficients.

Figure 2. SEM final model



Note. * p<.05, **p<.01. The following control variables were included as predictors of wealth (not displayed in figure): Age, gender, residence, mother tongue and married. All parameter estimates are standardized regression coefficients.

We also tested several alternative models. We first considered whether higher numeracy might have led participants to obtain greater schooling; thus, we reversed the direction of the pathway between schooling and numeracy, without changing any other pathway. The reversed pathway was significant but resulted in a poor-fitting model (CFI = 0.905; TLI = 0.877; RMSEA = 0.079; BIC = 10056.16). In a similar way, we reversed the pathways between schooling and fluid intelligence (CFI = 0.854; TLI = 0.819; RMSEA = 0.093; BIC = 10105.32) and schooling and crystallized intelligence (CFI = 0.928; TLI = 0.908; RMSEA = 0.067; BIC = 10038.45). These models also resulted in worse fit. Finally, we reversed all pathways between schooling, and numeracy, fluid intelligence and crystallized intelligence. In this model, numeracy and the two intelligence measures have a direct effect on schooling, and schooling has a direct effect on wealth. This model also resulted in a poor-fitting model (CFI = 0.772; TLI = 0.705; RMSEA = 0.123; BIC = 10112.14). After drawing a comparison of our final model (Figure 2) and these alternative models (using the BIC criteria), we found that our final model gives a better fit to the data than all of the alternative models (BIC final model = 10012.35 < BIC all alternative models).

Discussion

Using data from a field study conducted in 14 agrarian Quechua-speaking communities in Peru’s Andean highlands, we explored the extent to which numeracy skills were related to wealth. Results from linear regressions and SEM models revealed that numeracy had an independent, consistent, and robust effect on wealth. Specifically, the relationship between numeracy and wealth was substantial and statistically significant even after accounting for differences in fluid intelligence and crystallized intelligence, potential demographic confounders, and the direct effects of education. Likewise, the likelihood of holding each of the assets used to form the wealth index increased as numeracy increased (except for owning a bicycle). For instance, an individual with higher numeracy was 38%

more likely to own a fridge than an individual with equal demographic characteristics and intelligent measures but lower numeracy. Taken together, these findings provide additional support for the unique and independent role of numeracy in wealth accumulation. Moreover, the findings presented are strengthened by the fact that the sample was selected to be fairly homogenous in terms of lifestyle, parental education, post-schooling work experiences, and access to financial services. Therefore, these factors are unlikely to have accounted for our results.

One important contribution of the research reported in this paper lies in the fact that it was carried out in a community that is very different from previous research settings, which have focused primarily on North America and Europe. Nonetheless, in this relatively less financially developed economy, numeracy was also an important predictor of wealth. Then, even in this relatively less complex financial environment that makes fewer mathematical demands on individuals, numeracy still plays a clear role in predicting wealth.

It has been a common belief that people's numeracy goes beyond the capacity to calculate, and that it is systematically related to reasoning, risk and time preferences, and the level of motivation to attend to and elaborate upon numerical information (Peters, 2012). We think that it is through these mechanisms that numeracy is related to the wealth accumulation of these farmers. For instance, individuals with higher numeracy tend to be less impatient, preferring larger delayed rewards over smaller immediate rewards (Benjamin, Brown, & Schapiro, 2013). This patience is relevant to wealth accumulation because impatient people persistently report having lower savings (Hasting & Mitchell, 2011).

Numeracy is also related to risk preferences. Individuals with higher numeracy are more likely to take strategic risks, that is, to prefer a risky alternative when it is advantageous to do so and avoided it when it is not (Pachur & Galesic, 2013; Jasper, Bhattacharya, Levin, Jones, & Bossard, 2013). Moreover, this “strategic” risk management strategy has been shown to relate to higher earnings (Jasper et al., 2013). Farmers are frequently exposed to uncertainties such as changes in prices and weather conditions, plagues, and availability of labor and machinery. Although these risks are not under the control of the farmers, they can develop strategies to cope with them. For instance, the farmer may keep a stock of spare parts for the farm machinery to minimize risks of breakdowns or he may maintain a good relationship with the neighbors to assure their help in case of emergency. We expect farmers with higher numeracy to be more prone to use some kind of risk management strategy, which in turn reduces the variability in productivity and profitability and allows better planning and higher savings.

Finally, individuals with higher numeracy have shown to be better able to integrate multiple types of numeric information (Peters, Dieckmann, Västfjäll, Mertz, Slovic, & Hibbard, 2009), to have greater motivation to attend to numerical information (Peters, Västfjäll, Slovic, Mertz, Mazzocco, & Dickert, 2006), to remember numbers better (García-Retamero & Galesic, 2011), and to draw more affective meaning from numbers (Peters et al., 2006). Farmers are exposed to numerical information in the form of input prices, output prices and yields, as well as other technical data. We expected farmers with higher numeracy to attend more to these important numbers and use them more effectively in decisions (Peters et al., 2006; Dieckmann, Slovic, & Peters, 2009; Peters, Hart, & Fraenkel, 2011).

Numerous researchers have suggested that an inextricable covariation exists between schooling, intelligence, and numeracy. Moreover, it has been documented that both schooling and intelligence are correlated with wealth. Here, we provide evidence that numeracy is also associated with wealth. But are these three effects independent? A major shortcoming of the research on numeracy and wealth is that only a few earlier studies had controlled for general cognitive ability. In order to have a more robust test, we included measures of both fluid and crystallized intelligence. Although the findings presented here are consistent with the results reported in the extant literature, controlling for properly validated intelligence measures allows us to better advocate for a robust effect of numeracy on wealth, over and above other cognitive abilities and in a relatively homogenous population that, by its nature, controls for many of the sources of heterogeneity that exist in more developed countries (e.g., parental wealth saved in the stock market or bank that is passed down to children).

Finally, these findings are of relevance since a number of communities in the so-called underdeveloped countries often face financial environments that are similar to our Peruvian sample. Although these results need to be replicated in other populations in order to have a better understanding of the relationship between numeracy and wealth, our findings provide tentative evidence that the positive association holds true even in populations with less developed financial contexts. However, the fact that this population did not hold traditional financial products should not be understood as wealth accumulation being less important. Rather, wealth is accumulated in a different way through assets. Similar to the findings from traditional measures of wealth, higher wealth in these agrarian and less financially sophisticated communities has been related to important well-being outcomes such as better health (Pollack, Chideya, Cubbin, Williams, Dekker, & Braveman, 2007).

Appendix A

IRT analysis of the numeracy scale

Numeracy was assessed with three items modified from Lipkus, Samsa, and Rimer (2001) and designed to measure participants' probabilistic reasoning. Items are of the form of mathematical problems with a unique correct response. Each correct response is given a score of 1 and incorrect response a score of 0. Respondents answered the 3 items in the same order as presented below. Table A.1 presents the percentage of correct responses per item.

Item 1: Imagine you were going to buy a raffle ticket and you had three different raffles to choose from? In the first raffle, 1 out of every 100 people wins. In the second raffle, 1 out of every 1000 people wins. In the third raffle, 1 out of every 10 people wins. Which raffle would you rather play? a. 1 in 100; b. 1 in 1000; c. 1 in 10

Item 2: Imagine that 10 men and 20 women put their names on little pieces of paper and put them in a hat. If the papers were all mixed up, and you picked a name out of the hat without looking, do you think it would be the name of a woman or a man? a. man; b. woman

Item 3: If the chance of winning a raffle is 10%, how many people would you expect to win out of 1000? Answer __people

Before presenting the results of the IRT analysis, let us first explain why an IRT analysis was valuable for this research. We conceptualize numeracy as a continuous variable that ranges from very low to very high. Although we cannot directly observe participants' numeracy, we can infer participants' ability through their responses to a set of mathematical questions. Following a classical test theory approach, participants' numerical ability could be assessed by counting the number of correct responses. However, this approach is limited because items in the questionnaire may differ on their difficulty and on their capacity to discriminate between individuals with lower and higher numeracy. Consider, for example, the hypothetical responses of two participants, Juan and Pedro, who both answered only 1 of the questions correct. Juan, however, answered one of the “easy” questions correctly whereas Pedro correctly answered one of the “difficult” questions. Counting the number of correct responses would give Juan and Pedro the same score of one. Alternatively, weighting their responses by the difficulty and the discrimination capacity of the items would result in different total scores. IRT research has shown that weighted IRT scores better reflect the location of each of these participants along the numerical ability continuum (de Ayala, 2009).

Specifically, the difficulty parameter captures the location of the item along the numeracy continuum. In general, items located below zero are said to be “easy” and items above zero are “hard” (de Ayala, 2009). The discrimination parameter refers to how well the item differentiates between people with higher and lower numerical ability. Items with a high discrimination parameter are such that individuals with higher numeracy select the correct answer more often than individuals with lower numeracy.

A two-parameter logistic IRT model was estimated using the *irtoys* package for R. The item difficulty and the discrimination parameters are presented in Table A.1, Model A. An inspection of these estimates indicated that Item 2, with a negative discrimination parameter (Discrimination = -0.47) was inconsistent—participants with lower numeracy had a higher probability of answering the question correctly than those with higher numeracy. IRT theory suggests that items with negative discrimination parameters should be recoded or discarded (de Ayala, 2009). This item was not included in further analysis.

Next, the IRT model was estimated for the two items that remained. The difficulty and discrimination parameters are presented in Table A.1, Model B. The difficulty parameters indicated that Item 1 (Difficulty = -0.47) was relatively easier than Item 3 (Difficulty = 0.64). On the other hand, the discrimination parameters revealed that Item 1 (Discrimination = 1.36) could differentiate better between participants located at different locations of the numeracy continuum than Item 3 (Discrimination = 1.29).

Table A.1. Percentage of correct responses to the numeracy items and parameters estimated with IRT models

		IRT Model A		IRT Model B	
Item	**Correct responses**	**Discrimination**	**Difficulty**	**Discrimination**	**Difficulty**
1	138 (61.6%)	1.67	-0.42	1.36	-0.47
2	57 (25.5%)	-0.47	-2.42		
3	78 (34.8%)	1.09	0.71	1.29	0.64

Total scores were calculated using the maximum likelihood estimation (MLE) approach. MLE can be used to consider, not only whether the respondent answered each item correctly, but to weight the answer by the item's difficulty and discrimination parameters (Embretson & Reise, 2000). As a result of combining information on the respondent's entire pattern of responses as well as the characteristics of each item, MLE can provide many more distinctions among respondents than just counting the number of correct responses (Embretson & Reise, 2000; Van der Linden & Hambleton, 1997). Table A.2 contains the four possible response patterns, their frequency of occurrence and the corresponding total numeracy score. We rescaled the IRT scores by setting the minimum score to zero. In this way participants who answered both questions wrong received a total score of zero.

Table A.2. Response patterns for two numeracy items, frequencies of occurrence and corresponding numeracy score

Response pattern	**Respondents in each category**	**IRT Numeracy score**	**Numeracy scores rescaled (Min = 0)**
Item 1 and Item 4 incorrect	68 (30.4%)	-0.79	0
Item 1 correct and Item 4 incorrect	78 (34.8%)	0.05	0.84
Item 1 incorrect and Item 4 correct	18 (8.0%)	0.00	0.79
Item 1 and Item 4 correct	60 (26.8%)	0.84	1.63

Appendix B

Estimated probabilities of holding an asset from the wealth index

The probability of holding each of the assets (house durables and housing characteristics) from the wealth index was estimated using a mixed-effects logistic regression model. This model is an extension of a logistic regression model that takes into account the clustered structure of the data. In the present study, binary responses about the ownership of the different assets are nested within individuals. The probability of holding each of the assets was predicted using numeracy scores, cognitive ability scores and demographic variables. In addition, both the intercept and the slope coefficient for numeracy were allowed to vary across assets. In other words, we allow the average probability of ownership to be different for each asset and we also allow the effect of numeracy, on the estimated probability, to be different for each asset. Table B.1 and Table B.2 present the fixed-effects and random effects parameters, respectively.

Numeracy scores, cognitive ability scores and age were mean-centered; other demographic variables were coded as follows: gender (Male = 0, Female = 1); Mother Tongue (Spanish = 0, Quechua = 1); Residence (Small Town = 0, Rural = 1); Married or cohabitating (No = 0, Yes = 1). Accordingly, probabilities were estimated for a *typical sample responder*: a 44-year-old female, living in a rural area, married, whose mother tongue is Quechua, and with average scores for fluid intelligence and crystalized intelligence. Probabilities reported in the main text were calculated as described below.

The probability that a typical respondent with an average score for numeracy would hold asset *i* can be described as, $(p_{Holding\ asset\ i}) = \frac{\exp(\beta_0 + u_{0i})}{[1 + \exp(\beta_0 + u_{0i})]}$, where β_0 refers to the intercept (fixed-effect), u_{0i} represents the random intercept for asset *i* and *exp* refers to the exponential function $\exp(\beta_0 + u_{0i}) = e^{\beta_0+u_{0i}}$ (Agresti, 2007). As an illustration consider the following example. The probability that the typical respondent owned a stove was equal to $(p_{stove}) = \frac{\exp(0.73+0.26)}{[1+\exp(0.73+0.26)]} = 73\%$.

In a similar fashion, the probability that a typical respondent with high numeracy (1 SD above the mean) would hold asset *i* can be described as, $(p_{Holding\ asset\ i}) = \frac{\exp(\beta_0+u_{0i}+\beta_1+u_{1i})}{[1+\exp(\beta_0+u_{0i}+\beta_1+u_{1i})]}$, where β_0 is the intercept (fixed effect), β_1 is the fixed effect for numeracy, u_{0i} represents the random intercept for asset *i*, and u_{1i} represents the random slope for numeracy for asset *i*. In our example, the probability that this responder owned a stove was estimated to be $(p_{stove}) = \frac{\exp(0.73+0.26+0.56+0.50)}{[1+\exp(0.73+0.26+0.56+0.50)]} =$ 88.6%.

Finally, the probability that a typical respondent with low numeracy (1 SD below the mean) would hold asset *i* can be described as $(p_{Holding\ asset\ i}) = \frac{\exp(\beta_0+u_{0i}-\beta_1-u_{1i})}{[1+\exp(\beta_0+u_{0i}-\beta_1-u_{1i})]}$, where β_0 represents the intercept (fixed effect), β_1 is the fixed effect for numeracy, u_{0i} represents the random intercept for asset *i*, and u_{1i} represents the random slope for numeracy for asset *i*. The probability of owning a stove was equal to $(p_{stove}) = \frac{\exp(0.73+0.26-0.56-0.50)}{[1+\exp(0.73+0.26-0.56-0.50)]} = 48.5\%$.

Table B.1. Fixed-effects parameters of a mixed-effects logistic regression model used to predict the probability of holding an asset as function of numeracy and other predictors

	β (SD)
Fixed effects	
Numeracy (Mean centered) (β_1)	0.56* (0.23)
Fluid intelligence (Mean centered)	0.10* (0.05)
Crystalized intelligence (Mean centered)	0.03** (0.01)
Age (Mean centered)	0.02 (0.01)
Gender (Male = 0, Female = 1)	0.20 (0.21)
Mother Tongue (Spanish = 0, Quechua = 1)	-0.54* (0.25)
Residence (Small Town = 0, Rural = 1)	-1.93** (0.26)
Married or cohabitating (No = 0, Yes = 1)	-0.73** (0.26)
Constant (β_0)	0.73 (0.57)
N	240

Note. Entries in table are logistic regression coefficients (SD); *p < .05, **p< .01. The dependent variable is dichotomous and indicates whether asset *i* is held (1 = yes).

Table B.2. Random effects parameters of a mixed-effects logistic regression model used to predict the probability of holding an asset as function of numeracy and other predictors

Assets (*N*=228)	Random intercept (u_{0i})	Random slope for numeracy (u_{1i})
Housing quality		
Floor made of cement relative to made of earth	-0.60	0.26
Toilet facilities relative to no toilet inside the house	1.77	0.04
Piped water relative to other sources of water	3.23	-0.14
Household durables		
Stove	0.26	0.50
Fridge	-1.10	0.29
Computer	-1.88	-0.02
TV	1.32	-0.01
Stereo	-0.98	0.00
Landline	-2.13	-0.29
Cellphone	1.51	-0.32
Bike	-1.06	-0.82

Note. Entries in table are parameter estimates for the random effects

CHAPTER 4

Numeracy, willingness to take risk and decision strategies

This chapter is based on: Estrada-Mejia, C., De Vries, M., Zeelenberg, M., & Breugelmans, S.M. (2015). Numeracy, willingness to take risk and decision strategies. *Working paper*.

Abstract

Numeracy is defined as the ability to process basic probabilistic and numerical concepts. We examined the relationship between numeracy and willingness to take risks for a representative sample of the Dutch population (*N* = 2,156), controlling for potential confounding factors (e.g., age, gender, education, and income). We also modeled possible decision strategies underlying choices and tested whether strategy selection was conditional upon participant's numeracy, payoffs, or both. Specifically, we considered an expected value strategy (EV), as well as three heuristic strategies: least-likely, maximin, and maximax. Our findings revealed no significant differences on the willingness to take risk between individuals with low and high numeracy for low payoffs. However, for high payoffs, high numeracy individuals were significantly *less* willing to take risk than low numeracy individuals. In terms of decision strategies, as participants' numeracy increased, the likelihood of using EV increased when payoffs were low, but decreased when payoffs were high. The opposite was observed for the maximin strategy. Independently of level of payoffs, as numeracy increased, the likelihood of choosing the least-likely or the maximax strategy decreased. Implications for the research on numeracy and risky decision making are discussed.

Numeracy, defined as an individual's ability to understand and use numerical information, has been shown to play a significant role in how people make decisions (Dieckmann, Slovic, & Peters, 2009; Peters, Hart, & Fraenkel, 2011; Peters, Västfjäll, Slovic, Mertz, Mazzocco, & Dickert, 2006). Numerous studies revealed that low numerate people show consistent biases in the comprehension of risks and benefits (for reviews, see Dieckmann, 2009; Black, Nease, & Tosteson, 1995; Schwartz, Woloshin, Black, & Welch, 1997; Weinfurt et al., 2003), and that these biases often lead to disadvantageous decisions (Liberali, Reyna, Furlan, Stein, & Pardo; Peters et al., 2006; Slovic, Finucane, Peters, & MacGregor, 2004; Peters, Dieckmann, Dixon, Hibbard, & Mertz, 2007). This literature, however, has not achieved consensus on the relationship between numeracy and risk attitudes. The empirical evidence on whether people with low numeracy have different risk attitudes than people with high numeracy is mixed. It is important to understand this relationship, because if there is a systematic relationship between numeracy and risk attitudes, this could perhaps explain some of the biases and provide opportunities for intervention.

The relationship between numeracy and risk attitudes has been shown to be complex. Some studies have found that high numerate individuals are *more willing to take risk* and make *more choices consistent with expected-value maximization*[2] than low numerate individuals (Cokely & Kelley, 2009; Dave, Eckel, Johnson, & Rojas, 2010; Frederick, 2005; Pachur & Galesic, 2013). However, more recent work has revealed no differences in willingness to take risk, or the number of expected-value consistent choices, between participants with high versus low numeracy (Benjamin, Brown, & Shapiro, 2013; Jasper, Bhattacharya, Levin, Jones, & Bossard, 2013). Therefore, the true nature of the relationship between numeracy and risk attitudes remains unclear. In this paper we continue the investigation of the relationship between numeracy and willingness to take risk, by using a

[2] A choice consistent with expected-value maximization is for example to prefer a higher-expected-value gamble, such as 50% chance of €100 otherwise €0 over a guaranteed option of €40.

research approach that may overcome some of the limitations of previous research. We believe four distinctive features of our current research allow us to better investigate a potential association between numeracy and willingness to take risk.

First, the current study uses a large and heterogeneous sample (N = 2,156) of adults living in the Netherlands, which enhances the generalizability of our findings. In order to discover whether the association between numeracy and risk attitudes is a robust phenomenon, it is essential to observe individuals at all levels of numeracy (low, medium, and high). Previous studies (Benjamin et al., 2013; Cokely & Kelley, 2009; Frederick, 2005; Jasper et al., 2013), relying mainly on student populations, did not provide an opportunity to investigate the effect for a heterogeneous population. Since college students tend to be more numerate than the general population (Cokely & Kelley, 2009; Lipkus, Samsa, & Rimer, 2001; Reyna & Brainerd, 2007), it is not clear whether previous findings are applicable to a wider population or rather an artifact of the subject pool.

Second, we investigate the unique effect of numeracy on risk attitudes by controlling for potentially confounding socioeconomic factors that previous studies left unexamined. Abundant evidence has been accumulated showing that factors such as age, gender, education, and income influence risk attitudes (Bonsang & Dohmen, 2015; Dohmen, Falk, Huffman, Sunde, Schupp, & Wagner, 2011; Guiso & Paiella, 2004). We test whether numeracy has an effect above and beyond these factors. Numeracy is of most relevance for explaining differences in willingness to take risk to the degree that it can explain unique variance of the observed inter-individual heterogeneity.

A third distinctive feature is that subjects in the current study made choices over monetary lotteries involving both low and high stakes. Risk taking behavior under high stakes is a relevant area of economic research because many of our “real-world” decisions, such as saving for retirement or taking a mortgage, entail substantial monetary costs and rewards. Moreover, researchers have raised the concern that measures of risk attitudes with low payoffs (like the ones encountered in the laboratory) may be somewhat unrealistic and therefore not useful in measuring attitudes toward real-world risks (Harrison, List, & Towe, 2007; Holt & Laury, 2002). With the exception of one study in which the outcomes of hypothetical lotteries ranged up to $3,600 (Cokely & Kelly, 2009), previous studies have mainly looked at relatively low payoffs, stakes ranging up to €100. We study the impact of numeracy on risky choices with relatively high monetary outcomes (Payoff ranges between €3,000 and €9,750).

Moreover, after examining differences in risk attitudes of more and less numerate people, we investigate a possible mechanism to explain *how* and *why* these differences might arise. Specifically, we study the cognitive processes underlying choices between risky options. Within the decision making literature, researchers have identified a multitude of decision strategies that describe how probabilities and outcomes could be evaluated. Some of them, such as the expected value strategy (Huygens, 1657; Laplace, 1814), use information extensively by weighting and adding probabilities and outcomes. Other models, such as the maximin (Wald, 1945), use only a subset of information by focusing only on the outcomes. In essence, different strategies reflect different ways to cope with the uncertainties inherent in risky choices. The underlying hypothesis is that low and high numerate people might have different risk attitudes, because they use different decision strategies to cope with uncertainty. Let us next outline the decision strategies that we considered.

Numeracy and decision strategy

We modeled participants' choices using four different decision strategies that can be viewed as plausible competitors in risky decision making. [3] Specifically, we considered a compensatory model based on calculations of the expectation of the alternatives (*expected value strategy*: *EV*), two non-compensatory models that focus on the outcomes and disregard probability information, *maximin* (Wald, 1945) and *maximax* (Coombs, Dawes, & Tversky, 1970), and one non-compensatory strategy that focus on the probabilities, *least-likely heuristic* (Thorngate, 1980). The decision rules underlying each of these decision strategies are summarized in Table 1. We test whether numeracy and the stakes of the lotteries influence the strategy selection.

Table 1. Description of decision strategies

Name	**Decision Rule**
Expected value strategy	People aggregate the outcomes of each option, weighted by their respective probabilities, and choose the option with the most attractive expected value
Maximin strategy	People only consider the worst outcomes of each option and choose the option with the most attractive worst outcome
Maximax strategy	People only consider the best outcomes of each option and choose the option with the most attractive best outcome
Least-likely strategy	People identify each option’s worst outcomes and choose the option with the lowest probability of yielding the worst outcome

To our knowledge, only Pachur and Galesic (2013) have studied the correlation between numeracy and strategy selection. They provide some support for the hypothesis that numeracy influences the selection of the strategy. However, their studies are limited to risky decisions with low payoffs in the loss domain. We complemented their findings by studying the impact of numeracy on strategy selection in the gain domain and with decisions involving both high and low payoffs. Before we present the study let us discuss some mechanisms that may account for the link between numeracy and risk attitudes.

[3] A comprehensive compilation of heuristics can be found in Gigerenzer, Hertwig, and Pachur (2011).

Numeracy and risk attitudes

Numeracy encompasses the ability to understand and use numeric concepts, to perform basic mathematical operations, compare magnitudes, and comprehend ratio concepts such as fractions, proportions, percentages and probabilities (Lipkus et al., 2001; Schwartz et al., 1997). There are several mechanisms that may account for the link between numeracy and risk attitudes. For one, numeracy facilitates mathematical computations (e.g., doing addition, subtraction, multiplication, and statistical inferences; Ancker & Kaufman, 2007) and greater depth of numerical processing (e.g., make comparisons between numbers, integrate two or more pieces of information; Lipkus & Peters, 2009). Therefore, one might expect that numerate people will be more likely to integrate probabilities and outcome information and thus more likely to choose the option with the higher expected value. Put differently, people high in numeracy are expected to use the expected value strategy more often than those low in numeracy.

Another pathway through which numeracy might influence risk attitudes is by improving the interpretation and subjective meaning of the outcomes and probabilities. People give meaning to objective numbers by transforming them into subjective quantity (Schley & Peters, 2014; Furlong & Opfer, 2009). Less numerate people appear to have less precise mapping of objective quantities into subjective mental quantities (Schley & Peters, 2014). This could explain, for example, why their subjective risk estimates significantly differ from the objective value (Black et al., 1995; Weinfurt et al., 2003). Thus, if numeracy systematically increases or decreases an individual's risk perception, then risk may systematically appear as more or less attractive to that person.

As an alternative mechanism, numeracy may influence the relative importance of information. Low numeracy has been shown to increase the reliance on non-numerical sources of information, such as narrative information and mood states (Lipkus & Peters, 2009; Dieckmann et al., 2009). Therefore, one might expect that emotional reactions such as the thrill of winning, or the thrill of gambling, or the pain of losing, could systematically influence the risk attitudes of the low numerate. As a result of these emotional influences, low numerate people could appear as systematically more risk seeking or more risk averse.

The findings presented above suggest that (at least intuitively) numeracy and risk attitudes should be associated. However, the empirical evidence is mixed and the pattern of association is unclear. To further our understanding of the relationship between numeracy and risk taking behavior in the financial domain, we examined the relationship between numeracy and willingness to take risks using data from a large Dutch population sample. We tested whether numeracy was correlated with risk attitudes, whether risk attitudes of people with high versus low numeracy were conditional to the payoff, and also whether those with higher versus lower numeracy differed on the decision strategy underling their choices.

Method

Participants and background data

In total, 2,156 subjects participated in this study. All participants were members of the LISS panel,[4] an Internet panel managed by CentERdata, an organization affiliated with Tilburg University. Panel members complete one questionnaire over the Internet each month and are reimbursed for completing the questionnaires four times a year. All study data are publicly available at www.lissdata.nl. The LISS panel is a representative sample of the Dutch population in terms of observable background characteristics. Here, we used a random subsample, stratified to reflect the population.

[4] for more information about this panel see: http://www.centerdata.nl/en/databank/liss-panel-data-0

Comprehensive background data are available for the panel participants, including gender, age, income, education, data on numeracy, and experimental data on risk attitudes. Through the unique identification numbers of the panel members, we connected the surveys and experimental measures. Descriptive statistics are presented in Table 2.

Table 2. Descriptive statistics for the sample

		Payoff conditions			
Variable	**Complete Sample**	**Real-low condition**	**Hypothetical-low condition**	**Hypothetical-high condition**	***p value***
Numeracy (0-11)	8.4 (2.5)	8.4 (2.6)	8.5 (2.5)	8.3 (2.5)	.292
Age	50.9 (15.4)	51.5 (15.5)	50.7 (15.3)	50.5 (15.4)	.421
Female	48.4%	48.4%	50.1%	46.5%	.435
High Education	40.7%	39.7%	42.9%	39.8%	.392
Log income	3.1 (.3)	3.1 (.3)	3.1 (.3)	3.1 (.3)	.802
# of obs	2156	847	679	630	

Note. Entries are means. Standard errors in parentheses. The *p*-value reported in the last column refers to the *t* tests comparing mean scores between the three payoff conditions

Design and procedure

Demographic information and numeracy were measured in surveys administered weeks and months prior to the experiment to elicit risk attitudes. Risk attitudes were elicited in an incentivized experiment designed by Noussair, Trautmann, and Van de Kuilen (2013). The task was administered on a computer. Participants made 10 binary choices between lotteries grouped in two parts. Part one consisted of five choices between a guaranteed option and a risky lottery that paid €65 or €5 with equal probability. The guaranteed option varied from €20 to €40 in steps of €5. Part two consisted of five binary choices between two risky lotteries. The choices in part one were used to assess a participant’s willingness to take risk; the choices in part one and two were combined to profile the decision strategies. Part one always came first. A list of all choices is given in Appendix A.

Subjects were presented with one choice at a time. The five choices measuring willingness to take risk were ordered, such that the certain payoff increased (or decreased in counterbalanced conditions) monotonically. No indifference option was provided, so subjects always had to choose one of the lotteries. The presentation of the lotteries with respect to the position on the left or the right sides of the screen was counterbalanced.

Participants were randomly assigned to one of three conditions. Each subject participated in only one experimental condition. In the Real-low condition (*N* = 847) each individual had a 1 in 10 chance of being randomly selected to receive a real monetary payment. The payoffs in the Hypothetical-low condition (*N* = 679) were identical to the Real-low condition, except for the fact that no choices counted towards participant earnings. The Hypothetical-high condition (*N* = 630) was identical to the Hypothetical-low condition, except for the fact that payoffs were scaled up by a factor of 150. In all conditions, zero or negative earnings were impossible.

Measures

Demographics. Gender, age, and education were obtained for all participants. Participants who reported finishing higher vocational education or university received a score of 1 and 0 otherwise.

Income. LISS Panel members indicated their personal net monthly income in Euros for 2009. Estimated net annual income was obtained by multiplying the raw score by 12. Log-transformed scores were used for analyses.

Numeracy. Numeracy was measured using an 11-item scale (Lipkus et al., 2001) which tests for basic arithmetic and statistical skills. An example question is: “Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls how many times do you think the die would come up even (2, 4, or 6)?” (Correct answer: 500 out of 1,000). The total resulting numeracy score reflected the sum of correct answers, with higher scores indicating higher levels of numeracy. Possible scores range from 0-11, Cronbach's alpha = .78.

Willingness to take risk. The measure of willingness to take risk was operationalized as the proportion of risky choices: The number of times the participant chooses the risky lottery, instead of the guaranteed option, divided by 5. Higher scores indicate more willingness to take risk.

High-expected-value choices. The measure of high-expected-value choices corresponds to the proportion of choices of the option with higher expected value. For instance, choosing the risky option B when asked to choose between a guaranteed Option A (€20) and a risky Option B (50% chance of €45, otherwise €5: Expected value: €25) was coded as a high-expected-value choice. The measure was operationalized as the number of times the participant chose the option with the higher expected value divided by 4. We divided by 4 instead of 5 because one binary lottery choice was not included in this measure; for this option the expected value of the lottery was equal to the guaranteed option. Higher scores indicate more choices consistent with expected value.

Results

Descriptive analyses

Sample statistics are shown in Table 2. About 48.4% of the sample are female, average age is 50.9 years (*Range* = 19-88), and 40.7% of respondents have higher education. The measure for numeracy has a mean value of 8.4 (*SD* = 2.5, *Range* = 0-11). Different *t* tests comparing mean scores on numeracy and control variables between the three payoff conditions revealed no significant differences (All *p*-values > .292).

Analysis of payoff conditions

The effect of the payoffs on participants' choices and strategy selection was analyzed using two orthogonal contrasts. The *Low-high contrast* compared the Hypothetical-high payoff condition with the two low payoff conditions (Real-low and Hypothetical-low).

Participants in the Hypothetical-high condition received a value of -2 and all participants of the other two low payoff conditions received a value of 1. This contrast comparison investigates whether participants facing low stakes lotteries make different choices, or use different decision strategies, than participants facing high stakes lotteries. A second contrast called *Real-hypothetical contrast* compares the hypothetical low payoff condition with the real low payoff condition. This contrast assigns the value of 1 to participants in the real low payoff condition, -1 to participants in the hypothetical low payoff condition and 0 to participants in the high payoff condition. This comparison tests whether choices in the hypothetical low payoff condition differ from those in the real payment condition.

The first part of the analyses focuses on studying whether numeracy is correlated with willingness to take risk (operationalized as the proportion of risky choices) and with expected value consistent choices (operationalized as the proportion of choices of the option with higher expected value). Next, we tested whether more and less numerate participants differ on decision strategies.

Willingness to take risk

Table 3 presents the results of a regression analysis with willingness to take risk as dependent variable and numeracy, the two contrast variables (i.e., Low-High Contrast and Real-Hypothetical Contrast), their interaction with numeracy, and controls[5] as independent variables (Model 1). There was a significant main effect of numeracy (b = -0.008, SD = 0.003, t = -2.576, p = .010) such that numeracy was negatively correlated with willingness to take risk. There was also a significant main effect of the dummy contrasting the low payoff with the high payoff groups (Low-High Contrast) (b = -0.036, SD = 0.005, t = -7.033, p < .001). Willingness to take risk was significantly higher in the low payoff conditions (M = 35.3%,

[5] Control variables were included as covariates. The interactions between numeracy and the covariates were not statistically significant, ps > .05.

SD= 33.6) than in the high payoff condition (*M* = 24.3%, *SD* = 32.2). However, these main effects were qualified by a significant interaction between numeracy and the Low-high contrast ($b = -0.009$, $SD = 0.002$, $t = -4.238$, $p < .001$).

To interpret the interaction we performed two additional analyses. First, simple slope analyses demonstrated that high numerate participants (1 SD above the mean) were less willing to take risk when the payoff was high, compared to when the payoff was low ($b_{Low\text{-}High\ Contrast} = -0.059$, $SD = 0.007$, $t = -8.054$, $p < .001$). Willingness to take risk of low numerate participants (1 SD below the mean), did not differ between the high payoff vs. the low payoff conditions ($b_{Low\text{-}High\ Contrast} = -0.014$, $SD = 0.008$, $t = -1.824$, $p = .068$). Regression coefficients are shown in Table 3, Models 2 and 3 respectively.

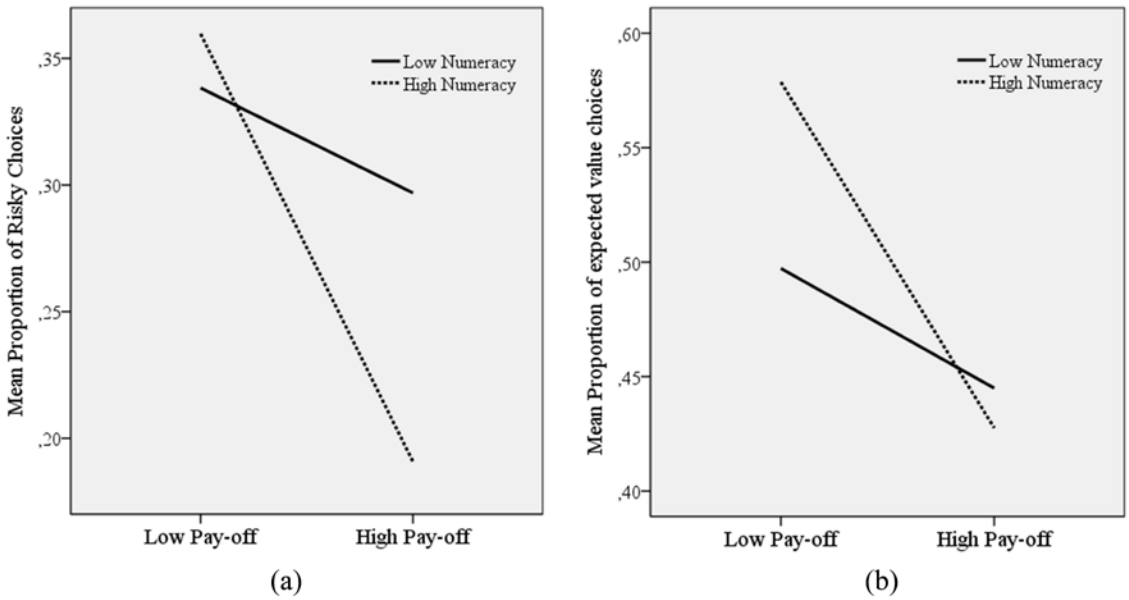
Table 3. The relationship between willingness to take risk and numeracy controlling for differences in demographic variables

	Model 1: Base line	**Model 2: High numeracy**	**Model 3: Low numeracy**	**Model 4: High payoff**	**Model 5: Low payoff**
Numeracy Scores	-0.008* (0.003)	-0.008* (0.003)	-0.008* (0.003)	-0.023** (0.006)	0.000 (0.004)
Real-hypothetical Contrast	-0.002 (0.008)	-0.004 (0.012)	-0.001 (0.012)		-.003 (0.009)
Low-High contrast	-0.036** (0.005)	-0.059** (0.007)	-0.014 (0.008)		
Numeracy * Real-hypo Contrast	0.000 (0.003)	0.000 (0.003)	0.000 (0.003)		
Numeracy * Low-High contrast	-0.009** (0.002)	-0.009** (0.002)	-0.009** (0.002)		
Age	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.001 (0.001)	0.000 (0.001)
Female	-0.071** (0.016)	-0.071** (0.016)	-0.060** (0.020)	-0.049 (0.028)	-0.081** (0.019)
High education	0.012 (0.016)	0.012 (0.016)	0.012 (0.016)	0.003 (0.029)	0.014 (0.019)
Monthly income	0.055* (0.027)	0.055* (0.027)	0.053* (0.028)	0.026 (0.050)	0.066* (0.033)
Dummy order	0.058** (0.014)	0.058** (0.014)	0.058** (0.014)	0.070** (0.025)	0.053** (0.017)
Dummy position	-0.018 (0.014)	-0.018 (0.014)	-0.018 (0.014)	0.008 (0.025)	-0.028 (0.017)
Constant	0.097 (0.090)	0.077 (0.090)	0.118 (0.090)	0.026 (0.161)	0.138 (0.108)
R^2	.058	.058	.058	.053	.033
# of obs	2156	2156	2156	630	1526

Note. Entries are regression coefficients. Standard errors in parentheses. *p < .05, **p< .01. Omitted categories: male and low education (primary and lower secondary education). Variables for which interactions are calculated are centered. *Real-hypothetical Contrast* = Contrast variable contrasting the low-real-payoff group with the low-hypothetical-payoff group; *Low-High Contrast* = Contrast variable contrasting the low-payoff groups with the high-payoff group; *Dummy order*= Dummy variable comparing the order of the presentation of the tasks; *Dummy position* = Dummy variable comparing the position of the presentation.

Next, separate regressions (Table 3, Models 4 and 5) per payoff condition revealed that the relationship between willingness to take risk and numeracy was not statistically significant when the payoff was low ($b_{numeracy}$ = 0.001, *SD* = 0.004, *t* = 0.006, *p* = .995), but it was significant when the payoff was high ($b_{numeracy}$ = -0.023, *SD* = 0.006, *t* = -4.079, $p <$ .001). When the stakes were high, willingness to take risk decreased as numeracy increased. These results are summarized in Figure 1a, which displays the proportion of risky choices separately for payoff condition and numeracy level.

Figure 1. Proportion of risky choices and proportion of high expected value choices presented separately for payoff condition and numeracy level (median split)



The results thus suggest that willingness to take risk does not vary systematically with numeracy. When the payoffs were low, there were no significant differences on the willingness to take risk between individuals with low and high numeracy. When the payoffs were high, individuals with higher numeracy were significantly less willing to take risk than participants with low numeracy. Furthermore, high numerate participants made fewer risky choices when the stakes were high as compared to when they were low (High payoff: 19.5% vs. Low payoff: 36.5%). The risky choices of low numerate participants appeared to be invariant to changes in payoffs (High payoff: 30.9% vs. Low payoff: 36.6%). For presentation purposes we created Table 4, Columns 1 and 2, which shows the proportion of risky choices, classifying participants into low versus high numeracy by means of median split (Median = 8.4) and payoff condition.

Table 4. Mean proportion of risky choices and expected value choices by numeracy level and payoff condition

	Proportion risky choices		**Proportion expected value choices**	
Numeracy	**Low payoff**	**High payoff**	**Low payoff**	**High payoff**
Low (Below mean)	36.6%	30.9%	49.8%	45.3%
High (Above mean)	36.5%	19.5%	58.2%	43.1%

High-expected-value choices

Table 5 presents the results of a regression analysis with the proportion of high-expected-value choices as dependent variable and numeracy, the two contrast variables, their interaction with numeracy, and controls[6] as independent variables (Model 6). There was a significant main effect of the Low-High Contrast variable (comparing the low payoff with the high payoff groups) (b = -0.035, SD = 0.004, t = -7.906, p < .001) and a significant interaction between numeracy and the Low-High Contrast (b = -0.006, SD = 0.002, t = -3.176, p = .002). Separate regression analyses per payoff condition (Table 5, Models 9 and 10) showed that the proportion of high-expected-value choices and numeracy was not statistically significant for high payoffs ($b_{numeracy}$ = -0.004, SD = 0.005, t = -0.751, p = .453) but it was significant for low payoffs ($b_{numeracy}$ = 0.009, SD = 0.003, t = 2.755, p = .006). In the low payoff condition, the proportion of choices with higher expected value increased as numeracy increased but there was no association when the payoff was high. Figure 1b shows the proportion of high-expected-value choices separately for payoff condition and numeracy level.

Simple slope analyses demonstrated that participants made fewer high-expected-value

[6] The interactions between numeracy and the covariates were not statistically significant *ps* > .05.

choices when the payoffs were high rather than low. This effect was stronger for high numerate participants (1 *SD* above the mean; $b_{Low\text{-}High\ Contrast}$ = -0.050, *SD* = 0.006, *t* = -7.896, *p* < .001) than for low numerate participants (1 *SD* above the mean; $b_{Low\text{-}High\ Contrast}$ = -0.021, *SD* = 0.007, *t* = -3.175, *p* = .002). Regression coefficients are shown in Table 5, Models 7 and 8 respectively.

Table 5. The relationship between expected value consistent choices and numeracy controlling for differences in demographic variables

	Model 6: Base Line	**Model 7: High Numeracy**	**Model 8: Low Numeracy**	**Model 9: High payoff**	**Model 10: Low payoff**
Numeracy Scores	0.004 (0.003)	0.004 (0.003)	0.004 (0.003)	-0.004 (0.005)	0.009** (0.003)
Real-Hypothetical Contrast	-0.005 (0.007)	0.004 (0.010)	-0.013 (0.011)		-0.005 (0.007)
Low-High Contrast	-0.035** (0.004)	-0.050** (0.006)	-0.021** (0.007)		
Numeracy * Real-hypo Contrast	0.003 (0.003)	0.003 (0.003)	0.003 (0.003)		
Numeracy * Low-High Contrast	-0.006** (0.002)	-0.006** (0.002)	-0.006** (0.002)		
Age	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)	0.000 (0.001)
Female	-0.063** (0.014)	-0.063** (0.014)	-0.063** (0.014)	-0.055* (0.024)	-0.067** (0.016)
High Education	0.038** (0.014)	0.038** (0.014)	0.038** (0.014)	0.007 (0.025)	0.050** (0.017)
Monthly income	0.062** (0.024)	0.062** (0.024)	0.062** (0.024)	0.025 (0.043)	0.076** (0.029)
Dummy order	0.020 (0.012)	0.020 (0.012)	0.020 (0.012)	0.020 (0.022)	0.022 (0.015)
Dummy position	-0.023 (0.012)	-0.023 (0.012)	-0.023 (0.012)	0.004 (0.022)	-0.034* (0.015)
Constant	0.358 (0.078)	0.370 (0.078)	0.347 (0.078)	0.371 (0.139)	0.362 (0.094)
R^2	.070	.070	.070	.014	.051
# of obs	2156	2156	2156	630	1526

Note. Entries are regression coefficients. Standard errors in parentheses. **p* < .05, ***p*< .01. Omitted categories: male and low education (primary and lower secondary education). Variables for which interactions are calculated are centered. *Real-hypothetical Contrast* = Contrast variable contrasting the low-real-payoff group with the low-hypothetical-payoff group; *Low-High Contrast* = Contrast variable contrasting the low-payoff groups with the high-payoff group; *Dummy order*= Dummy variable comparing the order of the presentation of the tasks; *Dummy position* = Dummy variable comparing the position of the presentation.

In sum, participants made fewer high-expected-value choices when the payoff was high compared to when it was low. However, this change in preferences was stronger for high numerate participants (High payoff: 43.1% vs. Low payoff: 58.2%) than for low numerate participants (High payoff: 45.3% vs. Low payoff: 49.8%) (Percentages reported in Table 4, Columns 3 and 4). In addition, when the payoff was high, there were no significant differences in the proportion of high-expected-value choices between low and high numerate participants. However, when the payoff was low, high numerate participants made more choices with higher expected value than their low numerate counterparts.

Strategy Selection

Our second goal was to examine whether more and less numerate participants rely on different strategies when choosing between high stakes and low stakes lotteries. To investigate this question, we first modeled each participant's choices with the EV, the least-likely, the maximin and the maximax strategy, and classified each participant to the strategy with the best fit. A detailed explanation of the classification procedure can be found in Appendix A. First, to understand the nature of the relationship we created Table 6, which shows the proportion of participants classified in each strategy broken down by numeracy and payoff condition. Overall, most participants were classified as using a maximin strategy (55.5%) or an EV strategy (19.8%). Participants with low numeracy appear to use the same strategy independent of the payoff, as shown by the fairly equal proportion of participants using each strategy in the low vs. high payoff condition. In contract, participants with high numeracy appear to use different strategies depending on the payoffs. Specifically, they seem to change from an EV to a maximin strategy when payoffs were increased.

Table 6. Distribution of strategies by numeracy level and payoff condition

	Low numeracy (Below mean)		High numeracy (Above mean)		Total sample
	Low payoff	High payoff	Low payoff	High payoff	
EV	15.7	14.8	25.6	15.6	19.8
Maximin	52.9	57.0	52.4	66.9	55.5
Least-Likely	11.1	12.5	5.7	3.1	7.6
Maximax	20.3	15.6	16.3	14.5	17.0
Total	100	100	100	100	100

Note. Entries are percentages.

Next, we conducted a multinomial logistic regression to assess whether a participant's strategy depends on the respondent's numeracy, the payoff condition, or both. A series of models were fitted and the most parsimonious model was retained, final estimates are presented in Table 7.

First, we examined the result graphically. The graphs in Figure 2 show the relationship between numeracy and the predicted probability for each decision strategy, by payoff condition. The relationship between numeracy and the probability of selecting an EV strategy (see Figure 2a) was generally positive when payoffs were low, indicating that higher numeracy was related to a higher probability of selecting an EV strategy, but it was almost constant when payoffs were high. On the other hand, the relationship between numeracy and the probability of selecting a maximin strategy (see Figure 2b) was strong and positive for high payoffs, and generally weak and positive for low payoffs. Furthermore, the relationship between numeracy and the probability of selecting the least-likely strategy (see Figure 2c) or the maximax strategy (see Figure 2d) was negative for both payoffs conditions, indicating that, independent of the payoff, higher numeracy was related to a lower probability of selecting either a least-likely or a maximax strategy.

We now turn to evaluate the selection of the strategies in comparative terms. We used the EV strategy as the reference category in the multinomial logistic regression. Therefore, the estimated parameters indicate whether numeracy, or the payoff condition, affects the likelihood of selecting the maximin, least-likely, or maximax strategy rather than the EV strategy.

Table 7, Column 1 presents the model comparing the EV strategy with the maximin strategy; overall there was a significant interaction between numeracy and the payoff conditions (*b* = -0.133, Wald χ^2 (1) = 7.124, p = .008). Therefore, the effect of numeracy on the likelihood of selecting a maximin strategy over an EV strategy depends on whether the payoff is low or high. To explore this further, we obtained the logit model for each payoff condition. The predicted log odds for participants in the *low payoff condition* was, $\ln\left(\frac{P(EV)}{P(Maximin)}\right) = 1.024 - 0.075\ (Numeracy)$. Similarly, the predicted log odds for participants in the *high payoff condition* was, $\ln\left(\frac{P(EV)}{P(Maximin)}\right) = 1.477 + 0.058\ (Numeracy)$. The estimated slopes in the previous equations (Slope low payoff condition = -0.075; Slope high payoff condition = 0.058) indicate that as participants' numeracy increased the odds of selecting a maximin strategy, rather than an EV strategy, increased when payoffs were high but decreased when payoffs were low.

The model comparing the least-likely strategy with the EV strategy is reported in Table 7, column 2. The interaction between numeracy and the payoff conditions was not statistically significant (*b* = -0.037, Wald χ^2 (1) = 0.258, p = .611). However, there was a significant main effect of numeracy (*b* = -0.129, Wald χ^2 (1) = 4.266, p = .039). The odds ratio showed that as numeracy increased the likelihood of selecting a least-likely strategy decreased (Odds ratio = 0.879). Finally, the model contrasting the maximax strategy with the EV strategy is reported in Table 7, column 3. Neither the interaction between numeracy and the payoff conditions (*b* = -0.116, Wald χ^2 (1) = 3.716, p = .054), nor the main effect of numeracy were statistically significant (*b* = -0.050, Wald χ^2 (1) = 0.912, p =.340).

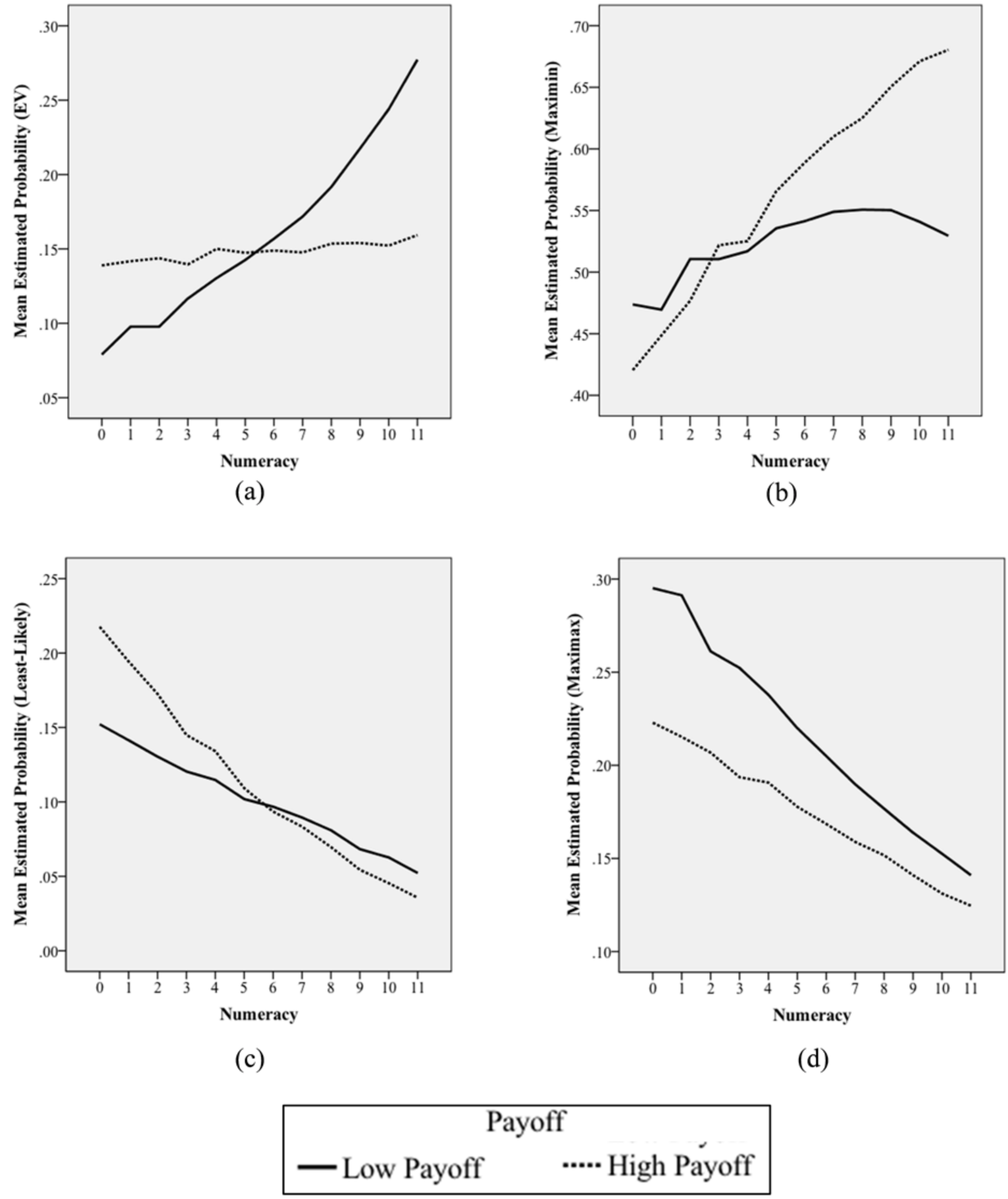
Table 7. Results of a multinomial logistic regression with Expected Value strategy as the reference category

	Maximin vs. EV		**Least-Likely vs. EV**		**Maximax vs. EV**	
	b (SD)	***Odds Ratio***	***b (SD)***	***Odds Ratio***	***b (SD)***	***Odds Ratio***
Numeracy	0.058 (0.043)	1.060	-0.129* (0.062)	0.879	-0.050 (0.053)	0.951
Female	-0.418** (0.109)	0.659	-0.137 (0.178)	0.872	-0.133 (0.138)	0.876
High education	0.257* (0.116)	1.293	0.750** (0.210)	2.117	0.177 (0.149)	1.193
Low-High Contrast	-0.453** (0.124)	0.636	-0.109 (0.212)	0.897	-0.126 (0.158)	0.882
Numeracy * Low-High Contrast	-0.133** (0.050)	0.876	-0.037 (0.072)	0.964	-0.116 (0.060)	0.891
Intercept	1.477 (0.139)		-1.320 (0.253)		-.073 (0.179)	

Note: Entries are regression coefficients. Standard errors in parentheses. *$p < .05$, **$p < .01$. Omitted categories: male and low education (primary and lower secondary education).

Taken together, these comparative analyses show that the likelihood of using maximin, rather than EV, depends on both numeracy and payoffs. As participants' numeracy increased, the likelihood of using a maximin strategy, rather than EV, increased when payoffs were high, but decreased when payoffs were low. On the contrary, independently of the payoffs, as numeracy increased, the likelihood of choosing the least-likely, rather than the EV, decreased. We did not find an association between numeracy and the payoff on the likelihood of selecting maximax rather than EV.

Figure 2. Graphs depicting the relationship between numeracy and predicted probability, by payoff condition, of each decision strategy



Discussion

The evidence for the effect of numeracy on the willingness to take risk is mixed. Some studies have found that high numerate individuals are more willing to take risk and make more choices consistent with expected-value maximization than low numerate individuals (Cokely & Kelley, 2009; Frederick, 2005; Pachur & Galesic, 2013; Dave et al., 2010) while others find no such effects (Benjamin et al., 2013; Jasper et al., 2013). Although informative, previous studies were limited in terms of the size and representativeness of the sample, and could not control for potentially confounding factors. Here, we examined the relationship between numeracy and willingness to take risk for a large Dutch population sample, controlling for potential correlated factors (e.g., age, gender, education, and income). Our findings revealed that willingness to take risk depends on both people's numeracy and the payoff. When the payoff was low, there were no significant differences in the willingness to take risk between individuals with low and high numeracy. On the contrary, when the payoff was high, individuals with higher numeracy were significantly *less* willing to take risk than participants with low numeracy. Furthermore, we found that participants with high numeracy made fewer risky choices when the stakes were high as compared to when they were low. In contrast, the number of risky choices of low numerate participants appeared to be invariant to changes in payoffs.

In terms of the proportion of choices consistent with expected-value maximization, we found that numeracy and the stakes of the lotteries also interact. When the payoff was low, high numerate participants made more choices consistent with expected value than their low numerate counterparts. However, when the payoff was high there were no differences in the proportion of expected value choices between low and high numerate participants. In general, all participants made fewer choices consistent with expected value when the payoff was high compared to when it was low.

Regarding the decision strategies underlying participants' choices, our findings revealed that the likelihood of using an EV or a maximin strategy depends on both numeracy and payoffs. Specifically, as participants' numeracy increased the likelihood of using EV increased when payoffs were low but decreased when payoffs were high. The opposite was observed for the maximin strategy: higher numeracy was related to a lower probability of selecting this strategy when payoffs were low and to a higher probability when payoffs were high. Finally, independently of the payoffs, as numeracy increased the likelihood of choosing the least-likely or the maximax strategy decreased.

We think that the main contribution of our research is that it reveals that the willingness to take risk of high numerate people is conditional upon the stakes at play. Conversely, the risk attitude of low numerate people appears to be invariant across the stakes. These differences might be explained by low numerate and high numerate people using different decision strategies. Participants with low numeracy appear to use the same decision strategy independent of the payoff. In contrast, for low payoffs, high numerate people were likely to use an expected value strategy; however, when the stakes increased, they changed to a risk conservative strategy, as is the maximin. Remember that according to the maximin strategy the decision maker should choose the alternative that provides the best outcome under the worst circumstances. This way, decision makers can maximize their outcome even if the circumstances turn out to be disadvantageous.

Our findings raise the query of why high numerate participants were less willing to take risk when the payoff was high compared to when it was low. One possible explanation is that they might have derived evaluative meaning from the numeric information by comparing the payoffs to more familiar monetary quantities. For instance, they could have compared the lottery outcomes to the cost of a meal in the low payoff condition and to the average monthly salary in the high payoff condition. Furthermore, this number-comparison process could have highlighted the potential detrimental financial consequences of taking a risky bet in the high payoff condition, and the less significant consequences of taking risk when the stakes were low. In that case, this number-comparison could have resulted in a change of the attractiveness of the gamble in the high payoff condition.

Note that in the high payoff condition, the difference between the worst possible outcome of the lottery and the guaranteed option was €3,750 on average. Therefore, choosing the lottery rather than the guaranteed option, and facing the lottery's worst outcome, implies a loss of €3,750, which is almost a €1,000 higher than the average monthly salary in this population (Mean gross monthly income = €2,460). Without a reference point or context, numbers are particularly difficult to evaluate (Hsee, 1996; Hsee & Rottenstreich, 2004; Hsee & Zhang, 2010). On the contrary, bringing context to the numbers, for example by comparing an unfamiliar quantity to a familiar quantity, facilitates its understanding (Peters, Dieckmann, Västfjäll, Mertz, Slovic, & Hibbard, 2009). For instance, knowing that you risk losing €3,750 is probably less informative than knowing that losing €3,750 is like losing your monthly salary.

Our findings also add to the growing literature documenting that the less numerate are relatively insensitive to differences between numeric magnitudes (Jasper et al., 2013; Kleber, Dickert, Peters, & Florack, 2013). Here, we show that the risky choices of the low numerate individuals were virtually invariant to differences in the stakes of the lottery.

A further contribution of the present research is the comparison of multiple decision strategies. Previous investigations could only discriminate whether participants were or were not making decisions in accordance with an EV strategy. In this paper we tested not only whether participants were using a compensatory EV strategy but also whether or not they decided in accordance with three other heuristic strategies. We suggest that the systematic comparison of different decision models could provide important insight on the cognitive processes underlying choices. In particular, the comparison of these four models can help researchers to best describe how people with low and high numeracy use information on probabilities and outcomes to make decisions facing risk.

Although our findings revealed that participants deviate more from expected-value-consistent choices when the payoff was high compared to when it was low, and that this effect was stronger for high numerate participants than for low numerate participants, a word of caution is needed here. Our measure was based on four choices. In three of those choices the risky option (the lottery) had a higher expected value than the guaranteed option. Therefore, participants choosing the guaranteed option were coded as deviating from an expected-value-consistent choice. It is possible, however, that this measure captures participants' risk aversion more than systematic deviations from normative choices. In order to better study whether individuals systematically deviate from normative choices consistent with expected-value maximization, it would be necessary to include options in the choice set in which the expected value of the guaranteed option is higher than the expected value for the risky option. If an individual systematically deviates from normative choices, he or she should choose the risky option also in this last case.

Conclusion and final remarks

In sum, although the overall emerging picture in the literature is that there is a relationship between numeracy and risk attitudes, the empirical evidence is mixed. In this paper we addressed this question using a large sample and a meticulous experiment for risk elicitation, and we found that the relationship between numeracy and risk attitudes is better represented as a complex mosaic rather than a simple pattern. When payoffs were low we did not find a difference between participants with low and high numeracy on their willingness to take risk.

On the contrary, when payoffs were high participants with high numeracy were more risk averse, and not less, as has been suggested before. We propose that our findings are consistent with high numerate individuals being more likely to bring context to the numbers and to realize the possible detrimental financial consequences of their choices. However, we are aware that although this is a possible explanation for our findings, this explanation is post hoc and other factors could have accounted for our findings.

Appendix A

Classification of participants into the decision strategies

In order to investigate the cognitive process underlying participants' choices, we modeled each participant's responses with the expected value (EV) strategy, the maximin strategy, the maximax strategy and the least-likely strategy, and classified each participant to the strategy with the best fit. Specifically, participants made 10 binary choices between lotteries and our goal was to determine the strategy that most likely generated those choices. We further refer to the 10 binary choices as problems - from problem 1 to problem 10. Table A.1 displays these problems. We followed the classification procedure proposed by Bröder and Schiffer (2003) and used a similar notation.

The first step was to determine, for each problem, the answer-choice consistent with following each of the 4 strategies. For example, in problem 1, first row in Table A.1, participants were asked to choose between a guaranteed Option A (€20) over a risky Option B (50% chance of €65, otherwise €5), a participant following the EV strategy prefers option B, while a participant following the minimax strategy prefers option A. Notice that based on the answers to this problem we can differentiate between a participant following the EV strategy and a participant following the minimax. However, we cannot discriminate between someone following the EV from someone following the maximax or the least-likely strategy, because individuals following any of these three strategies would prefer option B.

Problems 2 and 3 are similar too problem 1, they make the same predictions about the response-choices consistent with each of the strategies: someone following EV chooses B, following the minimax chooses A, the maximax chooses B and the least-likely strategy chooses B. On the contrary, problems 6, 7, and 9 make different predictions than problem 1: a participant following EV chooses A or B, the minimax chooses A, the maximax chooses A and following the least likely strategy chooses B. Note that these three problems cannot make a prediction about the response-choice that is consistent with following an EV strategy, because both options, A and B, have the same expected value. In that sense, both options are equally consistent (or inconsistent) with the strategy. All instances in which it was not possible to determine whether Option A or Option B was consistent with a particular strategy are shown in Table A.1 as ‘A-B’.

As explained above, each of the 10 problems can be characterized based on the 4 predictions that they make about the response-choice consistent with each strategy. Five different response patterns were identified and hence, we classified the 10 problems into 5 problem-types. Table A.1 displays the correspondence between problems and problem-type. Subsequently, the likelihood functions were calculated as described below.

Let k denote the decision strategy such that $k \in$ {EV, Minimax, Maximax, Least-likely, Random} with Random being the strategy of guessing. Let j be the problem-type as shown in Table A.1 with $j \in \{1, 2, 3, 4, 5\}$, and let n_j be the number of each problem-type j in the task. Further, for each participant i let n_{ijk} be the number of observed choices of problem-type j that are compatible with strategy k. Then, the likelihood of the observed frequencies under the assumption of strategy k can be calculated as follows:

$$L_{ik} = p\left(n_{ijk} \mid k, \varepsilon_{ik}\right) = \prod_{j=1}^{5} \binom{n_j}{n_{ijk}} \times (1 - \varepsilon_{ik})^{n_{ijk}} \times \varepsilon_{ik}{}^{(n_j - n_{ijk})}$$

Where ε_{ik} represents participants i’s error for strategy k. For each strategy ε_{ik} was estimated as the proportion of choices that deviated from strategy k’s predictions. Remember that we mentioned that some problems cannot make a prediction for a certain strategy (shown as ‘A-B’ in Table A.1). Therefore, ε_{ik} for the EV strategy was calculated as the number of choices inconsistent with an EV strategy divided by 4. Likewise, the ε_{ik} for the least-likely strategy was calculated as the number of choices inconsistent with a least-likely strategy divided by 8. Additionally, ε_{ik} = 0.5 for k = Random and for problems that cannot make a prediction (‘A-B’ in Table A.1). Finally, the likelihood value was undefined for ε_{ik}= 0, however, this also means that a participant’s choices perfectly match the predictions of strategy k. Therefore, in these cases, participants were classified as following that strategy.

Finally, after computing the likelihood functions for each strategy for each participant, we classified each participant into the strategy with the highest likelihood. We used the following criteria: if the likelihood of the best fitting strategy equaled or was lower than the value of the likelihood function under random choice, then the participant was classified as following a random strategy. However, none of the participants was finally classified as following a random strategy.

Table A.1. Lottery problems, response-choice predictions and problem-type classification

	Choices		Response-choice predictions				
	Option A	**Option B**	**EV**	**Minimax**	**Least-likely**	**Maximax**	**Problem-type**
1	Guaranteed €20	€65(.50)_ €5(.50)	B	A	B	B	1
2	Guaranteed €25	€65(.50)_ €5(.50)	B	A	B	B	1
3	Guaranteed €30	€65(.50)_ €5(.50)	B	A	B	B	1
4	Guaranteed €35	€65(.50)_ €5(.50)	A-B	A	B	B	2
5	Guaranteed €40	€65(.50)_ €5(.50)	A	A	B	B	3
6	€110(.25)_ €70(.25)_ €60(.50)	€90(.50)_ €80(.25)_ €40(.50)	A-B	A	B	A	4
7	€100(.25)_ €80(.25)_ €60(.50)	€90(.50)_ €70(.25)_ €50(.50)	A-B	A	B	A	4
8	€130(.25)_ €50(.25)_ €60(.50)	€90(.50)_ €100(.25)_ €20(.50)	A-B	A	A-B	A	5
9	€165(.25)_ €105(.25)_ €90(.50)	€135(.50)_ €120(.25)_ €60(.50)	A-B	A	B	A	4
10	€85(.25)_ €45(.25)_ €35(.50)	€65(.50)_ €55(.25)_ €15(.50)	A-B	A	A-B	A	5

Note. A guaranteed option indicates the participant receives that quantity for sure. Lottery problems are described by the payoff followed by the corresponding probability in parenthesis. For instance, "€65(.50)_€5(.50)" can be read as 50% chance of €65 and a 50% chance of €5. Response-choice predictions indicate, for each problem, the Option (A or B) consistent with that strategy. In the high payoff condition payoffs displayed in the table were scaled up by a factor of 150.

CHAPTER 5

General discussion

In this thesis I studied the psychology of numeracy and more specifically aimed to better understand the relationship between an individual's numeracy and his or her wealth. Numeracy refers to a person's ability to use mathematical knowledge in reflective and insight-based ways (see Chapter 1 for a more elaborate discussion of what numeracy is). Wealth refers to a person's financial assets (e.g., saving accounts), nonfinancial assets (e.g., art and precious metals) and liabilities (e.g., mortgages) accrued over the lifetime. Wealth is critical for people's well-being because it allows individuals to be economically secure, stable and independent, and to create opportunities for the next generation (Shapiro, Meschede, & Osoro, 2013). In this thesis I aimed to better understand whether numeracy is a primary force behind wealth accumulation. In this final chapter, I first summarize the main empirical findings, and then I elaborate on what we have learned from these findings with regards to the psychology of numeracy and its relationship with wealth. Finally, this chapter concludes with recommendations for future research.

Overview of the empirical chapters and main findings

The question of whether numeracy has a unique effect on wealth is central throughout Chapter 2. In particular, in this chapter I aimed at answering two questions: 1). Is the effect of numeracy on wealth sensitive to the inclusion of controls for differences in economic preferences, constraints, and beliefs; and 2). Does numeracy have an effect on the trajectory of wealth accumulation that people follow over time. The empirical findings revealed that numeracy has a unique effect on wealth, over and above the effect of other potential confounding factors such as risk preferences, seeking financial advice, beliefs about future income, financial knowledge and need for cognition. In addition, a longitudinal model showed that numeracy is a key determinant of the wealth accumulation trajectories that people follow over time. Over a 5-year period (2007 – 2011), while participants with low numeracy tend to decumulate wealth, participants with high numeracy tend to maintain a constant level of wealth. These findings provide clear indications that differences in individuals' numeracy, rather than more standard sources of heterogeneity, explain significant variation in wealth. These results are important because they show that numeracy is (at least to some degree) an independent construct, that is not acting as a proxy for some other cognitive variables, and that plays a unique role when it comes to explaining financial behavior.

In Chapter 3, a new sample was introduced to study whether the effect of numeracy on wealth extends to simpler financial environments. In line with Chapter 2, the empirical findings in Chapter 3 revealed that higher numeracy was also associated with higher wealth in an agrarian population from the Highlands of Peru. In this economy wealth is acquired not only through monetary exchanges, but also by barter and reciprocal labor. The finding that numeracy is related to wealth in this population is important because it indicates that even in this relatively less complex financial environment, where the mathematical demands are relatively low, numeracy still plays a clear role in predicting wealth. The findings in this chapter contribute to the numeracy literature by extending our understanding of the scope of the effects of numeracy. Specifically, they suggest that the effect of numeracy on financial behavior goes beyond facilitating mere calculations and extends to how people reason and think about numbers and quantities more generally. Chapter 3 further extends the results from Chapter 2 documenting that the association between numeracy and wealth was robust after accounting for differences in fluid intelligence, crystallized intelligence, and the direct effects of education.

Findings in Chapters 2 and 3 add to the numeracy literature by documenting that numeracy has a unique effect on maybe the most important economic outcome, namely an individuals' wealth. I believe establishing the existence of this association is the first step in our course to better understand the relationship between numeracy and wealth. Now that we have clear evidence that numeracy has a robust association with wealth, we can move to study what are the possible mechanisms by which numeracy affects wealth accumulation.

In the subsequent chapter, Chapter 4, I aimed to understand how numeracy and wealth can be related. To this end, this chapter builds forth on the idea that numeracy is systematically associated to individuals' economic preferences (i.e., risk and time preferences) that are likely to affect financial behavior. In particular, this chapter explored whether numeracy is associated with an individual's willingness to take risk and found that this relationship is more complex than we originally thought. When the payoff was low, there were no significant differences in the willingness to take risk between individuals with lower and higher numeracy. On the contrary, when the payoff was high, individuals with higher numeracy were significantly less willing to take risk than participants with lower numeracy. Furthermore, the findings show that while the risky choices of participants with higher numeracy varied according to the stakes of the lotteries, the choices of low numerate participants appeared to be invariant to changes in payoffs.

In order to gain further understanding on how and why differences in risk attitudes might arise, Chapter 4 explored whether these differences were explained by lower and higher numerate people using different decision strategies. Specifically, in this chapter I comparatively investigate the use of four decision strategies (i.e., expected value strategy, least-likely, maximin, and maximax). A decision strategy describes how the information is being used to make a decision. Then, it tells us what type of information is being prioritized, what type of information is being neglected, and what criteria are being used to choose between the different alternatives (Table 1 in Chapter 3 summarizes the decision criteria for these four strategies). Each of the strategies considered in this chapter has a particular way to handle probabilities and outcomes inherent to choices under risk. We can then use people's decision strategies to study the cognitive processes behind their choices. For instances, the decision strategy can tell us whether the person combined both outcome and probabilities, as is the case for people following an expected value strategy, or whether the person considered only the worst outcome independent of the probability, as is the case for someone following the maximin strategy. The findings in Chapter 4 revealed that as participants' numeracy increased, the likelihood of using an expected value strategy increased when payoffs were low, but decreased when payoffs were high. The opposite was observed for the maximin strategy. Independently of the payoffs, as numeracy increased the likelihood of choosing the least-likely or the maximax strategy decreased.

The findings in Chapter 4 are of particular importance because they add precision to the predictions of the risk attitudes and risk behaviors of the more and less numerate. Based on these findings, I would expect that the magnitude of the outcomes would help to predict the choices of the higher numerate, but it would be less informative to predict the choices of the lower numerate. The findings in Chapter 4 also imply that numeracy has an effect on how the information is processed and on the criteria that are being used when making a decision. This result is important because it provides first evidence that numeracy also influences the specific cognitive processes underlying individual decision making, and not only the handling of numbers. Below, in the section called "How is numeracy related to wealth?" I hypothesize on how different risk attitudes for low and high payoffs as well as the use of different decision strategies can lead to accumulating more wealth.

After having summarized the empirical findings presented in this thesis, let me now return to the central questions of this thesis, namely *what is numeracy* and *how is numeracy related to wealth*, and discuss the answers my research gives. I also elaborate on future lines of research that may further increase our understanding of the psychology of numeracy and its relationship with wealth and other financial outcomes.

What is numeracy?

In the Introduction I described that numeracy encompasses not only the ability to calculate but that it extends further to how people reason and think about numbers and quantities more generally (Peters, 2012; Nelson, Reyna, Fagerlin, Lipkus, & Peters, 2008; Fagerlin, Zikmund-Fisher, Ubel, Jankovic, Derry, & Smith, 2007; Cokely, Galesic, Schulz, Ghazal, & García-Retamero, 2012). However, theories on the psychology of numeracy have developed much faster than the empirical work that tests those theories (see Nelson et al., 2008) and only recently have we started to better understand what cognitive processes are colored by people's numeracy. For instance, there is by now substantive evidence that numeracy is systematically associated with cognitive biases such as framing effects (Peters et al., 2006), conjunction and disjunction fallacies, and the ratio-bias phenomena (Liberali, Reyna, Furlan, Stein, & Pardo, 2012). The findings obtained in Chapter 4 add to our understanding of the cognitive processes affected by numeracy. Specifically, these results suggest that numeracy influences how information about outcomes and probabilities is being used in order to make a decision, that is what information is prioritized, what information is neglected and what criteria are being used to select one alternative over the others.

Therefore, based on the findings in Chapter 4, I adhere to the idea of numeracy as an individual's ability that extends beyond calculation abilities to color the way people perceive their world, how they understand the problems around them and the strategies they use to solve those problems.

How is numeracy related to wealth?

After accumulating compelling evidence that the association between numeracy and wealth is robust, statistically significant and economically relevant (Chapters 2 and 3), we can hypothesize on how numeracy affects wealth. Based on the findings in Chapter 4, I propose that one possible mechanism is that numeracy is associated with the willingness to take risk and that willingness to take risk in turn influences individuals' financial choices. One finding from Chapter 4 that is of particular importance in light of this model, is the finding that participants with higher numeracy are less willing to take risk when the stakes at play are relatively high. This finding shows that the mechanism by which numeracy affects willingness to take risk and in turn wealth accumulation, seems to be modulated by the magnitude of the potential outcomes. How can a preference for taking less financial risk lead to accumulating higher wealth? I propose that by limiting the exposure to risk, individuals with higher numeracy reduce the volatility of their income. With a more stable cash flow of income, it is easier for individuals to make and stick to a budget and, therefore, easier to save. On the contrary, high income volatility, not only makes it more difficult for individuals to plan consumption and savings, but it can also cause them to turn to costly solutions to short-term cash flow shortfalls, with both factors having detrimental consequences on wealth.

Findings in Chapter 4 also revealed that numeracy was related to the decision strategies underlying people's choices. How can the maximin strategy and the expected value strategy affect wealth accumulation? I believe following a maximin strategy protects people from experiencing extreme negative outcomes. As I see it, individuals following this strategy adopt a prudent attitude towards risk. They foresee the potential negative consequences of their choices and take actions to protect themselves from extreme negative financial situations. This prudent risk behavior, when the outcomes are high, protects individuals from ending up in very disadvantageous financial situation, such as losing their life savings. One behavior that is consistent with this strategy would be to buy insurance for home and property damage. I would expect people with higher numeracy to have this type of insurance.

However, being too prudent is not always good because one may miss opportunities that are profitable. Especially in situations where the outcomes are not too consequential for people's finances, it may be advantageous to take risk. One behavior that is consistent with this strategy is to *not* buy insurance for small possession such as bikes or cellphones. Based on the findings in Chapter 4, I would expect people with higher numeracy to not have these type of insurances.

Can numeracy be improved?

Given the important role of numeracy on people's financial wellbeing, it is pertinent to ask whether and, if so, how numeracy can be improved. The latest report from the OECD's Programme for the International Assessment of Adult Competencies (PIAAC), which measures numeracy skills among adolescents and adults aged 16-65 from 24 countries, indicated that countries investing on providing a high-quality primary and middle education have made significant progress improving numeracy proficiency. For instance, while older Koreans (55-65 year-olds) are among the lowest-performing countries, younger Korean (16-24 year-olds) are among the top performers. The same was observed with Finns. The progress that these countries have made in improving numeracy skills of their population over successive generations strongly suggests that numeracy can be improved through policy and changes to the educational system (OECD, 2013).

A related question is whether it is possible to improve people's numeracy after they have completed their formal education (i.e., after finishing high school or a higher education). A recent overview of the literature (Brooks, Giles, Harman, Kendall, Rees, & Whittaker, 2001) and a meta-analysis (Torgerson, Porthouse, & Brooks, 2003) concluded that the overall evidence is suggestive of a benefit of adult numeracy interventions. However, the heterogeneity of the studies makes it difficult to determine the precise role of any particular type of intervention (i.e., counseling, seminar or workshop, exposure to information such as a newsletter or a fair; Brooks et al., 2001; Torgerson et al., 2003). Moreover, researchers have suggested to look at these findings with caution since they may be undermined by the presence of substantial publication bias (Torgerson et al., 2003).

Finally, we can ask the question of whether an intervention to improve people's numeracy would have long-lasting effects on people's wealth. To my knowledge there is no empirical evidence specifically testing this hypothesis. However, related research has been done in the field of financial literacy and financial education. The overall evidence suggests that the effect of financial education on financial outcomes is very limited (see Fernandes, Lynch, & Netemeyer, 2013). A meta-analysis performed on the impact of financial education on financial literacy and financial outcomes showed that interventions to improve financial literacy explain only 0.1% of variance in financial behaviors. This meta-analysis also revealed that benefits of financial education decline over time and even large interventions with many hours of instruction have negligible behavioral effects after 20 months (Fernandes et al., 2013). Experts in the field have suggested that one of the reasons to explain why these programs may fail is that there is not enough focus on the numeracy skills needed to improve people's financial capability (Carpena, Cole, Shapiro, & Bilal, 2011; Lusardi, 2012). There is, however, no empirical research to support their statement.

As yet, we have little concrete evidence to provide an answer to the question of how to improve numeracy. We have a pressing need for more and better research to inform the design of numeracy interventions that can support individuals to improve financial decision making.

Future directions

Based on the knowledge we have gained over the years, including the findings presented in this thesis, we have a solid based to believe that numeracy is closely linked to financial outcomes. However, the causal mechanisms at work are still under investigation. Future research, which I hope to have the opportunity to be part of, should focus on better understanding these mechanisms. One possible avenue for future research is to explore the effect of different mathematical competencies, that are part of the numeracy construct, on the financial decision making process. Mathematical competencies such as objective numeracy, subjective numeracy and symbolic-number mapping abilities (i.e., internal representation of numeric magnitude and the mapping of symbolic numbers onto those representations) have shown to have separable influences in evaluations and choice (Peters & Bjalkebring, 2015). Therefore, unraveling how they interact with financial information processing, preference formation and financial choices would give us novel insights on how numeracy impacts financial decision making. Moreover, this research would help us to design better interventions to improve the decision making of the low numerate by targeting more specific mathematical competencies.

Another interesting question entails the great heterogeneity of numeracy across countries. Comparative research has documented important differences in numeracy proficiency across countries (OECD, 2013). Future research could study how numeracy is taught in high and low numeracy achiever countries. An integrated approach investigating how numeracy is taught and practiced at school, at home, and in daily life would provide a better understanding of how citizens in the high-achiever countries appear to achieve those high numeracy scores. I am interested in studying what happens inside the classrooms, and specifically, to identify whether factors such as the level of cognitive demands, the number of hours of class per year, the quality of teachers' feedback, the type of mathematical books that children follow, the number of mathematical problems discussed in class, or the curriculum coverage could help us to explain these differences between countries.

This thesis also provides some methodological implications for the study of wealth. The findings presented here suggest that measures of numeracy, intelligence and education may not be interchangeable for the purpose of explaining differences in wealth. Each of these factors has a unique and independent effect on wealth and wealth accumulation over time, and may do so through various mechanisms. Therefore, based on the empirical evidence reported in this thesis, I recommend including measures of numeracy, along with measures of intelligence and education, as an important control measure in wealth research.

Concluding remark

Numbers are an inextricable part of people's life. Numbers are necessary not only for simple, daily tasks such as calculating an appropriate tip for a waiter, but also for more complex decisions such as buying a house or starting a new business. One context in which numbers are particularly pervasive, and have striking importance, is financial decision making. Financial information such as prices, fees, interest rates, amortizations, saving rates, risks, or profits are all communicated using numerical information. These numbers convey important information about the different alternatives and they are necessary to make well-founded judgments about the different options. I believe numeracy plays a critical role in how people cope with this information. Moreover, I believe the way people cope with numerical information has a profound effects on people's saving, spending and borrowing decisions, which are conducive to the accumulation or decumulation of wealth. Therefore, I plead for valuing numeracy as an important factor affecting people's financial outcomes, and I hope the research described in this thesis will also serve as an inspiration for future research.

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Final remark: this thesis is about numbers and although some people think that numbers are boring, I want to show you that they can actually be a lot of fun! Specially for you, I have prepared some cool games that you can explore in the next page. Enjoy!

Catalina Estrada-Mejia, October 2015

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Interesting mathematical problems!!

1. There is a three digit number. The second digit is four times as big as the third digit, while the first digit is three less than the second digit. What is the number?

2. Which 3 numbers have the same answer whether they're added or multiplied together?

3. There is a basket containing 5 apples, how do you divide the apples among 5 children so that each child has 1 apple while 1 apple remains in the basket?

4. Complete this grid with the digits 1 to 6 to make the sum correct. Perform each mathematical operation in the order shown, from left to right, e.g. 1 + 2 x 3 is treated as (1 + 2) x 3 = 9. Note: there is no ÷ 1, and at no point is a decimal or fraction used.

	+		−		x		÷		x		=	50

5. A ship anchored in a port has a ladder which hangs over the side. The length of the ladder is 200cm, the distance between each rung in 20cm and the bottom rung touches the water. The tide rises at a rate of 10cm an hour. When will the water reach the fifth rung?

Answers: (1) 141. (2) 1, 2 and 3. (3) 4 children get 1 apple each while the fifth child gets the basket with the remaining apple still in it. (4) $2 + 4 - 1 \times 6 \div 3 \times 5 = 50$. (5) The tide raises both the water and the boat so the water will never reach the fifth rung. Retrieved from http://www.brainbashers.com and http://www.kidsmathgamesonline.com.