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Major accident prevention decision-making: a large-scale survey-based analysis

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Abstract. *Decision-making under risk and uncertainty is not straightforward. This paper investigates how people make decisions when they need to choose between prevention and production investments and the decision involves risks and uncertainties that could have major negative consequences. A questionnaire was conducted among 405 students at the University of Antwerp, in Belgium. With regard to decision-making under risk, the findings reveal that the respondents behaved in a more risk-averse manner than predicted by the theory of expected values. Concerning decision-making under uncertainty, the respondents also displayed more risk-averse decision-making behaviour than anticipated, especially under circumstances of complete uncertainty. The study also shows that men are more likely to behave in a more risk-seeking manner than women are, and that people with a high intuitive thinking style are less risk-averse than people with a low intuitive thinking style. Furthermore, people with a high rational thinking style are more risk-averse than people with a low rational thinking style, and respondents with a high sensation-seeking style make decisions in a more risk-seeking way than respondents with a low sensation-seeking style.*

Keywords. decision-making, major accident prevention, risk, uncertainty, risk acceptance criteria

1. Introduction

Making decisions generally requires choosing among alternatives and their possible outcomes. The various alternatives and possible outcomes are frequently associated with risk and uncertainty. The same applies to decisions that companies need to make concerning investments in safety. Not investing in safety entails risk and uncertainty: it can result in loss, in the event of an accident, or in hypothetical gain, if the accident does not occur (Barkan et al., 1998).

There is no simple means of evaluating and managing the risks and uncertainties that are associated with decision-making (Klinke and Renn, 2002). In addition, decision-making under uncertainty is not the same as decision-making under risk. Under risk, all outcomes are known, as are the likelihoods of each outcome occurring. Under uncertainty, some of the alternatives, outcomes and likelihoods may be unknown (Mousavi and Gigerenzer, 2014). However, the distinction between risk and uncertainty remains unclear, as risks are very uncertain. After all, likelihoods are only an approximation of a prediction and predictions of risk are therefore characterised by uncertainty (Klinke and Renn, 2002; Aven and Kristensen, 2005).

2. Literature study

There is an extensive body of literature on decision-making under risk and uncertainty (Aliev et al., 2012). Several disciplines have formulated a wide range of perspectives, theories, models and mathematical formulas for modelling human behaviour under conditions of risk and uncertainty (Aven and Kristensen, 2005; Aliev et al., 2012). As a detailed overview would lead us too far, we discuss only those disciplines related to the focus of this study and their prevailing perspectives concerning decision-making. For example, engineers perform risk analyses to support their decision-making. This risk assessment can serve as a basis for rational decision-making about risks, allowing for the evaluation and classification of a risk situation as either acceptable or unacceptable (Rodrigues et al., 2014). Risk comprises two dimensions: (a) the possible consequences or extent of the loss; and (b) its associated likelihood, for example expressed as a probability (Aven and Kristensen, 2005; Meyer and Reniers, 2013). Based on these constitutive elements of risk, the value of the risk can be estimated (Meyer and Reniers, 2013). The simplest model for calculating the value of risk is a combination of the extent of the loss and the probability of occurrence (Klinke and Renn, 2002). Multiplying these two dimensions of risk together generates the expected value of the risk. The results of this risk assessment are often presented in a matrix-like form (Meyer and Reniers, 2013), which allows the risk to be classified as, for example, normal, intermediate or intolerable risk (WBGU, 2000).

Risk analyses are often used in combination with risk acceptance criteria in order to support decision-making (Aven and Kristensen, 2005; Rodrigues et al., 2014). Risk acceptance criteria are defined as the upper limits of acceptable risk and can be used to decide on the need for risk-reducing measures (Rodrigues et al., 2014). The criteria may result from the user's own risk appreciation, be legislation-driven or based on corporate guidelines. Defining risk acceptance criteria is difficult, however. A range of concerns need to be balanced in order to determine acceptable risks concerning the safety of assets, employees and third parties such as the external population (Abrahamsen and Aven, 2008). After all, acceptability should also consider the positive aspects of taking the risk, for example the benefits that such an activity would generate in terms of income and employment (Aven and Kristensen, 2005). A further element of complexity is that risk stakeholders are often divided in three categories: risk managers, risk receptors and risk beneficiaries (Freeman, 1984).

A number of mathematical theories and models with strong analytical power have been designed for decision-making under risk and uncertainty. For example, one of the predominant paradigms for decision-making under uncertainty is the expected utility theory (Abrahamsen and Aven, 2008). According to this theory, individuals tend to maximise expected utility; agents are motivated by material incentives (self-interest) and make decisions in a rational way (Aliev et al., 2012). However, mathematical theories and models define human behaviour as ideal and inanimate (Aliev et al., 2012). Decision-making tools can be useful in many cases, but it should be kept in mind that they are based on normative theories and models which structure decisions in a rational way (Aven and Kristensen, 2005). Obviously, people do not always act in a purely rational manner and it is often not possible to predict how people will make a choice. In recent decades, researchers have sought to identify and describe how people make decisions under risk and uncertainty and how actual behaviour diverges from the predictions of normative theories and models (Aven and Kristensen, 2005). For example, the prospect theory developed by Kahneman and Tversky includes psychological aspects linked to human behaviour. The theory assumes that people make decisions based on the potential value of losses and gains rather than the final outcome (e.g. Tversky and Kahneman, 1974; Tversky and Kahneman, 1992).

It is not only psychological factors that have an influence on the decision-making process. The perception, acceptance and tolerability of risk and uncertainty are shaped by a number of factors, both individual and organisational. Some examples include the context, the environment, the safety culture of an organisation, knowledge, the source of information and the personal characteristics of the decision maker (e.g. emotions and consideration of social issues such as responsibility) (Slovic et al., 2004; Aven and Kristensen, 2005; Naqvi et al., 2006; Rodrigues et al., 2014). The process is even more complicated when the decisions have to be made in a corporate environment: managers have to take decisions that relate not only to their own lives, but also to the company, its employees and environment (Busenitz and Barney, 1997).

The goal of this paper is to examine how people make decisions when they have to choose between prevention and production investments and the decision involves risks and uncertainties that may have major negative consequences (up to billions of euros worth of losses). We investigate the parameters of consequence and probability within which people judge investment in production to be worth taking a major accident risk for, and the parameters within which they consider a risk or uncertainty unacceptable and opt instead for major accident prevention investment. The paper explores how this decision-making evolves when the probability of an accident increases, when the possible loss increases, and when uncertainty about the probability of occurrence and possible loss increases. Obtaining insights into how these decisions are made (in general) is important for the understanding and management of activities involving potential major accidents (Aven and Kristensen, 2005).

In our analysis of decision-making under risk, we include accidents with major negative consequences, as mentioned above, as well as a variety of probabilities of occurrence. When both the probability of occurrence and the disaster potential are perceived as high, such risks are normally rejected (Klinke and Renn, 2002). Acceptance of accidents with high disaster potential and a low probability of occurrence, known as HILP accidents (High Impact Low Probability), is far less straightforward (Chichilnisky, 2000; Hastie, 2001). It could be argued that the occurrence of large-scale accidents may be unacceptable regardless of their probability. On the other hand, it is unfeasible for organisations to spend unlimited amounts of money on reducing or eliminating accident scenarios. Therefore, a certain level of risk and uncertainty has to be accepted (Rodrigues et al., 2014).

Besides decision-making under risk (in which the outcomes and their probabilities are known), we also consider decision-making under uncertainty. In an uncertain situation, the probability that an accident can occur is unknown and/or the extent of the loss should the accident occur is unknown. When these uncertainties remain, subjective judgements are inevitable (Klinke and Renn, 2002). This makes it difficult to predict decision-making.

3. Methodology

3.1. The questionnaire

A closed-question self-administered questionnaire was conducted among students at the University of Antwerp in Belgium in November and December 2014. The questionnaire was distributed during lectures at the university to students studying a range of disciplines (communication studies, political science, sociology, socioeconomic sciences, film studies and visual culture, linguistics and literature, philosophy, safety sciences, business engineering and medicine).

The questionnaire consisted of three parts. The first part covered socio-demographic variables: gender, year of birth, highest level of education achieved to date, work status (student or employed student, i.e. studying and working more than 50 days per year) and study programme. In the second part of the questionnaire, the respondents were asked to imagine they were responsible for taking decisions concerning investments within a company. They received the following background information about the company, which is based on data from an existing international petrochemical company:

- It is a petrochemical company with 200 employees
- The company has an annual profit of €10,000,000, an annual turnover of €300,000,000 and €1,000,000,000 capital

Given this information, the respondents were asked to make several choices between (a) a production investment and (b) a prevention investment. The investment amount was identical for each type of investment. The respondents had to indicate the response which, in their opinion, was the most ideal. It was clearly stated that there were no right or wrong answers.

If the respondents chose to make a production investment, the company would make an extra annual production profit of €500,000 over the next five years. If they chose to make a prevention investment, on the other hand, no extra production profit would be made but the investment would result in a lower probability that an accident would occur with major negative consequence. An important aspect of the scenarios was that the positive consequences of the investment, namely extra production profit in the case of production investment and the avoided loss caused by a major accident in the case of prevention investment, would be felt every year for the next five years.

Respondents were given four different scenarios with the following probabilities that a major accident would occur: (a) 1 in 100,000, (b) 1 in 10,000, (c) 1 in 100 and (d) 1 in 10. For each of the scenarios, six different possible losses each year for the next five years were also presented: (a) €20,000,000, (b) €50,000,000, (c) €100,000,000, (d) €500,000,000, (e) €1,000,000,000 and (f) €10,000,000,000. In total, then, respondents had to make choices between production and prevention investments in 24 known but risky situations.

Besides choosing between production and prevention investments in risky situations, respondents were also asked to make choices in uncertain situations. The following uncertainties were presented in the questionnaire: (a) both the probability of occurrence and the extent of loss remain uncertain, (b) the loss potential is unknown and the probability of occurrence is either low or high, and (c) the extent of the loss is high, but the probability of occurrence is unknown.

It was not explicitly stated in the questionnaire whether the losses would be of a human or material nature. The scale of the possible losses was based on realistic estimates provided by an existing international petrochemical company with the same characteristics as the company used in our questionnaire (numbers of employees, annual profit, annual turnover and capital).

In the third part of the questionnaire, the respondents were asked to score seventeen statements about their personalities using a five-point Likert scale ranging from strongly disagree to strongly agree. Ten of the statements measured preference for information processing using the Short Rational-Experiential Inventory. Of these ten statements, five measured need for cognition (rational thinking style) and five measured faith in intuition (intuitive thinking style) (Pacini and Epstein, 1999; in Dutch translated by Van Ouytsel et al., 2014). The remaining seven statements measured self-reported sensation-seeking, which is a predictor of a wide array of unsafe behaviours. Individuals who score highly in terms of sensation-seeking appear to be drawn to activities that are high in risk (Ponnet et al., 2015). To measure this sensation-seeking behaviour, the Brief Sensation-Seeking Scale was used (Hoyle et al., 2002).

3.2. Analytic strategy

The results of the questionnaires were analysed using IBM SPSS Statistics 22 software. Firstly, the general results for choices between production and prevention investments were compared to the cumulative expected values of these investments. As previously mentioned, the theory of expected value can provide a reference for discussing how decisions are taken (Aven and Kristensen, 2005).

If a respondent chose to make a production investment, the company would make an extra annual production profit of €500,000 over the next five years. After a five-year period, the production investment would result in an extra profit of €2,500,000 (interests aside).

The cumulative expected value of an investment depends on the probability that an accident will occur and the associated extent of losses. Here we calculate the cumulative expected value for the following example: consider a prevention investment that avoids a major accident with an occurrence probability of 1 in 100,000 and losses worth €20,000,000 per year over the next five years. A probability of 1 in 100,000 corresponds to a probability of 0.001%. This produces a cumulative expected value of (0.001% * 5) * €20,000,000. Thus, after five years the cumulative expected value would be €1,000.

The same calculation can be carried out for all other combinations of probabilities and losses considered in the questionnaire. The results of all cumulative expected values can be found in Table 1. Table 2 shows the investments (production or prevention) with the highest cumulative expected value.

Insert Table 1 here.

Insert Table 2 here.

Based on the respondents' answers, we calculated whether the majority of respondents had chosen the production investment or prevention investment for each probability and possible loss given. The distribution of the matrix from the respondents' answers was then compared to the matrix from Table 2.

As described above, several factors can have an influence on the decision-making process. Some factors were thus included in the analyses to determine whether certain individuals make decisions in a more risk-averse or risk-seeking manner. The results were compared per gender (male or female). Comparison among age groups was not possible as most of the respondents were in the same age category (90.0% were aged between 18 and 22 years old). The same applies to the work status of the respondents (student or employed student) (5.2% were employed students).

Based on the Short Rational-Experiential Inventory, respondents with a high rational thinking style were compared to those with a low rational thinking style, and respondents with a high intuitive thinking style were compared to those with a low intuitive thinking style. Similarly, using the Brief Sensation-Seeking Scale, the choices of respondents with high sensation-seeking behaviour were compared to those with low sensation-seeking behaviour.

3.3. Limitations of the study

Due to the study population, namely university students, the respondents were relatively young (90.0% were aged between 18 and 22 years old) and had little or no professional experience (only 5.2% were employed students). As a result, it may not be straightforward to generalise the results to a broader population. However, it can be argued that lay people's perceptions of acceptance of risk and uncertainty should be taken into consideration, in addition to those of experts (Aven and Kristensen, 2005). The opinion of the lay public could provide a more realistic and objective assessment of risk and uncertainty (Klinke and Renn, 2002). As shown in previous studies, age can have an impact on the decision-making process. Although young people seem to be more risk-taking than older generations (e.g. Mather, 2006; Rolison et al., 2012), there is some disagreement about why attitudes toward risk and uncertainty change with age (Tymula et al., 2013). Future research could take people's responsibility into account and use other scales for measuring risk attitudes, such as the need for arousal or resistance to change. To address the problem of generalisability, a follow-up study among safety decision-makers in a large Belgian chemical company (3500 employees) with a highly developed safety department has been planned, during which the distribution of decisions about production and prevention investments will be examined in a real-life setting. The results of this follow-up study will be compared to the results of the study described in this paper.

4. Results

In total, 405 questionnaires were completed. Of all respondents, 61.0% were female. The average age was 20.14 years (*SD* = 2.80). The youngest respondent was 17 years old and the oldest was 50

(90.0% were aged between 18 and 22). Education was measured as the highest level of education achieved at the time of questionnaire administration: 73.3% of the respondents had completed higher secondary education, 24.5% had obtained a Bachelor degree and 2.2% had obtained a Master degree. In total, 94.8% of the respondents were students and 5.2% were employed students. Regarding study programme, 45.4% were studying political and social sciences (communication studies, political science, sociology, socioeconomic sciences or film studies and visual culture), 24.7% were studying medicine, 23.0% were studying business engineering and 6.9% were studying in other disciplines (linguistics and literature, philosophy or safety sciences).

4.1. General results

Table 3 shows the proportions of respondents that chose each type of investment in each scenario. Table 4 shows whether the majority of respondents chose the production investment or the prevention investment. In this table, a comparison is also made between the choices of the respondents and the cumulative expected values of these investments: the distribution of the matrix from the respondents' answers and the matrix in Table 2. Where the distribution of the respondents' investments does not match the distribution of the investments with the highest cumulative expected value, these cells are underlined (single underlined in cells where the distribution does not match the highest cumulative expected value due to more risk-averse decisions and double underlined in cells where the distribution does not match the highest cumulative expected value due to more risk-seeking decisions). Cumulative expected values cannot be calculated for unknown probabilities of occurrence and unknown losses, which makes this comparison impossible for such investments (presented in Table 4 in italics).

Insert Table 3 here.

Insert Table 4 here.

4.2. Results per gender

Table 5 shows the proportions of respondents that chose each type of investment per gender. Where there is a significant difference ($p < 0.05$) between investments made by male and female respondents, this is indicated with an asterisk.

Insert Table 5 here.

4.3. Rational and intuitive thinking styles

Five items were used to measure respondents' need for cognition (rational thinking style) on a five-point Likert scale (Cronbach's $\alpha = 0.75$). The average rational thinking style score for all respondents was 3.43 out of 5 ($SD = 0.69$). A one-way ANOVA revealed a significant between-group difference for gender: $F(1,401) = 13.68$; $p < 0.001$. The average rational thinking style scores were 3.66 ($SD = 0.61$) for the male respondents and 3.28 ($SD = 0.70$) for the female respondents. Low scores (average score of 1 or 2 out of 5) were obtained by 19.4% of the respondents on rational thinking style, and high scores (average score of 4 or 5 out of 5) were obtained by 24.5%. Table 6 gives the proportions of respondents with high and low rational thinking styles that chose each type of investment. When there is a significant difference ($p < 0.05$), this is indicated with an asterisk.

Insert Table 6 here.

Five items were used to measure the respondents' faith in intuition (intuitive thinking style) on a five-point Likert scale (Cronbach's α = 0.81). Here, respondents scored an average of 3.39 out of 5 (*SD* = 0.69). A one-way ANOVA revealed a significant between-group difference for gender: F (1,400) = 13.44 ; $p < 0.001$. Average intuitive thinking style scores were 3.24 (*SD* = 0.68) for the male respondents and 3.49 (*SD* = 0.68) for the female respondents. Low scores (average score of 1 or 2 out of 5) were obtained by 21.9% of respondents on intuitive thinking style and high scores (average score of 4 or 5 out of 5) were obtained by 23.2%. Table 7 shows the proportions of respondents with high and low intuitive thinking styles that chose each type of investment. When there is a significant difference ($p < 0.05$ or $p < 0.001$), this is indicated with one or two asterisks respectively.

Insert Table 7 here.

4.4. Sensation-seeking

Seven items were used to measure the sensation-seeking behaviour of the respondents on a five-point Likert scale (Cronbach's α = 0.80). The average sensation-seeking score of all respondents was 4.93 out of 7 (*SD* = 1.11). A one-way ANOVA revealed a significant between-group difference for gender: F (1,402) = 4.96 ; $p < 0.05$. Average sensation-seeking scores were 5.08 (*SD* = 1.05) for the male respondents and 4.83 (*SD* = 1.14) for the female respondents. Low scores on the sensation-seeking scale (average score of 1,2 or 3 out of 7) were obtained by 17.6% of the respondents, and high scores (average score of 5,6 or 7 out of 7) were obtained by 55.4%. Table 8 gives the proportions of respondents with high and low sensation-seeking style that chose each type of investment. Where there is a significant difference ($p < 0.05$), this is indicated with an asterisk.

Insert Table 8 here.

5. Discussion

This study explores how people make decisions about production and prevention investments when these decisions involve risks and uncertainties that may have major negative consequences. We investigate how decision-making evolves when the accident probability increases, when the possible loss increases, and when uncertainty about the probability of occurrence and possible loss increases. The results obtained from analysing 405 questionnaires provide an insight into the risk-seeking and risk-averse choices made by our respondents. Here, a 'risk-seeking choice' can be defined as a preference for investing in production over prevention. In a 'risk-averse choice', the risk or uncertainty is judged unacceptable and a prevention investment is consequently chosen over a production investment.

5.1. Decision-making under risk: comparison of investment choices with cumulative expected values

According to calculated cumulative expected values, the higher the accident probability and the higher the possible loss, the more advantageous it is to opt for a prevention investment. If the accident probability is equal to 1 in 100,000, then, according to the theory of expected values, it is always better to make a production investment, regardless of the possible losses incurred due to the accident (calculation based on the figures used in the survey). The survey results indicate that respondents make decisions in a more risk-averse way than we might anticipate from by the theory of expected values. The majority of our respondents chose the production investment only when the possible loss caused by a major accident was equal to or less than €100,000,000. As mentioned above, evaluating the acceptance of a major accident with a low probability (HILP event) is not straightforward (Klinke and Renn, 2002; Rodrigues et al., 2014) and not always rational. With regard to the higher probabilities of occurrence, i.e. 1 in 10,000 and 1 in 100, the respondents behaved in a more risk-averse manner than predicted by the cumulative expected values. Klinke and Renn (2002) explain this risk-averse behaviour by referring to people's moral obligation to prevent harm to human beings and the environment. They argue that risk is related to the experience of something that people fear or regard as negative. Another explanation can be found in the Random Regret Minimisation framework, which postulates that, when choosing, people anticipate and aim to minimise regret and therefore behave in a more risk-averse way (Chorus, 2010).

5.2. Decision-making under uncertainty

As previously mentioned, predicting decision-making in uncertain situations remains a challenge. When there was uncertainty about the possible loss that could be caused by an accident, the majority of the respondents in our study opted for the prevention investment, regardless of the probability that the accident would occur. As the probability that the accident would occur increased, the number of respondents opting for the production investment decreased. The number of respondents choosing the production investment also decreased as the possible losses increased. When there was complete uncertainty, in other words when both the accident probability and possible loss were unknown, the majority (95.0%) of respondents chose the prevention investment. Under circumstances of complete uncertainty, risk is usually categorised as intolerable as catastrophic consequences may be involved. A risk-averse attitude is therefore perceived as appropriate (Klinke and Renn, 2002).

5.3. Gender differences in decision-making

Significant differences were found between male and female respondents when the lower probabilities of occurrence (1 in 100,000 and 1 in 10,000) were combined with the higher possible losses (€500,000,000, €1,000,000,000, and €10,000,000,000). Male respondents behaved in a more risk-seeking way when it came to these combinations, i.e. they were more likely to opt for the production investment. As the possible loss increased, however, the difference between genders decreased. These results are consistent with existing studies which indicate that men behave in a more risk-seeking way than women (e.g. Borghans et al., 2009; Dohmen et al., 2011; Butler et al., 2014). When it comes to making decisions about HILP events (events involving extremely low probabilities and extremely high consequences), men display more risk-seeking decision-making behaviour than do women. Furthermore, this study provides support for the notion that – regardless of whether they have to take decisions – men score higher on rational thinking and sensation-seeking than women do and women score higher than men on intuitive thinking.

5.4. Personality characteristics

When the highest probability, 1 in 10, was combined with the lower possible losses of €20,000,000, €50,000,000, and €100,000,000, respondents with a high rational thinking style behaved in a more risk-averse way than respondents with a low rational thinking style. Similarly, when the lowest probability, 1 in 100,000, was combined with an unknown possible loss, answers from respondents with a low intuitive thinking style reflected the overall results, that is, a prevention investment. However, the majority of respondents with a high intuitive thinking style opted for a production investment in this case. These differences are statistically significant. Another significant difference found between the high and low intuitive thinking styles relates to the combination of the probability of 1 in 10,000 with an unknown possible loss: respondents with a low intuitive thinking style were more likely to behave in a risk-averse way than respondents with a high intuitive thinking style. Butler et al. (2014) have also done research on how intuition and reasoning or rationality affect decision-making under risk and uncertainty. They found similar results: people with a high intuitive thinking style are more risk-seeking and people with a high rational thinking style are less risk-seeking. To use the terminology of Stanovich and West (2000), individuals with a high rational thinking style rely on effortful, deliberative reasoning and systematic processing of information. When decisions are based on intuition, on the other hand, there is no systematic comparison of alternatives: a decision is taken rapidly by evaluating the main features of the problem (Butler et al., 2014). One explanation for the finding that people with a high intuitive thinking style behave in a more risk-seeking way could be the fact that the high speed of intuitive thinking puts intuitive thinkers at a comparative advantage in situations involving high risk and uncertainty, making them less averse. Individuals who are more adept at using their intuition may feel more comfortable dealing with uncertainty and risk and thus develop a higher tolerance for both (Klein, 1998; Klein, 2003; Dijksterhuis, 2004; Lee et al., 2009; Butler et al. 2014).

When the probability of 1 in 10,000 was combined with an unknown possible loss, we found that respondents with a high sensation-seeking style made decisions in a more risk-seeking way than did respondents with a low sensation-seeking style. This finding is unsurprising: a number of other studies have already proven that higher levels of self-reported sensation-seeking are associated with greater risk-taking in various domains (e.g. Zuckerman and Kuhlman, 2000; Rolison and Scherman, 2003; Boyer, 2006; Ponnet et al., 2015).

6. Conclusions

Decision-making under risk and uncertainty is not straightforward and acceptance of risk and uncertainty is influenced by a number of factors. Gaining insights into these decision-making processes is important for the understanding and management of activities that involve potential major accidents.

This study indicates that young people behave in a more risk-averse way than would ordinarily be anticipated based on the theory of expected values when making decisions involving major negative consequences. Only when low accident probabilities were combined with low potential losses did respondents make more risk-seeking decisions and opt for production investments. The respondents also made risk-averse decisions under circumstances of uncertainty: only when evaluating known, relatively low possible losses did they choose to make production investments; otherwise, the preference was always for prevention. Under circumstances of complete uncertainty, almost all respondents behaved in a risk-averse manner. The study also showed that men are more likely to behave in a risk-seeking way than women are; that people with a high intuitive thinking style are less risk-averse than people with a low intuitive thinking style; that people with a high rational thinking style are more risk-averse than people with a low rational thinking style; and that respondents with a high sensation-seeking style behave in a more risk-seeking way than respondents with a low sensation-seeking style. In other words, we can conclude that women, low intuitive thinkers, high rational thinkers and low sensation-seekers generally take more cautious decisions regarding investments when choosing between production and prevention.

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Tables and figures

Table 1. Cumulative expected values corresponding to production and prevention investments

			Probability that an accident will occur			
			1 in 100,000	1 in 10,000	1 in 100	1 in 10
Loss caused by the accident	€20,000,000	Production	€2,500,000	€2,500,000	€2,500,000	€2,500,000
		Prevention	€1,000	€10,000	€1,000,000	€10,000,000
	€50,000,000	Production	€2,500,000	€2,500,000	€2,500,000	€2,500,000
		Prevention	€2,500	€25,000	€2,500,000	€25,000,000
	€100,000,000	Production	€2,500,000	€2,500,000	€2,500,000	€2,500,000
		Prevention	€5,000	€50,000	€5,000,000	€50,000,000
	€500,000,000	Production	€2,500,000	€2,500,000	€2,500,000	€2,500,000
		Prevention	€25,000	€250,000	€25,000,000	€250,000,000
	€1,000,000,000	Production	€2,500,000	€2,500,000	€2,500,000	€2,500,000
		Prevention	€50,000	€500,000	€50,000,000	€500,000,000
	€10,000,000,000	Production	€2,500,000	€2,500,000	€2,500,000	€2,500,000
		Prevention	€500,000	€5,000,000	€500,000,000	€5,000,000,000

Table 2. Investment with the highest cumulative expected value

		Probability that an accident will occur			
		1 in 100,000	1 in 10,000	1 in 100	1 in 10
Loss caused by the accident	€20,000,000	Production	Production	Production	Prevention
	€50,000,000	Production	Production	Production = Prevention	Prevention
	€100,000,000	Production	Production	Prevention	Prevention
	€500,000,000	Production	Production	Prevention	Prevention
	€1,000,000,000	Production	Production	Prevention	Prevention
	€10,000,000,000	Production	Prevention	Prevention	Prevention

Table 3. Proportion of respondents choosing each type of investment

Loss caused by the accident		Probability that an accident will occur: 1 in 100,000	1 in 10,000	1 in 100	1 in 10	Unknown
€20,000,000	Production	89.4%	82.2%	46.7%	20.0%	75.9%
	Prevention	10.6%	17.8%	53.3%	80.0%	24.1%
€50,000,000	Production	80.2%	68.7%	25.4%	7.7%	56.9%
	Prevention	19.8%	31.3%	74.6%	92.3%	43.1%
€100,000,000	Production	63.2%	40.2%	11.1%	5.4%	34.0%
	Prevention	36.8%	59.8%	88.9%	94.6%	66.0%
€500,000,000	Production	30.9%	19.0%	4.7%	2.2%	16.3%
	Prevention	69.1%	81.0%	95.3%	97.8%	83.7%
€1,000,000,000	Production	15.1%	9.7%	2.0%	2.0%	9.2%
	Prevention	84.9%	90.3%	98.0%	98.0%	90.8%
€10,000,000,000	Production	9.7%	6.2%	1.7%	1.7%	4.7%
	Prevention	90.3%	93.8%	98.3%	98.3%	95.3%
Unknown	Production	43.2%	34.2%	12.0%	7.2%	5.0%
	Prevention	56.8%	65.8%	88.0%	92.8%	95.0%

Table 4. Investment chosen by the majority of respondents

		Probability that an accident will occur				
		1 in 100,000	1 in 10,000	1 in 100	1 in 10	*Unknown*
Loss caused by the accident	€20,000,000	Production	Production	Prevention	Prevention	*Production*
	€50,000,000	Production	Production	Prevention	Prevention	*Production*
	€100,000,000	Production	Prevention	Prevention	Prevention	*Prevention*
	€500,000,000	Prevention	Prevention	Prevention	Prevention	*Prevention*
	€1,000,000,000	Prevention	Prevention	Prevention	Prevention	*Prevention*
	€10,000,000,000	Prevention	Prevention	Prevention	Prevention	*Prevention*
	Unknown	*Prevention*	*Prevention*	*Prevention*	*Prevention*	*Prevention*

Note: Single underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-averse decisions and double underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-seeking decisions. Italics are used where it is not possible to compare the distribution of respondents' investments with the distribution of the investment with the highest cumulative expected value. Dark grey is used where production investment is the prevailing selection and light grey is used where prevention investment is the prevailing selection.

Table 5. Proportion of male and female respondents choosing each type of investment

Loss caused by the accident				Probability that an accident will occur				
				1 in 100,000	1 in 10,000	1 in 100	1 in 10	Unknown
	€20,000,000	Production	Male	88.6%	82.3%	48.7%	17.7%	80.1%
			Female	89.9%	82.2%	45.3%	21.5%	73.3%
		Prevention	Male	11.4%	17.7%	51.3%	82.3%	19.9%
			Female	10.1%	17.8%	54.7%	78.5%	26.7%
	€50,000,000	Production	Male	84.2%	68.4%	25.9%	5.7%	52.2%
			Female	77.7%	69.0%	25.1%	8.9%	59.9%
		Prevention	Male	15.8%	31.6%	74.1%	94.3%	47.8%
			Female	22.3%	31.0%	74.9%	91.1%	40.1%
	€100,000,000	Production	Male	65.2%	44.9%	11.4%	4.4%	33.8%
			Female	61.9%	37.2%	10.9%	6.1%	34.1%
		Prevention	Male	34.8%	55.1%	88.6%	95.6%	66.2%
			Female	38.1%	62.8%	89.1%	93.9%	65.9%
	€500,000,000	Production	Male	37.6%*	25.3%*	3.8%	1.9%	19.6%
			Female	26.7%*	15.0%*	5.3%	2.4%	14.2%
		Prevention	Male	62.4%*	74.7%*	96.2%	98.1%	80.4%
			Female	73.3%*	85.0%*	94.7%	97.6%	85.8%
	€1,000,000,000	Production	Male	20.4%*	13.4%*	1.9%	1.9%	12.1%
			Female	11.7%*	7.3%*	2.0%	2.0%	7.3%
		Prevention	Male	79.6%*	86.6%*	98.1%	98.1%	87.9%
			Female	88.3%*	92.7%*	98.0%	98.0%	92.7%
	€10,000,000,000	Production	Male	14.0%*	9.6%*	1.3%	1.9%	5.7%
			Female	6.9%*	4.0%*	2.0%	1.6%	4.0%
		Prevention	Male	86.0%*	90.4%*	98.7%	98.1%	94.3%
			Female	93.1%*	96.0%*	98.0%	98.4%	96.0%
	Unknown	Production	Male	45.9%	37.4%	11.5%	5.8%	5.7%
			Female	41.6%	32.1%	12.3%	8.2%	4.5%
		Prevention	Male	54.1%	62.6%	88.5%	94.2%	94.3%
			Female	58.4%	67.9%	87.7%	91.8%	95.5%

Note: ***** There is a significant difference ($p < 0.05$) between investments made by male and female respondents. Single underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-averse decisions and double underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-seeking decisions.

Table 6. Proportion of respondents with high and low rational thinking styles choosing each type of investment

Loss caused by the accident			Probability that an accident will occur: 1 in 100,000	1 in 10,000	1 in 100	1 in 10	Unknown
€20,000,000	Production	High rationality	85.9%	77.8%	49.5%	19.2%*	72.7%
		Low rationality	92.3%	84.6%	47.4%	33.3%*	76.9%
	Prevention	High rationality	14.1%	22.2%	50.5%	80.8%*	27.3%
		Low rationality	7.7%	15.4%	52.6%	66.7%*	23.1%
€50,000,000	Production	High rationality	81.8%	67.7%	26.3%	6.1%*	50.5%
		Low rationality	84.6%	74.0%	34.6%	15.4%*	64.1%
	Prevention	High rationality	18.2%	32.3%	73.7%	93.9%*	49.5%
		Low rationality	15.4%	26.0%	65.4%	84.6%*	35.9%
€100,000,000	Production	High rationality	63.6%	41.4%	13.1%	3.0%*	31.6%
		Low rationality	65.4%	48.7%	19.2%	11.5%*	42.3%
	Prevention	High rationality	36.4%	58.6%	86.9%	97.0%*	68.4%
		Low rationality	34.6%	51.3%	80.8%	88.5%*	57.7%
€500,000,000	Production	High rationality	33.3%	23.2%	6.1%	2.0%	22.2%
		Low rationality	30.8%	21.8%	5.1%	5.1%	20.5%
	Prevention	High rationality	66.7%	76.8%	93.9%	98.0%	77.8%
		Low rationality	69.2%	78.2%	94.9%	94.9%	79.5%
€1,000,000,000	Production	High rationality	19.2%	16.2%	3.0%	2.0%	14.1%
		Low rationality	14.1%	6.4%	1.3%	2.6%	11.5%
	Prevention	High rationality	80.8%	83.8%	97.0%	98.0%	85.9%
		Low rationality	85.9%	93.6%	98.7%	97.4%	88.5%
€10,000,000,000	Production	High rationality	10.1%	11.1%	3.0%	3.0%	6.1%
		Low rationality	11.5%	3.8%	1.3%	2.6%	7.7%
	Prevention	High rationality	89.9%	88.9%	97.0%	97.0%	93.9%
		Low rationality	88.5%	96.2%	98.7%	97.4%	92.3%
Unknown	Production	High rationality	41.4%	27.8%	11.1%	8.2%	4.0%
		Low rationality	48.7%	40.3%	15.6%	13.0%	7.8%
	Prevention	High rationality	58.6%	72.2%	88.9%	91.8%	96.0%
		Low rationality	51.3%	59.7%	84.4%	87.0%	92.2%

Note: ***** There is a significant difference ($p < 0.05$) between investments made by respondents with high and low rational thinking styles. Single underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-averse decisions and double underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-seeking decisions.

Table 7. Proportion of respondents with high and low intuitive thinking styles choosing each type of investment

				Probability that an accident will occur				
				1 in 100,000	1 in 10,000	1 in 100	1 in 10	Unknown
Loss caused by the accident	€20,000,000	Production	High intuition	90.3%	84.9%	50.5%	18.3%	77.4%
			Low intuition	89.8%	86.4%	51.1%	20.5%	73.9%
		Prevention	High intuition	9.7%	15.1%	49.5%	81.7%	22.6%
			Low intuition	10.2%	13.6%	48.9%	79.5%	26.1%
	€50,000,000	Production	High intuition	82.8%	71.0%	20.4%	7.5%	64.5%
			Low intuition	81.8%	71.6%	29.5%	9.8%	51.1%
		Prevention	High intuition	17.2%	29.0%	79.6%	92.5%	35.5%
			Low intuition	18.2%	28.4%	70.5%	93.2%	48.9%
	€100,000,000	Production	High intuition	67.7%	38.7%	11.8%	6.5%	40.9%
			Low intuition	62.5%	44.3%	10.2%	4.5%	28.4%
		Prevention	High intuition	32.3%	61.3%	88.2%	93.5%	59.1%
			Low intuition	37.5%	55.7%	89.8%	95.5%	71.6%
	€500,000,000	Production	High intuition	28.0%	17.2%	5.4%	2.2%	18.3%
			Low intuition	34.1%	20.5%	3.4%	4.5%	15.9%
		Prevention	High intuition	72.0%	82.8%	94.6%	97.8%	81.7%
			Low intuition	65.9%	79.5%	96.6%	95.5%	84.1%
	€1,000,000,000	Production	High intuition	16.1%	9.7%	4.3%	3.2%	11.8%
			Low intuition	15.9%	8.0%	1.1%	2.3%	9.1%
		Prevention	High intuition	83.9%	90.3%	95.7%	96.8%	88.2%
			Low intuition	84.1%	92.0%	98.9%	97.7%	90.9%
	€10,000,000,000	Production	High intuition	10.8%	6.5%	3.2%	2.2%	7.5%
			Low intuition	11.4%	6.8%	1.1%	2.3%	3.4%
		Prevention	High intuition	89.2%	93.5%	96.8%	97.8%	92.5%
			Low intuition	88.6%	93.2%	98.9%	97.7%	96.6%
	Unknown	Production	High intuition	58.7%**	43.5%*	15.2%	12.1%	6.5%
			Low intuition	31.0%**	24.7%*	8.0%	6.8%	4.5%
		Prevention	High intuition	41.3%**	56.5%*	84.8%	87.9%	93.5%
			Low intuition	69.0%**	75.3%*	92.0%	93.2%	95.5%

Note: ***** There is a significant difference ($p < 0.05$) between investments made by respondents with high and low intuitive thinking styles. ** There is a significant difference ($p < 0.001$) between investments made by respondents with high and low intuitive thinking styles. Single underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-averse decisions and double underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-seeking decisions.

Table 8. Proportion of respondents with high and low sensation-seeking styles choosing each type of investment

				Probability that an accident will occur				
				1 in 100,000	1 in 10,000	1 in 100	1 in 10	Unknown
Loss caused by the accident	€20,000,000	Production	High sensation-seeking	90.2%	84.4%	48.7%	20.1%	76.2%
			Low sensation-seeking	90.1%	81.7%	47.9%	23.9%	78.9%
		Prevention	High sensation-seeking	9.8%	15.6%	51.3%	79.9%	23.8%
			Low sensation-seeking	9.9%	18.3%	52.1%	76.1%	21.1%
	€50,000,000	Production	High sensation-seeking	82.1%	70.4%	27.2%	8.5%	57.4%
			Low sensation-seeking	76.1%	67.1%	23.9%	5.6%	56.3%
		Prevention	High sensation-seeking	17.9%	29.6%	72.8%	91.5%	42.6%
			Low sensation-seeking	23.9%	32.9%	76.1%	94.4%	43.7%
	€100,000,000	Production	High sensation-seeking	62.9%	42.4%	11.2%	5.8%	38.6%
			Low sensation-seeking	63.4%	36.6%	9.9%	4.2%	29.6%
		Prevention	High sensation-seeking	37.1%	57.6%	88.8%	94.2%	61.4%
			Low sensation-seeking	36.6%	63.4%	90.1%	95.8%	70.4%
	€500,000,000	Production	High sensation-seeking	34.5%	20.5%	4.9%	1.8%	18.8%
			Low sensation-seeking	25.4%	18.3%	5.6%	2.8%	14.1%
		Prevention	High sensation-seeking	65.5%	79.5%	95.1%	98.2%	81.2%
			Low sensation-seeking	74.6%	81.7%	94.4%	97.2%	85.9%
	€1,000,000,000	Production	High sensation-seeking	16.6%	10.8%	2.2%	2.2%	10.8%
			Low sensation-seeking	12.7%	8.5%	1.4%	1.4%	8.5%
		Prevention	High sensation-seeking	83.4%	89.2%	97.8%	97.8%	89.2%
			Low sensation-seeking	87.3%	91.5%	98.6%	98.6%	91.5%
	€10,000,000,000	Production	High sensation-seeking	11.2%	7.6%	2.2%	1.8%	4.9%
			Low sensation-seeking	8.5%	1.4%	1.4%	1.4%	5.6%
		Prevention	High sensation-seeking	88.8%	92.4%	97.7%	98.2%	95.1%
			Low sensation-seeking	91.5%	98.6%	98.6%	98.6%	94.4%
	Unknown	Production	High sensation-seeking	46.6%	40.6%*	12.7%	8.7%	5.0%
			Low sensation-seeking	39.1%	24.3%*	10.0%	5.6%	5.6%
		Prevention	High sensation-seeking	53.4%	59.4%*	87.3%	91.3%	95.0%
			Low sensation-seeking	60.9%	75.7%*	90.0%	94.4%	94.4%

Note: * There is a significant difference (p < 0.05) between investments made by respondents with high and low sensation-seeking styles. Single underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-averse decisions and double underlining is used in cells where the distribution does not match the highest cumulative expected value due to more risk-seeking decisions.