Measuring ambiguity preferences: A new ambiguity preference module[†]

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Abstract

Ambiguity preferences are important to explain human decision-making in many areas in economics and finance. To measure individual ambiguity preferences, the experimental economics literature advocates using incentivized laboratory experiments. Yet, laboratory experiments are costly and require a lot of time and administrative effort. This study develops an ambiguity preference survey module that can reliably measure ambiguity preferences when carrying out laboratory experiments is impractical, such as in large scale surveys or field studies.

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1 Introduction

In many circumstances of everyday life, people take decisions in uncertain environments. In most situations, the probabilities of the possible outcomes are only vaguely known to decision makers, if at all. Since the seminal works of Knight (1921) and Ellsberg (1961), the absence of precise information on probabilities is referred to as ambiguity, and has been recognized as a form of uncertainty distinct from the standard notion of risk.

Preferences towards ambiguity – and ambiguity aversion in particular – have shown to be an important determinant of individual decision-making.[1] Incorporating ambiguity preferences in economic models helps to explain a variety of phenomena in economics and finance that cannot be attributed to risk aversion alone.[2]

Given the importance of ambiguity preferences for a wide range of decisions in everyday life, it is important for empirical researchers to measure these preferences. The experimental economics literature advocates measuring ambiguity preferences using decision tasks incentivised with money in laboratory settings. However, these procedures are costly, time-consuming, and often complex to implement.

The objective of this paper is to provide a tool to measure ambiguity preferences when carrying out laboratory experiments is impractical, such as in large scale surveys or field studies. Using a large set of widely used hypothetical thought experiments and attitudinal questions taken from the economics and psychology literature, this paper develops an ambiguity preference survey module. Individual ambiguity preferences are measured using a standard, incentivised decision task. Then we assess whether hypothetical thought experiments and attitudinal questions can reliably predict ambiguity preferences. Ap-

[1] Empirical studies show that ambiguity aversion can explain, among others, patterns in stock market participation (Ahn et al., 2014; Bianchi and Tallon, 2016; Dimmock, Kouwenberg and Wakker, 2016; Dimmock, Kouwenberg, Mitchell and Peijnenburg, 2016) and health behaviours among adolescents (Sutter et al., 2013).

[2] For example, theoretical models show that ambiguity aversion can explain the lower than expected investment in financial markets (Dow and Werlang, 1992; Mukerji and Tallon, 2001; Cao et al., 2005; Garlappi et al., 2007; Easley and O'Hara, 2009; Bossaerts et al., 2010) and real investment projects (Nishimura and Ozaki, 2007), the economic evaluation of climate change (Weitzman, 2009; Millner et al., 2013), the equity premium puzzle (Collard et al., 2015) or low reservation wages for job searchers (Nishimura and Ozaki, 2004).

plying a rigorous selection procedure that considers all possible combinations of thought experiments and attitudinal questions, this paper identifies a concise set of predictors that explain a large part of the variation in ambiguity preferences elicited experimentally.

The ambiguity preference survey module consists of five survey items. The first item is a hypothetical, path-dependent thought experiment in the spirit of the original Ellsberg (1961) two-colour urn experiment. This item is at the same time the best single predictor of ambiguity preferences. Besides, the survey module includes four attitudinal questions. In addition, we also propose a more parsimonious survey module that consists of a smaller subset of three items in total, the thought experiment and two attitudinal questions. Yet, this smaller module comes at the cost of a lower explanatory power. To make the ambiguity preference module easy to use in practical applications, we also propose a ready-to-use ambiguity preference score that allows a simple and quick assessment of ambiguity preferences once the survey data has been collected.

We test the validity of the ambiguity preference module using a variety of tests. First, we examine how well the preference module can explain ambiguity preferences in-sample. Second, we resort to a entirely different sample of subjects of similar size to test the predictive power of the preference module out of sample. Finally, we use a test-retest procedure to establish a benchmark against which the quality of the preference module can be compared. Taken together, these tests show that the ambiguity preference module allows to reliably measuring ambiguity preference for different samples of subjects.

This paper is related to several streams of literature. Most of all, the paper complements a number of studies that propose survey modules to measure economic preferences without relying on incentivized experiments. So far, this literature has focused on risk preferences, impatience and trust, but has neglected ambiguity preferences. For example, Dohmen et al. (2011) show that a self-reported willingness to take risks correlates with experimentally elicited risk preferences. Questions of this type are now routinely used to measure risk preferences in large surveys, including the German Socio-Economic

Panel and other surveys (Guiso and Jappelli, 2009; Vieider et al., 2015; Donkers et al., 2001; Ashraf et al., 2006).[3] Similarly, time preferences are collected in surveys using self-reported attitudes on impatience and hypothetical choice tasks of present and future rewards (Cole et al., 2013; Bernard et al., 2014). Trust can be measured using attitudinal trust questions, which has been shown to correlate with behaviour in trust games (Fehr et al., 2003). Most closely related to this paper is the recent study by Falk et al. (2016) that examines the ability of hypothetical decision tasks and survey questions to predict preferences for risk, time discounting, altruism, trust, positive and negative reciprocity in incentivised experiments. Similar to our paper, they propose a survey module to measure these six preferences.

Our paper complements these studies by providing a module on ambiguity preferences. The ambiguity preference module allows researchers to extend empirical studies on ambiguity preferences to large scale field studies based on the general population. This is especially important in light of recent advances in theoretical models assuming ambiguity, whose predictions have rarely been tested empirically.

Furthermore, by analysing the predictive power of the ambiguity preference module using out-of-sample tests, this paper makes also a methodological contribution when designing preference survey modules. While previous papers mainly concentrate on achieving a high explanatory power of their preference modules in-sample, these modules are rarely tested on different, independent samples. By showing that our ambiguity preference module can reliably explain ambiguity preferences for a different sample of similar size, we further substantiate the validity of the preference module.

This paper is also related to some recent studies that measure ambiguity preferences in large representative samples. In most of these studies, however, the ambiguity preference elicitation is not experimentally validated. For example, Butler et al. (2014) and Bianchi and Tallon (2016) assume that their non-incentivized Ellsberg-style thought experiments

[3] For a recent review on measuring risk preferences in large surveys, see Coppola (2014).

reveal true preferences. In fact, by showing that these thought experiments are significantly correlated to ambiguity preferences obtained in incentivized decision tasks, our study gives empirical support to their assumptions. A notable exception are the recent papers by Cohen et al. (2011), Dimmock et al. (2015), Dimmock, Kouwenberg, Mitchell and Peijnenburg (2016) and Dimmock, Kouwenberg and Wakker (2016) that measure ambiguity preferences for large samples of the population using incentivized decision tasks. Yet, given the financial and administrative costs, such large-scale field studies are likely to remain the exception rather than the rule.[4]

The remainder of the paper develops as follows. Section 2 describes the experimental design of this study, including a detailed description of the various measures of ambiguity preferences. Next, section 3 presents the experimental results. The ambiguity preference module is derived in section 4 together with a series of validity tests. Section 5 provides some discussion and conclusions.

2 Experimental design

This section presents the research design, followed by a detailed description of the incentivized tasks, hypothetical thought experiments and attitudinal questions to measure ambiguity and risk preferences. Then we present the experimental procedure and provide a short description of the participants.

2.1 Research design

This study evaluates whether hypothetical thought experiments and attitudinal survey questions can offer a reliable alternative to measure individual ambiguity preferences as obtained in incentivized laboratory decision tasks.

Our research design involves two parts. In the first part, we measure each subject's am-

[4]For example, the study by Dimmock, Kouwenberg, Mitchell and Peijnenburg (2016) paid USD 23,850 in real incentives.

biguity preferences using a standard task with monetary rewards. Such incentives aim to ensure that the subjects' choices reveal their true preferences. The preferences obtained from the incentivized task form our experimental ambiguity preference benchmark. In the second part, we measure the subjects' ambiguity preferences using hypothetical thought experiments and attitudinal questions. Then we assess whether these measures of ambiguity preferences can reliably predict the ambiguity preference benchmark.

It is well known that ambiguity preferences depend on many factors. For example, Curley and Yates (1989) show that ambiguity preferences depend on the probability of the risky alternative offered. When facing unlikely events, subjects tend to exhibit ambiguity-seeking preferences. Furthermore, Cohen et al. (1987) show that ambiguity preferences are contingent on the outcome domain. When confronted with potential losses, the majority of subjects are less ambiguity averse, or even show ambiguity-seeking preferences (Chakravarty and Roy, 2009; Kocher et al., 2015; Baillon and Bleichrodt, 2015). To minimize the effect of such factors, all our incentivized tasks and hypothetical thought experiments measure ambiguity preferences in the gain domain, using non-extreme probability ranges.

This paper measures individual ambiguity preferences in the sense of the Ellsberg (1961) thought experiment, defining ambiguity as the absence of information on exact probabilities. While there are other sources of ambiguity (Abdellaoui et al., 2011), the ambiguity notion in the tradition of Ellsberg is one of the most important concepts in the experimental and behavioural economics literature.

2.2 Incentivized tasks

The literature has proposed many different designs to measure ambiguity preferences.[5] We rely on the well-established design to measure ambiguity preferences using binary choice lists between risky and ambiguous lotteries. The lotteries are presented in the form

[5]For a review, see Camerer and Weber (1992) and Trautmann and van de Kuilen (2016).

of two-colour urns, similar to Ellsberg (1961). Binary choice lists are considered easier to understand than the BDM mechanism (Becker et al., 1964), and are thus likely to result in more precise estimates of ambiguity preferences.[6]

The ambiguity preference task presents subjects with a decision table with 11 choices between drawing a ball from either a risky or an ambiguous urn. The composition and payoff structure of the ambiguous urn is identical in all 11 situations. In contrast, the expected payoff of the risky urn increases from one situation to the next. This change is induced by increasing the probability of winning some prize, while leaving the potential prize constant. The task has been implemented in student and non-student samples as early as by Lauriola and Levin (2001). As Dimmock et al. (2015) show, this particular design allows measuring ambiguity preference independent of the subject's utility function, and thus risk preferences. The point at which subjects switch from preferring the ambiguous urn over the risky urn reveals their ambiguity preferences.[7]

In order to separate the subjects' behaviour under ambiguity from risk effects, we also include a task to elicit risk preferences. In this task, taken from Chakravarty and Roy (2009), subjects are presented a decision table with 10 choices between drawing a ball from a low-risk urn and high-risk urn. As the list proceeds, the low-risk urn remains identical while the expected payoff from the high-risk urn increases monotonically. The point at which subjects switch from the low-risk urn to the high-risk urn reveals information on subject risk preferences. Both tasks are reproduced in appendix A.

[6] See Karni and Safra (1987), Noussair et al. (2004) and Horowitz (2006) for some of the shortcomings of the BDM mechanism.

[7] We also considered measuring ambiguity preferences using a binary choice list where the expected payoff of the risky urn changes by monotonically decreasing its prize (but not its probability), see for example Chakravarty and Roy (2009). However, in such a setting the switching point depends on the subjects' risk preferences. Although it is possible to first estimate risk preferences, such a procedure increases the overall measurement error of the estimated ambiguity preferences.

2.3 Hypothetical thought experiments

Following Ellsberg (1961), the literature has proposed a large variety of hypothetical thought experiments to measure ambiguity preferences. Non-incentivized elicitation methods have the advantage of lower costs and reduced complexity, thereby reducing the time needed to measure preferences. In this study, we implement two common thought experiments to measure ambiguity preferences:[8]

i. The first thought experiment replicates the seminal two-colour Ellsberg (1961) urn experiment. Following Butler et al. (2014), subjects are offered five answer possibilities to allow differentiating between different degrees of ambiguity preferences.

ii. Second, we design a new dynamic version of the Ellsberg (1961) thought experiment where subjects are presented sequential decisions between a risky and an ambiguous urn. While the ambiguous urn is identical in all situations, the composition of the risky urn changes from one situation to the next depending on the subject's previous choices.[9]

Appendix B presents the two thought experiments in detail.

2.4 Attitudinal survey questions

While using survey questions to measure risk preferences is common (Guiso and Paiella, 2008; Dohmen et al., 2011), there is yet no study in economics that explicitly uses questionnaires to measure ambiguity preferences. Measuring ambiguity preferences with attitudinal questions faces the challenge that the connotation of the word "ambiguity" in spoken language is rather different from the notion of ambiguity in economics. We hence

[8] As such, any incentivized task can be transformed into a non-incentivized tasks by removing the monetary incentives. Still, the complexity of the so-obtained elicitation method is higher compared to standard thought experiments.

[9] Similar path dependent designs are used in Baillon et al. (2012), Baillon and Bleichrodt (2015), Dimmock et al. (2015) and Dimmock, Kouwenberg, Mitchell and Peijnenburg (2016).

resort to survey questions from validated self-reported attitudinal scales in the psychology literature on ambiguity (in)tolerance. In these attitudinal questionnaires, subjects are asked to indicate the extent to which they agree or disagree with a list of statements on a scale from 1 to 7.

We implement the Intolerance of Ambiguity Scale by Kirton (1981), one of the most widely used and renowned scale on ambiguity attitudes in psychology.[10] In addition, we include selected items from more recent scales, like the Ambiguity Tolerance scales (Budner, 1962; Norton, 1975; McLain, 2009) and the Uncertainty Response Scale by Greco and Roger (2001) that correspond to the notion of ambiguity as absence of exact probabilities used in the economics literature. Since it has been argued that ambiguity attitudes are related to optimism and pessimism (Chateauneuf et al., 2007) and self-esteem (Heath and Tversky, 1991), we include attitudinal questions on optimism/pessimism from the Extended Life Orientation test by Chang et al. (1997) and a self-esteem measure by Robins et al. (2001). Together with some own additions, the survey questionnaire contains 46 attitudinal questions in total. The complete list is included in Appendix C.

2.5 Experimental procedure

The experiment was conducted in May and October 2013 at Birkbeck College, University of London. The laboratory sessions were implemented in z-tree (Fischbacher, 2007). Each session consisted of four parts. The first part included the attitudinal questionnaire as described in section 2.4. The hypothetical thought experiments (see section 2.3) followed in part 2. The third part included a standard demographic questionnaire. Finally, the last section consisted of the incentivized tasks, see section 2.2. The first task was the risk task, followed by ambiguity task.

This particular sequence was chosen to reduce potential spill-over effects between the four

[10] Kirton (1981) is widely used in empirical work in social psychology. For a review, see Furnham and Ribchester (1995). The scale develops from earlier works by Budner (1962), Rydell and Rosen (1966) and Mac Donald Jr. (1970).

parts. More specifically, we expected students to think more carefully about their choices in the incentivized tasks rather than in the thought experiments or the questionnaire. To avoid that the subjects' answers in the thought experiments to be influenced by answers in the incentivised tasks we placed the incentivized decision tasks after the thought experiments.[11] In two pilot sessions we reversed the order to test for order effects, and find none.

In the ambiguity tasks, participants were asked to select the colour of the winning ball. This ensures that subjects had no reason to believe that the experimenter had any strategic incentive to manipulate the colour of the balls in the ambiguous urn (Chow and Sarin, 2002; Charness et al., 2013).

The tasks were incentivised with monetary payoffs. The payment modality was common knowledge. Subjects were informed that one situation of each task would be randomly selected by the computer at the end of the session. Then the computer would randomly draw one ball from the urn chosen. This procedure ensures that subjects state their true preferences (Bade, 2013). Earnings from the tasks were calculated in terms of points, and then converted at a rate of 2:1 into GBP. On average, subjects earned GBP 18.45, which includes a fixed show-up fee of GBP 10.[12] Earnings were paid in private at the end of the sessions.

2.6 Participants

121 subjects participated in the study, all of them students of three University of London colleges. The participants were recruited via electronic mail and announcements at the beginning of graduate and undergraduate lectures of various study programmes. The sample contains 54 (45%) male and 67 (55%) female subjects, with an average age of about 26 years. The sample of participants is remarkably diverse in terms of age, nationality,

[11] Individuals often aim to be consistent in their decisions (Falk and Zimmermann, 2016), thereby avoiding cognitive dissonance (Festinger, 1957).

[12] The lowest payment was GBP 10, the highest payment GBP 26. Since the sessions lasted for about 40 minutes, the payoffs are sizable.

and fields of study. For a detailed sample statistics see appendix D.

3 Experimental results

3.1 Ambiguity task

Table 1 presents the subjects' choices between drawing a ball from the risky or the ambiguous urn in the incentivized ambiguity task. In around 55% of the situations, subjects prefer drawing a ball from the risk urn over drawing a ball from the ambiguous urn. In binary choice lists, a typical strategy is a threshold strategy. Since the relative attractiveness of the lotteries changes monotonically from situation to situation, many participants prefer one urn over the other up to a switching point, from which they prefer the other urn. Since there is no chance of winning anything in the risky urn (urn 1) in situation 0, the ambiguous urn (urn 2) is the natural choice. However, as the probability of winning a prize in the risky urn increases, it becomes more attractive.

Yet, subjects may switch from one choice to the other more than once. This behaviour is difficult to reconcile with standard preference models under ambiguity. The percentage of subjects that switch more than once is fairly small at around 4%, in line with the study on risk preferences by Holt and Laury (2002).

The columns on the right of table 1 present the switching points of the subjects, i.e., the last situation before a subject switches from the ambiguous urn (urn 2) to the risky urn (urn 1). In case a subject exhibits multiple switching points, we follow Falk et al. (2016) and calculate the subject's average switching point. Since multiple switching pointy may indicate a misapprehension of the task, we also present the switching points for the sample of consistent decision makers.

3.2 Risk task

Table 2 summarizes the results from the risk task. In about 56% of the situations, subjects prefer drawing a ball from the comparably safe urn over drawing a ball from the very risky urn. Again, the large majority of subjects (95%) exhibits a threshold strategy. Since the expected earnings of the risky urn are zero in situation 0, all subjects prefer the safe urn. As the relative attractiveness of the risky lottery increases monotonically from situation to situation, many subjects switch at some stage to the risky urn. In case a subject exhibits multiple switching points, we again calculate the subject's average switching point. The two columns on the right present the switching points for all decision makers and consistent decision makers separately.

3.3 Ambiguity preference benchmark

This section derives the experimental ambiguity preference benchmark from the switching points of the incentivized ambiguity task. Following Dimmock et al. (2015), we use the subject's so-called matching probability (or risk equivalent) as ambiguity preference benchmark. The matching probability m is defined as the subjective probability at which a subject is indifferent between a risky and the ambiguous lottery. If $m < 0.5$, a subject is ambiguity-averse; if $m > 0.5$ a subject is ambiguity-seeking.[13]

We construct a subject's matching probability from the switching point in the incentivized ambiguity task. Since the probability of winning a prize in the risky urn increases in 10% steps, the task does not allow to determine a subject's exact matching probability, but only up to intervals of 10%. We therefore define the matching probability as the mid-point of these intervals. For example, if a subject's switching point is 5, this implies a matching probability between 50% and 60%. We therefore assign a matching probability of 55%.

[13]Because of symmetry of the two colours and an implicitly assumed exchangeability condition (Chew and Sagi, 2006, 2008), a matching probability of 0.5 is the subjective probability of an ambiguity-neutral decision maker. From this, it follows that a matching probability larger than 0.5 corresponds to ambiguity seeking preferences, and that a matching probability smaller than 0.5 corresponds to ambiguity averse preferences. See Dimmock et al. (2015) for a theoretical derivation.

Panel A of table 3 presents the summary statistics of the preference benchmark for the entire sample and the sample of consistent subjects. The average matching probability is around 0.44, which corresponds to ambiguity-averse preferences, on average.

Panel B presents the distribution of ambiguity preferences when classifying subjects in two or three ambiguity preference groups. The upper row uses a binary classification that distinguishes between ambiguity seeking ($m > 0.5$) and ambiguity averse decision makers ($m < 0.5$). The lower row presents the results based on a classification into three groups, including ambiguity neutrality, where ambiguity neutrality is defined as $m \in [0.45, 0.55]$.[14] The benchmark classifies 73% of subjects as ambiguity averse using a binary segmentation of preferences. However, a classification in three preference categories shows that almost two thirds of the sample can be considered ambiguity neutral.

Panel C presents the Spearman (1904) rank correlation between ambiguity preference benchmark and several socio-economic characteristics. Similar to Binmore et al. (2012) and Dimmock et al. (2015), we do not find any gender differences in ambiguity preferences, neither an effect of the educational background or age. Finally, we replicate the standard result that ambiguity preferences are distinct from risk preferences.

3.4 Thought experiments

Table 4 analyses the results from the two thought experiments. Panel A shows that in the Ellsberg (1961) thought experiment with five answer possibilities, 64% of subjects are ambiguity averse, 28% are ambiguity seeking and 8% ambiguity neutral. In the dynamic Ellsberg urn experiment, we transform the subjects' choices into a matching probability, similar to the incentivized ambiguity task. Again, this matching probability is defined as the mid-point of the probability interval that is consistent with the subject's choices. Panel B shows that the average risk equivalent is 44%. This is remarkably similar to the ambiguity preference benchmark, and consistent with the notion of ambiguity aversion.

[14] If a subject is ambiguity neutral ($m = 0.5$), then he is indifferent between switching after situation 4 or 5, which correspond to an estimated matching probability of 0.45 or 0.55.

Panel C presents the distribution of subjects into two or three broad ambiguity preference groups, similar to panel B of table 3. Yet, since Ellsberg thought experiment explicitly allows for ambiguity neutrality, it is not possible to apply a binary classification for this elicitation method. When using a binary classification, most subjects are ambiguity averse. However, similar to the incentivized task, there is a substantial fraction of ambiguity-neutral decision makers.

Panels D and E compare the ambiguity preferences obtained from the thought experiments to the benchmark. With 27%, the dynamic Ellsberg urn exhibits the highest rank correlation with the benchmark. The classic Ellsberg urn experiment correlates to 19% with the ambiguity preference benchmark. This lower correlation is likely to result from the significantly fewer answer possibilities, and hence cross-sectional variation, in this thought experiment.

Panel E presents an analysis of the subjects' within-person consistency of the ambiguity preferences obtained from the two thought experiments relative to the ambiguity preference benchmark. More precisely, the panel presents the fraction of subjects that exhibit the same ambiguity attitude in the thought experiments as in the ambiguity preference benchmark. This analysis shows that the dynamic Ellsberg thought experiment performs rather well in classifying subjects similar to the benchmark (53% of the subjects), which is significantly higher than the fraction of consistent preferences one would observe if the preferences were independently distributed.

4 Ambiguity preference module

This section analyses to which extent thought experiments and attitudinal questions can be used to predict ambiguity preferences. We identify a set of thought experiments and attitudinal questions that best predict the ambiguity preference benchmark and propose an ambiguity preference survey module that reliably measures ambiguity preferences when laboratory experiments are not feasible.

The next section presents the item selection procedure. Section 4.2 then presents the survey module. Section 4.3 tests the validity of the preference module. Finally, section 4.4 proposes a ready-to-use ambiguity preference score.

4.1 Item selection procedure

The construction of the ambiguity preference survey module faces the challenge of finding the optimal trade-off between parsimony and a sufficiently high explanatory power of ambiguity preferences. To determine the items that best proxy for ambiguity preferences, we follow the procedure by Falk et al. (2016).

This procedure consists of two steps. First, for a given number of predictors, we estimate linear regression models for all possible combinations of predictors. Considering all possible combinations of thought experiments and attitudinal questions in equal basis avoids imposing arbitrary selections and takes into account all possible correlation patterns among the predictors.[15] Then we select the set of predictors that maximize the explained variation of the ambiguity preference benchmark, i.e. the R^2. Evaluating the predictive power for a given number of predictors is useful for practical purposes since survey data collection often imposes space and time constraints.

In the second step, we use standard information criteria to select the best specification out of the models chosen in the first step. In an attempt to avoid over-fitting the data and identifying a concise preference module, we resort to the Bayesian Information Criterion (BIC) by Schwarz (1978), since it contains a larger penalty for additional explanatory variables relative to the Akaike Information Criterion (AIC) by Akaike (1974) or the adjusted R^2.

[15] Other possible item selection procedures include stepwise forward selection, stepwise backward selection, or the Lasso technique by Tibshirani (1996). Each of these techniques has considerable drawbacks that make them unsuitable for our purpose. For a critical discussion on these alternative selection procedures, please see Falk et al. (2016), footnote 13.

4.2 The ambiguity preference module

Table 5 presents the selected items for a given number of predictors up to the specification with the lowest overall BIC. Panel A reports the regressions when using all decision makers; panel B reports the regressions when considering the subset of consistent decision makers only. Column (1) shows the best predictor (in terms of R^2) when using one predictor; column (2) shows the two best predictors when using two predictors, and so on. For both samples, the best single predictor is the dynamic Ellsberg thought experiment, which alone explains around 4% to 5% of the variation in the ambiguity preference benchmark. In fact, this hypothetical thought experiment is very similar in spirit to the hypothetical thought experiment to measure risk preferences in the streamlined version of the preference module by Falk et al. (2016).

When using the entire sample of 121 subjects (panel A), the best specification in terms of BIC contains five explanatory variables, including the dynamic Ellsberg thought experiment and four survey questions. Together, these items explain about 21% of the variation in ambiguity preferences. When confining to the sample of 116 consistent subjects (panel B), the best specification (in terms of BIC) includes three predictors, the dynamic Ellsberg thought experiment and two survey questions. These three predictors achieve an R^2 of 12%. It is important to note that the selected survey items in the smaller sample are a subset of the items selected in the entire data sample. Although the explanatory power of the models is not very high, they are comparable to those of risk preferences reported by Falk et al. (2016).

Table 6 presents the exact wording of the ambiguity preference modules for both samples. In addition, panel C includes the best single-item ambiguity preference measure, the dynamic Ellsberg urn experiment.

4.3 Tests of the ambiguity preference module

4.3.1 In-sample tests

As a first assessment of the quality of the ambiguity preference module, we analyse the module's in-sample fit, i.e., the degree to which the module can capture ambiguity preferences. To this end, we calculate the in-sample linear correlation between the predicted ambiguity preferences using the preference module and the ambiguity preference benchmark. The predicted ambiguity preferences are calculated as the fitted values of the regressions. Depending on the length of the preference module, the correlations range between 22% for the single-item module up to 46% for the 5-item module, see the second column of table 6. These correlations are sizable, and highly significant. Furthermore, they are comparable to similar studies on risk preferences (Falk et al., 2016).

4.3.2 Out-of-sample tests

While the in-sample fit is an important criterion to assess a module's ability to capture the subjects' true preferences, it is not free from limitations. Most important, adding more module items always improves the explanatory power in-sample, but can worsen the module's ability to predict preferences for another subject pool (over fitting). Hence, a more important test of any preference module is not the in-sample fit, but its accuracy in predicting preferences out of sample.

To analyse the predictive power of the ambiguity preference module out of sample, we replicate the incentivized tasks and the entire ambiguity preference module on a completely different pool of subjects. This second round of experiments was conducted in March 2016 at the ExpReSS Lab at Royal Holloway, University of London.[16]

With 99 subjects, this second sample is almost of equal size as the original data sample. Relative to the original sample, the average age of participants is significantly younger

[16]The experimental procedure of this second round of experiments is identical those described in section 2.

(18.3 years) and has larger fraction of female participants (75%).

The procedure of the out-of-sample test is as follows. First, we predict ambiguity preferences of the *second* sample of subjects using the answers to the preference modules (as in table 6). The predicted values are calculated using the coefficient estimates obtained from the *original* sample (see table 5). Then we correlate the predicted ambiguity preferences with the actual ambiguity preference benchmark elicited for this *second* sample of subjects.

The results are presented in the right column of table 6. Depending on the module, the out-of-sample correlations between predicted and actual ambiguity preferences are between 20% and 29%, and in most cases highly significant. Again, these correlations are comparable to those of risk preferences (Falk et al., 2016).

With the exception of the single-item module, the out-of-sample correlation is lower than the in-sample correlation. This is expected, since the module coefficients are obtained from a completely different data set. Yet, the dynamic Ellsberg urn thought experiment is even better in predicting ambiguity preferences out-of-sample than in-sample. This further underlines the reliability of this module item in measuring ambiguity preferences.

4.3.3 Test-retest

Although the in-sample and out-of-sample correlations are sizeable and statistically significant, it is difficult to judge their magnitude in absolute terms. Put differently, it is an important question against what value these correlations should be benchmarked. A possible benchmark is 100%, as this would mean that the ambiguity preference module is able to exactly capture individual ambiguity preferences as obtained in the incentivized task. Yet, using a benchmark of 100% assumes that ambiguity preferences measured in both the incentivized task and the preference module are free from any measurement errors. This is however a rather unreasonable assumption; it is more likely that ambiguity preferences are measured with noise. For example, Einav et al. (2012) suggest that the standard practice to measure continuous preference parameters empirically using a discrete grid automatically implies some measurement error. Once measurement errors are taken into account, the correlation between ambiguity preference benchmark and ambiguity preference module is expected to be less than one – even if the preference module measures the underlying preference equally well as the ambiguity preference benchmark. To determine the correlation one can expect once measurement errors have been taken into account, Falk et al. (2016) adopt the test-retest procedure. This approach suggests that a more appropriate benchmark against which to assess the in-sample and out-of-sample correlations is the correlation between two measures of the incentivized ambiguity task for the same subject. The idea is that the best predictor of the ambiguity preference benchmark is the ambiguity preference benchmark itself. This correlation is likely to be below 100% because of noise.

The test-retest is carried out using a sub-sample of 26 subjects that participated in the study twice, about 5 months after their first participation. The test-retest correlation is then obtained by correlating the first observation of the subjects' experimental ambiguity preference benchmark with their second observation. The test-retest correlation is 32.9%, with a p-value of 0.101, i.e., close to being significant at the 10% level.[17] This correlation is comparable to a test-retest of risk preferences in Falk et al. (2016).

The test-retest correlation can then be used as a benchmark against which to evaluate the in-sample and out-of-sample correlations between preference benchmark and ambiguity preference module (see table 6). Relative to the test-retest correlation, our ambiguity preference survey module explains a high fraction of the explainable variation in ambiguity preferences, and can therefore be considered sufficiently reliable.

[17] The test-retest Spearman (1904) rank correlation is 38.6%, with a p-value of 0.059.

4.4 Ambiguity preference score

The ambiguity preference module is easily implementable in all kinds of surveys, including phone-based surveys. Answering the preference module takes less than 5 minutes. After the data collection, the answers to the preference module have to be aggregated into a single preference parameter for each subject. This section proposes a ready-to-use ambiguity preference score that allows to easily converting the answers to the preference module into such a parameter.

Table 7 presents the ambiguity preference module together with the conversion rule into the ambiguity score. First, the answers to the thought experiment and the survey questions are transformed into a score for each item. For the thought experiment, this score is given by the matching probability of the thought experiment. For the survey items, the score is given in the table. The ambiguity preference score is then obtained by adding all individual scores plus 150 (to account for the constant).[18] By construction, ambiguity-neutral decision makers have an ambiguity preference score of 200. A low ambiguity preference score corresponds to ambiguity-averse preferences; a high ambiguity score corresponds to ambiguity-seeking preferences.

Table 8 presents the descriptive statistics of the long and short ambiguity preference scores for both samples of subjects. Panel A shows that the average ambiguity preference score is clustered around 180, regardless of the data sample and the preference module. This corresponds to ambiguity averse preferences, on average. More precisely, the ambiguity preference score classifies between 74% and 89% of subjects as ambiguity averse (score < 200), see panel B. This is not too different from the ambiguity preference benchmark, that classifies 73% of subjects ambiguity averse.

[18] The conversion rule is derived from the coefficients in the regression tables, see table 5. Instead of using the fitted values of the regression as in the previous section, we simplify the calculation by scaling all coefficients. This normalization keeps the interpretation unchanged. We first take the average coefficient of the dynamic Ellsberg thought experiment in the short and the long module, which is 0.00234. Then we divide the average absolute value of the coefficients of the survey items (0.0166) and the constant (0.3564) by this number, and round to the nearest integer. This gives normalized coefficients of 7 for the survey items and 150 for the constants. The negative signs of two of the survey items reflect their negative coefficients in the regressions.

Panel C examines the linear correlation of the ambiguity preference score with the ambiguity preference benchmark, self-reported risk preferences using a single-item survey question following Dohmen et al. (2011), and a measure of cognitive skills by Bilker et al. (2012). Note that the latter two measures are not available for the original data set. As expected, the in-sample correlation with the ambiguity preference benchmark is substantial, and very close to the correlations between the fitted values and the ambiguity preference benchmark, see table 6. Again, the out-of-sample correlation is weaker in the second data set. Nevertheless, for the long preference module it is still significant at the 5% level.

Finally, the table shows that individual ambiguity preferences as measured by the ambiguity preference score is not measuring self-reported risk preferences following Dohmen et al. (2011), nor is related to cognitive skills, as measured by the Raven's Standard Progressive Matrix test.

5 Conclusions

This paper proposes a novel and experimentally validated ambiguity preference module to measure individual ambiguity preferences. We use responses to a variety of thought experiments and attitudinal survey questions to predict individual ambiguity preferences obtained from state-of-the-art incentivized experimental tasks. Applying an iterative selection procedure considering all possible combinations of predictors, the paper identifies a set including one thought experiment and four attitudinal questions that is best in predicting ambiguity preferences. This set forms our ambiguity preference module.

The ambiguity preference module passes a number of validation tests, including in-sample and out-of-sample tests using two completely different subject pools. Taken together, these tests show that the ambiguity preference module allows to reliably measuring ambiguity preference for different samples of subjects. The ambiguity preference module thus combines the rigour of laboratory experiments with the convenience of survey questionnaires. It is simple, easy to implement, and cost-effective.

The ambiguity preference module allows to reliably measure ambiguity preferences when conducting incentivized laboratory experiments is infeasible. It therefore can be valuable for empirical researchers interested in measuring ambiguity preferences when conducting large scale surveys or field studies, where it is often impractical to use incentivized decision tasks. The preference module might also be useful to experimental researchers with time and money constraints, who seek to include a simple control measure of ambiguity preferences in experimental studies.

We hope that the ambiguity preference module also offers some guidance to empirical researchers in selecting hypothetical thought experiments and attitudinal questions to measure ambiguity preferences. Previous studies have proposed a variety of different types of thought experiments, all of which differ from each other. For example, although path-dependent Ellsberg thought experiments have been used in the past, there is yet no consensus on the design. These differences limit the comparability of ambiguity preferences across studies.

Finally, the ambiguity preference module might also provide a new tool for the financial service industry. While it is standard to use simple questionnaires to assess the clients' risk preferences, ambiguity preferences have been left unexplored because of the lack of simple assessment methods. By using the ambiguity preference module, private banks could improve the personality assessment of their clients to tailor better asset allocation strategies.

We do not want to argue that the ambiguity preference module is always preferable to measure ambiguity preferences over incentivized decision tasks. But given the relevance of ambiguity preferences for economic decision-making, we argue that ambiguity preferences should be measured more often in empirical studies and we provide a toolkit to reliably do so.

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Tables

Table 1: Descriptive statistics of incentivized ambiguity task

Panel A: Choices and switching points

Risky choices			Switching point			Switching point (consistent DMs)		
Risky choices	Obs.	Fraction	Switching point	Obs.	Fraction	Switching point	Obs.	Fraction
0/11	0	0.0%	0	0	0.0%	0	0	0.0%
1/11	0	0.0%	1	0	0.0%	1	0	0.0%
2/11	0	0.0%	2	2	1.7%	2	2	1.7%
3/11	0	0.0%	3	9	7.4%	3	8	6.9%
4/11	7	5.8%	4	28	23.1%	4	27	23.3%
5/11	26	21.5%	5	49	40.5%	5	48	41.4%
6/11	50	41.3%	6	25	21.5%	6	25	21.6%
7/11	28	23.1%	7	6	5.0%	7	6	5.2%
8/11	8	6.6%	8	1	0.8%	8	0	0.0%
9 /11	2	1.7%	9	0	0.0%	9	0	0.0%
10/11	0	0.0%	10	0	0.0%	10	0	0.0%
11/11	0	0.0%	11	0	0.0%	11	0	0.0%
Total	121	100.0%	Total	121	100.0%	Total	116	100.0%

Panel B: Summary statistics

	Observations	Mean	Standard deviation	Lowest	Highest
Risky choices	121	55.3%	0.10%	36.4%	81.8%
Switching point	121	4.91	1.08	2	8
Switching point (consistent DMs)	116	4.90	1.04	2	7

The table summarizes the results of incentivized ambiguity task. In panel A, the three columns on the left report the number of situations subjects preferred drawing a ball from the risky urn (urn 1) over drawing a ball from the ambiguous urn (urn 2). The columns on the right report the switching points of the subjects. More precisely, it indicates the last situation before a subject switches from the ambiguous urn (urn 2) to the risky urn (urn 1). 5 subjects exhibit multiple switching points, i.e., they display inconsistent choices. In this case, we calculate the average switching point. The three columns on the right exclude these inconsistent decision makers. Panel B presents the summary statistics of the fraction of risky choices and the switching points. For a detailed description of the task, see appendix A.

Table 2: Descriptive statistics of incentivized risk task

Panel A: Choices and switching points

Choices			Switching point			Switching point (consistent DMs)		
Safe choices	Obs.	Fraction	Switching point	Obs.	Fraction	Switching point	Obs.	Fraction
0/10	0	0.0%	0	0	0.0%	0	0	0.0%
1/10	1	0.8%	1	1	0.8%	1	1	0.8%
2/10	1	0.8%	2	1	0.8%	2	1	0.8%
3/10	4	3.3%	3	4	3.3%	3	4	3.5%
4/10	23	19.0%	4	23	19.0%	4	23	20.0%
5/10	36	29.8%	5	37	30.6%	5	34	29.6%
6/10	22	18.2%	6	21	17.4%	6	19	16.5%
7/10	18	14.9%	7	18	14.9%	7	18	15.7%
8/10	10	8.3%	8	10	8.3%	8	9	7.8%
9/10	2	1.7%	9	2	1.7%	9	2	1.7%
10/10	4	3.3%	10	4	3.3%	10	4	3.5%
Total	121	100.0%	Total	121	100.0%	Total	115	100.0%

Panel B: Summary statistics

	Observations	Mean	Standard deviation	Lowest	Highest
Save choices	121	56.4%	0.17%	10%	100%
Switching point	121	5.64	1.66	1	10
Switching point	115	5.63	1.68	1	10

The table summarizes the results of incentivized risk task. In panel A, the three columns on the left report the number of situations subjects preferred drawing a ball from the save urn (urn A) over drawing a ball from the risky urn (urn B). The columns on the right report the switching points of the subjects. More precisely, it indicates the last situation before a subject switched from the safe urn (urn A) to the risky urn (urn B). 6 subjects exhibit multiple switching points, i.e., they display inconsistent choices. In this case, we calculate the average switching point. The three columns on the right exclude these inconsistent decision makers. A switching point of 0 means that the subject always preferred the risky urn; a switching point of 10 means that the subject always preferred the safe urn. Panel B presents the summary statistics of the fraction of safe choices and the switching points. For a detailed description of the task, see appendix A.

Table 3: Ambiguity preference benchmark

Panel A: Ambiguity preference benchmark (m)

	Obs.	Mean	Std. Dev.	Min	Max
All subjects	121	0.441	0.108	0.15	0.75
Only consistent DMs	116	0.440	0.104	0.15	0.65

Panel B: Distribution of ambiguity preferences

	Groups	Ambiguity seeking	Ambiguity neutral	Ambiguity averse
All subjects	2	27%	–	73%
	3	6%	62%	32%
Only consistent DMs	2	27%	–	73%
	3	5%	63%	32%

Panel C: Correlation between benchmark, socio-demographic characteristics and risk preferences

	Rank correlation	p-value
Female	−0.052	0.568
Age	0.078	0.396
Education of mother	0.003	0.973
Risk aversion	0.070	0.448

The table presents the ambiguity preferences of the incentivized task as measured by the subject's matching probability m (or risk equivalent). Panel A reports the descriptive statistics. Panel B describes the distribution of ambiguity preferences when classifying subjects in two or three ambiguity preference groups. The upper row uses a binary classification that distinguishes between ambiguity seeking ($m > 0.5$) and ambiguity averse decision makers ($m < 0.5$). The lower row presents the results based on a classification into three groups, including ambiguity neutrality, where ambiguity neutrality is defined as $m \in [0.45, 0.55]$. Panel C presents the rank correlation (Spearman, 1904) between the ambiguity preference benchmark, selected socio-economic characteristics and an experimental measure of risk aversion. *, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Table 4: Non-incentivized thought experiments

Panel A: Ellsberg (1961) urn

	Observations	Fraction
Strong preference for ambiguous urn	12	9.9%
Slight preference for ambiguous urn	22	18.2%
Indifferent between both urns	10	8.3%
Slight preference for risky urn	40	33.1%
Strong preference for risky urn	37	30.6%
Total	121	100.0%

Panel B: Dynamic Ellsberg urn

Matching probability	Observations	Fraction
2.5%	1	0.8%
12.5%	4	3.3%
22.5%	5	4.1%
27.5%	5	4.1%
32.5%	11	9.1%
37.5%	25	20.7%
42.5%	6	5.0%
47.5%	20	16.5%
52.5%	27	22.3%
57.5%	10	8.3%
62.5%	1	0.8%
67.5%	2	1.7%
72.5%	2	1.7%
77.5%	1	0.8%
95%	1	0.8%
Total	121	100.0%
	Mean	Standard deviation
Matching probability	43.9%	13.8%

Panel C: Distribution of ambiguity preferences

Elicitation method	Groups	Ambiguity seeking	Ambiguity neutral	Ambiguity averse
Ellsberg (1961) urn	2	–	–	–
	3	28%	8%	64%
Dynamic Ellsberg urn	2	36%	–	64%
	3	14%	39%	47%

Panel D: Correlation between ambiguity preferences and non-incentivized tasks

Elicitation method	Rank correlation	p-value
Ellsberg (1961) urn	0.186**	0.041
Dynamic Ellsberg urn	0.268***	0.003

Panel E: Individual consistency of ambiguity preferences and non-incentivized tasks

Elicitation method	Consistent preferences	Difference to independent distribution	Test of association
Ellsberg (1961) urn	35%	7.45%*	
Dynamic Ellsberg urn	53%	12.8%***	***

Annotation to table 4

The table summarizes the results of the two non-incentivized thought experiments. Panels A and B present the descriptive statistics. Panel C describes the distribution of ambiguity preferences when classifying subjects in two/three broad ambiguity preference groups, similar to table 3. Since the Ellsberg thought experiment explicitly allows for ambiguity neutrality, it has been excluded from from the binary classification. Panel D presents the rank correlation (Spearman, 1904) between the ambiguity preference benchmark and the ambiguity preferences obtained from the non-incentivized tasks. Panel E reports the individual consistency of the estimated ambiguity preferences when classifying subjects into three broad ambiguity preferences groups. The first column presents the fraction of individually consistent preferences, i.e., subjects that exhibit the same ambiguity attitude in the thought experiments and the ambiguity preference benchmark. The second column presents the difference of the observed consistency compared to the fraction of individually consistent preferences that one would observe if the ambiguity measures were independently distributed. The last column shows the statistical significance of a two-sided Fisher (1922) test of association between each pair of ambiguity preferences. For a detailed description of the thought experiments, see appendix B.

Table 5: Predicting the ambiguity preference benchmark

Panel A: All decision makers

Explanatory variables	(1)	(2)	(3)	(4)	(5)
Dynamic Ellsberg urn	0.00172**	0.00170**	0.00228***	0.00254***	0.00272***
	(2.45)	(2.46)	(3.28)	(3.64)	(3.96)
Item 19		0.01488**			
		(2.07)			
Item 1			−0.01568***	−0.01711***	−0.01765***
			(−2.99)	(−3.27)	(−3.45)
Item 2			0.01676***	0.01693***	0.01842***
			(2.99)	(3.06)	(3.37)
Item 35				0.01569**	0.02169***
				(2.02)	(2.72)
Item 41					−0.01291**
					(−2.43)
Constant	0.36547***	0.33812***	0.35937***	0.32144***	0.35036***
	(11.32)	(9.80)	(9.95)	(7.98)	(8.50)
BIC	−192.54	−192.05	−195.26	−194.66	−195.91
R^2	4.79%	8.12%	14.00%	16.93%	20.98%
adj. R^2	3.99%	6.56%	11.79%	14.06%	17.54%
Observations	121	121	121	121	121

Panel B: Consistent decision makers

Explanatory variables	(1)	(2)	(3)
Item 19	0.01521**	0.01508**	
	(2.14)	(2.16)	
Dynamic Ellsberg urn		0.00147**	0.00196***
		(2.13)	(2.80)
Item 1			−0.01290**
			(−2.46)
Item 2			0.01613***
			(2.91)
Constant	0.41080***	0.34695***	0.36238***
	(24.91)	(10.18)	(10.14)
BIC	−191.64	−191.46	−192.31
R^2	3.87%	7.59%	11.95%
adj. R^2	3.03%	5.96%	9.59%
Observations	116	116	116

The table presents regressions of the ambiguity preference benchmark (m) on the preferences obtained from non-incentivized thought experiments and the attitudinal questions. We estimate linear regression models for all possible combinations of predictors. The table reports the specifications with the highest adjusted R^2 for a given number of predictors up to the specification with the lowest overall BIC. Panel A reports the regressions when using all decision makers; panel B reports the regressions when only considering consistent decision makers. T-statistics are given in the parenthesis below the estimated coefficients. *, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Table 6: The ambiguity preference modules

Module items	In-sample prediction Observations	In-sample prediction Correlation with benchmark	Out-of-sample prediction Observations	Out-of-sample prediction Correlation with benchmark
Panel A: Short preference module (derived from consistent subjects)	116	0.346^{***}	92	0.196^{*}
		(< 0.001)		(0.062)
Thought experiment: Dynamic Ellsberg urn				
Survey item 01: There is a right way and a wrong way to do almost everything.				
Survey item 02: Practically every problem has a solution.				
Panel B: Long preference module (derived from all subjects)	121	0.458^{***}	99	0.285^{***}
		(< 0.001)		(0.004)
Thought experiment: Dynamic Ellsberg urn				
Survey item 01: There is a right way and a wrong way to do almost everything.				
Survey item 02: Practically every problem has a solution.				
Survey item 35: I feel relieved when an ambiguous situation suddenly becomes clear.				
Survey item 41: I find it hard to make a choice when the outcome is uncertain.				
Panel C: Single item module	121	0.219^{**}	99	0.262^{***}
		(0.016)		(0.009)
Thought experiment: Dynamic Ellsberg urn				

This table presents the recommended ambiguity preference survey modules. Panel A presents the 3-item module obtained from consistent subjects. Panel B presents the 5-item module obtained from all subjects. Panel C presents the recommended single-item ambiguity preference measure using the dynamic Ellsberg thought experiment. The in-sample predictions presents the correlation between ambiguity preference benchmark (m) and the fitted values of the regression as presented in table 5. The out-of-sample predictions presents the correlation between ambiguity preference benchmark (m) and the fitted values of the regression as presented in table 5 using the 2016 data sample. P-values are given in parenthesis. *, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Table 7: Construction of the ambiguity preference score

Ambiguity preference module items	Conversion into ambiguity score						
Dynamic Ellsberg two-color urn thought experiment (see Appendix B)	Score equals risk equivalent (in percent) consistent with the subject's choices (see panel B of table 4)						
Attitudinal survey questions Please respond to the following statements by indicating the extent to which you agree or disagree with them on a scale from 1 (I strongly agree) to 7 (I strongly disagree).	Score depending on answer:						
	1	2	3	4	5	6	7
Survey items for short module:							
- There is a right way and a wrong way to do almost everything.	-7	-14	-21	-28	-35	-42	-49
- Practically every problem has a solution.	7	14	21	28	35	42	49
Additional survey items for long module:							
- I feel relieved when an ambiguous situation suddenly becomes clear.	7	14	21	28	35	42	49
- I find it hard to make a choice when the outcome is uncertain.	-7	-14	-21	-28	-35	-42	-49

This table presents the conversion of the short and long ambiguity preference module (left column) into an ambiguity preference score (right column).

First, the answers to the thought experiment and the survey questions are transformed into a score for each item. Second, the ambiguity preference score is obtained by adding all individual scores plus 150 (for the constant).

Ambiguity-neutral decision makers have an ambiguity preference score of 200. A low ambiguity preference score corresponds to ambiguity-averse preferences; a high ambiguity score corresponds to ambiguity-seeking preferences.

Example (long module): Suppose a subject reveals in the dynamic Ellsberg urn experiment a matching probability of 37.5% and answers to all 4 survey questions 1 ("I strongly agree"). Then the long ambiguity preference score equals 37.5 -7 + 7 + 7 - 7 + 150 = 187.5.

Table 8: Ambiguity preference score

Panel A: Average ambiguity preference score

Data set	Original data set	Second data set
Short module	186.07	188.19
Long module	175.02	181.47

Panel B: Classification of subjects

Data set		Original data set	Second data set
Short module	Ambiguity-averse	90 (74%)	76 (77%)
	Ambiguity-seeking	31 (26%)	23 (23%)
Long module	Ambiguity-averse	108 (89%)	83 (84%)
	Ambiguity-seeking	13 (11%)	16 (16%)

Panel C: Correlation statistics

Data set		Original data set	Second data set
Short module	Ambiguity preference benchmark	0.333***	0.160
		(<0.001)	(0.129)
	Risk preferences (Dohmen et al., 2011)	–	-0.105
			(0.300)
	Cognitive skills	–	-0.128
			(0.207)
Long module	Ambiguity preference benchmark	0.414***	0.204**
		(<0.001)	(0.043)
	Risk preferences (Dohmen et al., 2011)	–	-0.162
			(0.109)
	Cognitive skills	–	-0.128
			(0.208)

The table presents the descriptive statistics of the ambiguity preference scores for both samples of subjects. Panel A reports the average ambiguity preference scores. Panel B presents the classification into ambiguity-averse and ambiguity-seeking subjects. Panel C reports the linear correlation of the ambiguity preference score with the ambiguity preference benchmark, the risk preferences measured following Dohmen et al. (2011), and the measure of cognitive skills by (xxx). P-values are given in parenthesis. *, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Appendix A: Incentivized tasks

This appendix describes the two incentivized tasks in detail. Before each task, subjects were presented examples to familiarize with the design of the tasks. In addition, subjects were asked several control questions to ensure that they understood the payoff structure.

Ambiguity task: The task extents the Ellsberg (1961) thought experiment to different situations, similar to Lauriola and Levin (2001) and Butler et al. (2014).

> *In this task, we present you a decision table with 11 situations. Each situation offers you a choice between drawing a ball from two different urns, urn 1 or urn 2. Both urns contain 10 balls, either white or black.*
>
> - *Urn 1: The composition of urn 1 changes from one situation to the next. While the number of balls in one color (e.g., white) increases incrementally from 0 to 10, the number of balls of the other color (e.g., black) decreases accordingly.*
> - *Urn 2: The composition of urn 2 is identical in each situation. However, you don't know how many balls are white and how many balls are black. Any combination is possible. There might be from 0 to 10 white balls, with the remaining balls being black.*
>
> *One ball will be drawn from the urn you choose. The points you can earn depend on the color of the ball drawn. Only one color yields some points. You can choose whether the color that yields points is white or black. Please choose the color of the ball that provides you points:*
>
> - *white*
> - *black*
>
> *Please look at the decision table below.*[19] *In each of the 11 situations, we would like you to indicate from which urn (urn 1 or urn 2) you prefer drawing a ball. As explained before, both urns contain 10 balls, either white or black.*
>
> - *Urn 1: The composition of urn 1 changes from one situation to the next. The number of white balls increases incrementally from 0 white balls in situation 0 to 10 white balls in situation 10, while the number of black balls decreases accordingly.*
> - *Urn 2: The composition of urn 2 is identical in all situations. However, the exact composition of urn 2 is unknown. Any combination of white and black balls is possible: there might be 10 white balls, or 10 black balls, or any other possible combination of white and black balls.*
>
> *If a white ball is drawn, you earn 10 points. If a black ball is drawn, you earn no points.*
>
> *At the end of the session, the computer will randomly select one out of the 11 situations. Then, depending on whether you have chosen urn 1 or urn 2 in that situation, the computer will randomly draw one ball from that urn. Depending on*

[19] The actual decision table presented to the subjects depends on the color chosen. In this appendix, we assume that the selected color is white. If the selected color is black, the word "white" has to be replaced with "black", and vice versa.

the color of the ball, you earn the points indicated in the table. Notice that even though you will make 11 decisions, only one of these will determine the points you earn, but you will not know in advance which situation will be selected (they are equally likely to be selected).

In each situation, from which urn do you prefer to draw a ball, urn 1 or urn 2?

Situation	URN 1: If a white ball is drawn you earn 10 points	URN 2: If a white ball is drawn you earn 10 points	Your choices
0	0 white balls, 10 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
1	1 white ball, 9 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
2	2 white balls, 8 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
3	3 white balls, 7 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
4	4 white balls, 6 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
5	5 white balls, 5 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
6	6 white balls, 4 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
7	7 white balls, 3 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
8	8 white balls, 2 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2
9	9 white balls, 1 black ball	unknown composition	Urn 1 ◯ ◯ Urn 2
10	10 white balls, 0 black balls	unknown composition	Urn 1 ◯ ◯ Urn 2

Risk task (Chakravarty and Roy, 2009): This task is taken from decision sheet B of Chakravarty and Roy (2009).

In this task you need to fill in the decision table shown below. The decision table consists of 10 different situations, listed 1 to 10. Each situation offers you a choice between drawing a ball from two different urns, urn A or urn B. Both urns contain 10 balls, either white or black.

- *The composition of urn A is identical in all 10 situations. There are 5 white balls and 5 black balls.*
- *The composition of urn B changes from one situation to the next. The number of white balls increases incrementally from 0 white balls in situation 1 to 9 white balls in situation 10, while the number of black balls decreases accordingly.*

At the end of the session, the computer will randomly select one out of the 10 situations. Then, depending on whether you have chosen urn A or urn B in that situation, the computer will randomly draw one ball from that urn. Depending on the color of the ball, you earn the points indicated in the table. Notice that even though you will make 10 decisions, only one of these will determine the points you earn, but you will not know in advance which situation will be selected (they are equally likely to be selected).

In each situation, from which urn do you prefer to draw a ball, urn A or urn B?

Situation	URN A: If a white ball is drawn you earn 6 points If a black ball is drawn you earn 4 points	URN B: If a white ball is drawn you earn 10 points If a black ball is drawn you earn 0 points	Your choices
1	5 white balls, 5 black balls	0 white balls, 10 black balls	Urn A ◯ ◯ Urn B
2	5 white balls, 5 black balls	1 white ball, 9 black balls	Urn A ◯ ◯ Urn B
3	5 white balls, 5 black balls	2 white balls, 8 black balls	Urn A ◯ ◯ Urn B
4	5 white balls, 5 black balls	3 white balls, 7 black balls	Urn A ◯ ◯ Urn B
5	5 white balls, 5 black balls	4 white balls, 6 black balls	Urn A ◯ ◯ Urn B
6	5 white balls, 5 black balls	5 white balls, 5 black balls	Urn A ◯ ◯ Urn B
7	5 white balls, 5 black balls	6 white balls, 4 black balls	Urn A ◯ ◯ Urn B
8	5 white balls, 5 black balls	7 white balls, 3 black balls	Urn A ◯ ◯ Urn B
9	5 white balls, 5 black balls	8 white balls, 2 black balls	Urn A ◯ ◯ Urn B
10	5 white balls, 5 black balls	9 white balls, 1 black ball	Urn A ◯ ◯ Urn B

Appendix B: Non-incentivized thought experiments

Ellsberg urn experiment

Please imagine the following situation: You can choose between drawing a ball from two different urns, urn A and urn B. Urn A contains 100 balls, some are white and some are black. However, you don't know how many balls are white and how many balls are black. Any combination is possible. There might be from 0 to 100 white balls, with the remaining balls being black. Urn B contains 100 balls as well, but you know that it contains exactly 50 white balls and 50 black balls. Now choose a color, either white or black. Suppose you win £100 if you draw a ball of the color you have selected. If the ball is of the other color, you win nothing. From which urn would you prefer drawing a ball?

1. *I have a strong preference to draw a ball from urn A.*
2. *I have a slight preference to draw a ball from urn A.*
3. *I am indifferent between drawing a ball from urn A or from urn B.*
4. *I have a slight preference to draw a ball from urn B.*
5. *I have a strong preference to draw a ball from urn B.*

Dynamic Ellsberg urn experiment

Please imagine the following situation: You can choose between drawing a ball from two different urns, urn A and urn B. Urn A contains 100 balls, some are white and some are black. However, you don't know how many balls are white and how many balls are black. Any combination is possible. There might be from 0 to 100 white balls, with the remaining balls being black. Put differently, you do not know the probability of drawing a white or a black ball. Urn B contains 100 balls as well, but you know the exact number of white and black balls in this urn. In other words, you know the exact probability of drawing a white or a black ball. Now choose a color, either white or black. Suppose you win £100 if you draw a ball of the color you have selected. If the ball is of the other color, you win nothing. Please choose the color of the ball that provides you £100:

- *white*
- *black*

We present you now several situations.[20] *The composition of urn A is identical in each situation. The composition of urn B is different in each situation.*

1. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 45 white balls and 55 black balls, i.e., there is a 45% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A → go to situation 2*
   (b) *Urn B → go to situation 3*

[20] The actual situations presented to the subjects depend on the color chosen. In this appendix, we assume that the selected color is white. If the selected color is black, the word "white" has to be replaced with "black", and vice versa.

2. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 65 white balls and 35 black balls, i.e., there is a 65% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A $\rightarrow$ go to situation 4*
   (b) *Urn B $\rightarrow$ go to situation 5*
3. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 25 white balls and 75 black balls, i.e., there is a 25% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A $\rightarrow$ go to situation 6*
   (b) *Urn B $\rightarrow$ go to situation 7*
4. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 75 white balls and 25 black balls, i.e., there is a 75% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A $\rightarrow$ go to situation 8*
   (b) *Urn B $\rightarrow$ go to situation 9*
5. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 55 white balls and 45 black balls, i.e., there is a 55% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A $\rightarrow$ go to situation 10*
   (b) *Urn B $\rightarrow$ go to situation 11*
6. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 35 white balls and 65 black balls, i.e., there is a 35% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A $\rightarrow$ go to situation 12*
   (b) *Urn B $\rightarrow$ go to situation 13*
7. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 15 white balls and 85 black balls, i.e., there is a 15% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*
   (a) *Urn A $\rightarrow$ go to situation 14*
   (b) *Urn B $\rightarrow$ go to situation 15*
8. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 80 white balls and 20 black balls, i.e., there is a 80% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

(a) *Urn A $\rightarrow$ go to situation 16*
(b) *Urn B*

9. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 70 white balls and 30 black balls, i.e., there is a 70% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

   (a) *Urn A*
   (b) *Urn B*

10. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 60 white balls and 40 black balls, i.e., there is a 60% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

   (a) *Urn A*
   (b) *Urn B*

11. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 50 white balls and 50 black balls, i.e., there is a 50% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

   (a) *Urn A*
   (b) *Urn B*

12. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 40 white balls and 60 black balls, i.e., there is a 40% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

   (a) *Urn A*
   (b) *Urn B*

13. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 30 white balls and 70 black balls, i.e., there is a 30% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

   (a) *Urn A*
   (b) *Urn B*

14. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 20 white balls and 80 black balls, i.e., there is a 20% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

   (a) *Urn A*
   (b) *Urn B*

15. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball*

from urn B in which there are 10 white balls and 90 black balls, i.e., there is a 10% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.

(a) *Urn A*
(b) *Urn B → go to situation 17*

16. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 90 white balls and 10 black balls, i.e., there is a 90% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

    (a) *Urn A*
    (b) *Urn B*

17. *What would you prefer? Drawing a ball from urn A with unknown composition, i.e., you do not know the probability of drawing a white ball or drawing a ball from urn B in which there are 5 white balls and 95 black balls, i.e., there is a 5% chance of drawing a white ball? Remember, you win £100 if you draw a white ball, and nothing otherwise.*

    (a) *Urn A*
    (b) *Urn B*

Appendix C: Survey questionnaire

The survey or self-assessment questions to elicit ambiguity preferences are mostly taken from self-reporting scales in the psychology literature.

> *In this part, we present you a list of statements. Please indicate the extent to which you agree or disagree with them. Please do not spend too much time on each statement. There are no right or wrong answers and therefore your first response is important. Nevertheless, try to be as honest as you can be. Answer according to your own feelings, rather than how you think most people would answer. Don't worry about being consistent in your responses. Be sure to answer every statement.*
>
> *Please respond to the following statements by indicating the extent to which you agree or disagree with them on a scale from 1 (I strongly agree) to 7 (I strongly disagree).*

Intolerance of Ambiguity Scale by Kirton (1981). Items based on Mac Donald Jr. (1970) and Rydell and Rosen (1966):

1 There's a right way and a wrong way to do almost everything.

2 Practically every problem has a solution.

3 I have always felt that there is a clear difference between right and wrong.

4 Nothing gets accomplished in this world unless you stick to some basic rules.

5 If I were a doctor, I would prefer the uncertainties of a psychiatrist to the clear and definite work of someone like a surgeon or a x-ray specialist.

6 Vague and impressionistic pictures really have little appeal for me.

7 Before an examination, I feel much less anxious if I know how many questions there will be.

8 The best part of a jigsaw puzzle is putting in that last piece.

9 I don't like to work on a problem unless there is a possibility of coming out with a clear-cut and unambiguous answer.

10 I like to fool around with new ideas, even if they turn out later to be a total waste of time.

11 Perfect balance is the essence of all good composition.

Items based on Budner (1962):

12 An expert who doesn't come up with a definite answer probably doesn't know too much.

13 There is really no such thing as a problem that can't be solved.

14 A good job is one where what is to be done and how it is to be done are always clear.

15 In the long run it is possible to get more done by tackling small, simple problems rather than lange and complicated ones.

16 What we are used to is always preferable to what is unfamiliar.

17 A person who leads an even, regular life in which few surprises or unexpected happenings arise, really has a lot to be grateful for.

18 I like parties where I know most of the people more than the ones where all or most of the people are complete strangers.

Besides the Intolerance of Ambiguity Scale by Kirton (1981) the questionnaire also included selected items from other studies.

Item from the Tolerance of Ambiguity Scale by Budner (1962):

19 I would like to live for a while in a foreign country that is new to me.

Items from the Ambiguity Tolerance Scale by Norton (1975):

20 In a decision-making problem in which there is not enough information to process the problem, I feel very uncomfortable.

21 I am tolerant of ambiguous situations.

22 Vague and impressionistic pictures appeal to me more than realistic pictures.

23 I like movies or stories with definite endings.

24 The best part about reading a poem is then being able to read a commentary explaining the poem's meanings.

Items from the Extended Life Orientation test by Chang et al. (1997):

25 In uncertain times, I usually expect the best.

26 When I undertake something new, I expect to succeed.

27 If something can go wrong for me, it will.

28 I rarely count on good things happening to me.

Items from the Uncertainty Response Scale by Greco and Roger (2001):

29 When making a decision, I am deterred by the fear of making a mistake.

30 When a situation is uncertain, I generally expect the worst to happen.

31 I find the prospect of change exciting and stimulating.

32 I enjoy unexpected events.

33 The idea of taking a trip to a new country fascinates me.

34 Before making any changes, I need to think things over thoroughly.

35 I feel relieved when an ambiguous situation suddenly becomes clear.

36 When uncertain, I act very cautiously until I have more information about the situation.

37 I prefer to stick to tried and tested ways of doing things.

Items from the Ambiguity Tolerance Scale II by McLain (2009):

38 I try to avoid situations that are ambiguous.

39 I avoid situations that are too complicated for me to easily understand.

40 I generally prefer novelty over familiarity.

41 I find it hard to make a choice when the outcome is uncertain.

Single-item measure of self-esteem by Robins et al. (2001)[21]:

42 I have high self-esteem.

Other items (own additions):

43 I like novelties.

44 I voluntarily accept new challenges.

45 When a situation is uncertain, I never take action until I know all the risks involved.

46 Do you consider yourself as a pessimist or an optimist?

[21] Similar to Robins et al. (2001), this item uses a 5 point answer scale.

Appendix D: Sample description

Table D.1: Summary of sample characteristics

Panel A: Gender

	Observations	Percentage
male	54	44.6%
female	67	55.4%
total	121	100.0%

Panel B: Marital status

	Observations	Percentage
single	112	92.6%
married	5	4.1%
divorced	3	2.5%
widowed	1	0.8%
total	121	100.0%

Panel C: Age

	Observations	Percentage
up to 20 years	11	9.1%
21 - 25 years	59	48.8%
26 - 30 years	29	24.0%
over 30 years	22	18.2%
total	121	100.0%
average	121	26.3 years

Panel D: Nationality

	Observations	Percentage
United Kingdom	45	37.2%
Italy	12	9.9%
Germany	9	7.4%
China	7	5.8%
Poland	6	5.0%
other countries	42	34.7%
total	121	100.0%

Panel E: Main field of studies

	Observations	Percentage
Politics and International Relations	14	11.6%
Economics	11	9.1%
Business Studies	10	8.3%
Modern Languages and Cultures	10	8.3%
Psychology	9	7.4%
Development Studies	9	7.4%
Humanities	9	7.4%
other subjects	49	40.5%
total	121	100.0%