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Individual antecedents of real options appraisal:
The role of national culture and ambiguity

Tarik Driouchi[1,*], Lenos Trigeorgis[2] and Raymond HY So[3]

[1,] Corresponding author: King's College London, London, UK. <tarik.driouchi@kcl.ac.uk>*
[2] University of Cyprus, Nicosia, Cyprus; MIT, Cambridge, Massachusetts, USA. <lenos@mit.edu>
[3] King's College London, London, UK. <raymond.so@kcl.ac.uk>

Abstract: This paper studies the antecedents of cognitive options appraisal in a cross-cultural sample of specialists and generalists. Examining the role of national culture and ambiguity in the real option logic, we show that individuals have more propensity to intuitively value options opportunities using ambiguity-based approaches than standard Bayesian benchmarks, and identify the-drivers behind such behavioral deviations. We find that knowledge and cultural factors, along with age, gender and international life-experience, influence subjective real options values and ambiguity attitudes. Results also confirm the higher tolerance for uncertainty of the Chinese relative to others.

Keywords: real options; ambiguity; multiple-priors; Choquet utility; national culture; business education

1. Introduction

Extant experimental and empirical research on behavioral real options documents how individual decision makers deviate from Bayesian appraisal when explicitly asked to assess investments with embedded contingent-claims (Pitts and Busby 1997; Denison 2009; Brady 2014). Because of heterogeneity, cognition and subjective biases, investors, managers and other types of decision makers seem to either value real options at a discount (under-investment) owing to their pessimism and uncertainty aversion (Miller and Shapira 2004; Leiblein et al. 2017) or overvalue options (over-investment) as a result of overconfidence and overoptimism (Howell and Jägle 1997; Devers et al. 2007). Yet, we do not know the specific reasons or individual factors behind such deviations in appraisal and what triggers the real options under/over-investment problem at the individual level. We also do not know whether or how individual differences across samples and firms affect the aforementioned appraisal patterns. Addressing these issues is essential for decision making research as cognition, personal characteristics and ambiguity preferences[1] play an important role in shaping risk appetite and individual ability to learn from uncertainty (Gilboa and Marinacci 2013; Borgonovo and Marinacci 2015; Doan et al. 2019; Balter and Pessler 2020). This should also help to explain decision makers and managers' tendencies to act proactively or cautiously when appraising highly uncertain optional investment choices.

We address the above gaps in financial decision making and cognition research, and reconcile the existing real options evidence by showing that ambiguity aversion and ambiguity-seeking play a joint role in option valuation - offering explanations into how and why this happens - , underline factors behind such deviations and confirm that differences across groups matter in cognitive option appraisal and investment decision making. We further validate

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[1] We define ambiguity in this paper as uncertainty beyond probabilistic risk (i.e., deviations from Bayesianism). Ambiguity aversion (pessimism) can be viewed as the tendency to overweight events with bad outcomes when faced with uncertainty, while ambiguity-seeking (optimism) is interpreted as one's propensity to overweight good, but less probable, outcomes displaying uncertainty-liking behavior. In this study, we employ the terms "ambiguity", "uncertainty" (as opposed to risk) and "Knightian uncertainty" interchangeably.

existing frameworks of uncertainty in behavioral decision theory (e.g., Einhorn and Hogarth 1985; Gilboa and Schmeidler 1989; Schmeidler 1989; Ghirardato et al. 2004; Kast and Lapied 2010; Borgonovo and Marinacci 2015), demonstrating that experimental option prices from our survey participants are not so different from intrinsic values produced by ambiguity-based approaches from the multiple-priors (MP) and Choquet utility (CU) appraisal families (see e.g., Hey et al. 2010; Baillon et al. 2016; Balbás et al. 2016; Hu et al. 2018). We also extend recent work by Miller and Shapira (2004) and Leiblein et al. (2017) on behavioral real options and undervaluation by: 1) examining empirically how ambiguity or subjective uncertainty affects the cognitive option appraisal processes of individuals from different countries, and 2) unveiling the role of national culture and personal characteristics in shaping ambiguity behavior and option-based investment decision making. More generally, we investigate how national culture, miscalibration and ambiguity influence investment appraisal and explicit real options assessment.

We address the following practically-relevant questions: do national culture and ambiguity play a role in the real options logic? If so, which personal attributes effectively influence cognitive option appraisal and ambiguity attitudes? Answering these questions is important as it can also help to understand further the antecedents of under/over-investment in practice (see e.g., Shao et al. 2013; Chui and Kwok 2008) and serve to identify the determinants of ambiguity as potential reasons behind suboptimal investment decisions.

Several experimental and laboratory studies have sought to elucidate why groups and individuals violate the expected utility maximization paradigm in appraising lotteries and financial investment plans when faced with risk or uncertainty (Abdellaoui et al. 2005; Murphy et al. 2016). Various papers have also highlighted the role of cognition and miscalibration in valuation and forecasting (Ben-David et al. 2013; Trautmann and Schmidt 2012). Others refer to situational factors such as culture, temporal distance, home bias, psychology and individual characteristics (Sharp and Salter 1997; Bontempo et al. 1997; Onay et al. 2013) as drivers behind heterogeneous appraisal. Despite this mounting evidence, not many papers have been devoted to the investigation and explicit appraisal of option-based investments and real options opportunities. The closest papers in this area are Howell and Jägle (1997), Miller and Shapira (2004), List and Haigh (2010), Wang et al. (2012), Brady (2014), Denison et al. (2012), Devers et al. (2007) and Rockenbach (2004) and Abbink and Rockenbach (2006), all provide promising descriptive evidence on the behavioral implications of the real option logic but only study cognitive option appraisal patterns in national/homogeneous datasets.[2]

We extend this stream of experimental research by relying on option pricing specifications under ambiguity to help explain and interpret valuation behavior in a heterogeneous sample of 84 international postgraduate students (later expanded to 142 participants for further validation), and underline the role of national culture and individual characteristics in investment appraisal and ambiguity tolerance. To our knowledge, this is the first empirical study linking explicit real options appraisal to ambiguity, national culture and other situational attributes. Also since the option-based view has been recognized as an important strand in decision making research (Delaney 2018; Tavares-Gärtner et al. 2018; Trigeorgis and Tsekrekos 2018; Maier et al. 2019), it is useful to investigate the

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[2] Also related but mostly concerned with escalation of commitment and its real options decision making implications are the works of Denison (2009), Salter et al. (2013) and Tiwana et al. (2007). More recently, Murphy et al. (2016) test and validate behavioral decision making theories in sequential commitment and investment timing in a laboratory setting where rolling a die is equivalent to proceeding to a subsequent investment stage.

role of national culture and other individual characteristics in the real options logic and understand why real options practice is not always in line with Bayesian theory (e.g., Yavas and Sirmans 2005; Denison 2009; Alexander et al. 2012; Ghosh and Troutt 2012; Morreale et al. 2019).

Our experimental survey evidence shows that option pricing knowledge and cultural attributes can help explain differences in real option assessment among participants. We find that students with fundamental and specialist knowledge of options or majoring in Accounting, Finance or Economics (AFE) appraise real options opportunities more cautiously relative to others without such knowledge. In accord with the cushion hypothesis of Hsee and Weber (1999), we validate the prediction that more long-term oriented and collectivist societies (e.g., Confucian) assign more value to situations with contingent or remote payoffs than individualistic counterparts. We also corroborate the influence of personal characteristics on individuals' propensity to seek or avoid uncertainty. We find that gender, age and the number/diversity of countries one has lived in (a proxy for international life experience) are associated with ambiguity aversion in our sample. In terms of appraisal patterns and ambiguity specifications, participants' assessment decisions tend to be more in line with the MaxMax criterion (i.e., best case scenario) when buying real options (WTP: willingness-to-pay) implying they are optimistically focused on positive returns and favorable uncertainty in upside prospects. When it comes to selling real options, respondents often follow MaxMin MP (worst-case appraisal), α-MP (i.e., "averaging" between best and worst case), non-additive probabilities (rank-dependent CU) and MaxMax schemes suggesting that accounting for regret and ambiguous volatility dispersions can be more important in willingness-to-accept (WTA) situations. The observed heterogeneity in appraisal and ambiguity tolerance are explained by national culture, demographic and international situational factors.[3]

The paper proceeds as follows. Section 2 reviews the relevant literature and introduces our ambiguity-based option appraisal frameworks. Section 3 describes the data and experimental survey methodology. Section 4 presents the results and findings, which we divide into: i) the role of personal attributes, national culture and ambiguity in real options valuation, and ii) the determinants of ambiguity in our dataset. Section 5 concludes and discusses implications.

2. Background literature and cognitive appraisal frameworks

As noted, specific experimental and survey evidence on contingent-claims valuation, option trading and cognitive real options appraisal can be found in Howell and Jägle (1997), Rockenbach (2004), Abbink and Rockenbach (2006), Devers et al. (2007), Wang et al. (2012), List and Haigh (2010), Denison et al. (2012) and Miller and Shapira (2004). Howell and Jägle (1997) examine growth options awareness among UK managers. Based on a sample of 82 individuals, they show that senior executives tend to overvalue real options opportunities. Examining the case of executive stock options, Devers et al. (2007) report similar findings in a US-based (male-dominated) sample of 94 MBA students but unveil an interaction effect of stock price trend on the relationship between volatility and option value. Using a sample of 64 MBA students, Miller and Shapira (2004) examine individuals' propensity to value option

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[3] Notwithstanding, we also find that a non-negligible proportion of WTP and WTA outcomes are anchored to Black-Scholes (Bayesian) option values, pointing to subjective assessment under risk rather than ambiguity only. Our overall findings hold in online and offline surveys.

lotteries lower than the expected value of the lottery and report that their US-based survey participants are both risk and uncertainty averse. More recently, Brady (2014) revisits the design and findings of Miller and Shapira (2004) from a prospect theory perspective on a sample of 67 business school students from Australia to find evidence of risk biases in real option pricing and S-shaped utility curves for valuation. Through a set of laboratory experiments, Rockenbach (2004) and Abbink and Rockenbach (2006) investigate option trading strategies and no-arbitrage opportunities in a sample of 18 students and 24 professional traders based in Germany. Wang et al. (2012) study the extent to which switching real options values in a laboratory experiment involving 66 undergraduate student subjects based in Switzerland are in line with specific stochastic processes such as mean reversion, Brownian motion or a mix of both among other specifications. Rockenbach (2004) and Abbink and Rockenbach (2006) find evidence of mental accounting among their participants and highlight the existence of a knowledge "curse" among professional traders, while Wang et al. (2012) report some evidence of learning and Bayesian real options behavior in their Swiss sample. Denison et al. (2012) document, in an experimental setting of 70 undergraduate/postgraduate students based in the US, how the way of displaying accounting and financial information influences judgment and individuals' propensity to incorporate optionality in long-term appraisal. List and Haigh's (2010) findings validate the bad news principle and loss aversion hypothesis on a large pool of students and professional traders.

Despite the above related work and some recurrent evidence of deviations from Bayesian behavior, no empirical research has examined the real option valuation problem in terms of willingness-to-pay (WTP) or willingness-to-accept (WTA)[4] from an ambiguity perspective or considering national culture to explain investment appraisal patterns. We address this gap in the literature by examining the role of subjective uncertainty attitudes in explicit option appraisal via a family of behavioral valuation models under ambiguity. We investigate the effects of cultural attributes on appraisal patterns and study the determinants of ambiguity in our international sample of specialist and generalist postgraduate students. We look for evidence of ambiguity among participants and identify some of the behavioral criteria or decision rules adopted by decision makers when appraising uncertain real options opportunities. We also verify whether there are cross-cultural differences in real options values among participants. In line with extant research that relies on students' familiarity with real options principles (e.g., Miller and Shapira 2004; Devers et al. 2007; Denison et al. 2012; Wang et al. 2012), we examine option appraisal behavior in a postgraduate student dataset. However, we take care to differentiate between specialists and generalists in our experimental study and investigate the role of national culture and international heterogeneity in the real options valuation problem.

We view ambiguity in this paper as uncertainty beyond probabilistic risk. More specifically, we define ambiguity as the behavioral deviations from Bayesian appraisal caused by lack of (or incomplete) information, uncertainty in model specification and one's inability to rule out the number of distributions associated with their cognitive valuation processes (see e.g., Einhorn and Hogarth 1985; Hogarth and Kunreuther 1989; Zmeškal 2010; Kojadinovic 2007; Kou and Peng 2016). When experiencing ambiguity, economic agents can mentally adjust their valuation estimates using anchor-based, distribution-based approaches or other related decision rules (see also

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[4] Della Seta et al. (2014) investigate the role of risk and ambiguity in real options timing vis-à-vis deferral and agents' willingness-to-wait. Viefers (2015) is also more concerned with ambiguity and investment timing matters.

March 1987; Zmeškal 2005; Marichal 2007; Coff and Laverty 2007; Baillon and L'Haridon 2016). Before proceeding to our empirical sections on the drivers of real option appraisal and determinants of ambiguity, we introduce next our cognitive appraisal models[5] - starting with the risk-neutral framework as a standard Bayesian benchmark - and summarise our main research predictions.

2.1. Risk-neutral appraisal (Bayesian benchmark)

Under risk-neutral appraisal,[6] the value of a real investment opportunity or option value O_{RN} is derived from the underlying asset price or project value V, which follows an objective Brownian motion or lognormal diffusion - forming the basis of the Black-Scholes-Merton (BSM) valuation - with drift μ and volatility σ:

$$dV(t) = \mu V(t)dt + \sigma V(t)dB_t \qquad (1)$$

The risk-neutral (RN) specification of call option value O_{RN} is as follows:

$$O_{RN}(V) = e^{-rT}\, E^{Q^{RN}}\, max\,(V_T - I, 0) \qquad (2)$$

where $V_T = f\,(V_0, T, r, \sigma)$ is the risk-neutral future asset value at maturity T, I is the investment cost (exercise price), $E^{Q^{RN}}$ the expectation operator under risk-neutrality and r is the risk-free interest rate (opportunity cost earned on funds not yet invested). Option value O_{RN} is the present value (discounted at risk-free rate r) of the expected payoff from the option opportunity. In line with Black and Scholes (1973), the above benchmark RN specification assumes certain or deterministic drift and volatility, and results in homogeneous (universal) valuation and indifference towards uncertainty. This assumption does not hold, however, in real life decision making situations (Miller and Shapira 2004; Millo and MacKenzie 2009; Moldoveanu 2009). This is where ambiguity, subjective or Knightian uncertainty become relevant. Economic agents can have varying ambiguity preferences when faced with unpredictable business situations. This could lead to subjective discounting, miscalibration and heterogeneous model specification (e.g., regarding growth rates μ and/or volatility σ), and may make individuals follow specific rules, adjustments or behavioral criteria in their appraisal of highly uncertain contingent-claims (Miller and Arikan 2004; Leiblein et al. 2017).

Three main classes of ambiguity models dominate the literature on decision making criteria under ambiguity. The first class of models (MP) considers a set of possible beliefs and probability measures a decision maker might have, and evaluates uncertain bets under ambiguity aversion using multiple-priors. Seminal MP models include Gilboa and Schmeidler (1989) and their MaxMin worst-case criterion over convex sets of probability measures, and Ghirardato et al. (2004) and their α-MaxMin framework (α-MP) with pessimism and optimism. Maccheroni et al. (2006) generalize MP theory to ambiguity situations with (dynamic) variational representations of preferences where

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[5] Appendix A lists the ambiguity-based valuation frameworks (with anchoring-and-adjustment processes) used.

[6] To account for other Bayesian appraisal effects, we also test the risk aversion-based (RA) option valuation model by Bartunek and Chowdhury (1997) and following Huang and Litzenberger (1988):

$$O_{RA}(V) = e^{-rT}\ \left(E^{Q^{RA}}[(\ \ max\,(V_T - I, 0)^{1-\gamma})]^{1/(1-\gamma)}\right)$$

where O_{RA} is the call option value under constant relative risk aversion (CRRA) and γ is the risk aversion parameter. In line with the empirical findings of Bartunek and Chowdhury (1997), we use γ = .2 in our valuation tests.

multiplier preferences with robust control à la Hansen and Sargent (2001) are also a special case.[7] Suitable for the evaluation of two-stage prospects, the second class of models (also referred to as source-dependent utility) encompasses recursive and two-stage ambiguity models with second-order priors and second-order expectations where ambiguity is represented through a difference in utility between risk and uncertainty (Attema et al. 2018). Examples of prominent models include the recursive model of Segal (1987), the smooth ambiguity model by Klibanoff et al. (2005), and the subjective compound lottery model of Ergin and Gul (2009). The third class of models considers rank-dependent and Choquet expected utility (CU) where ambiguity is modeled by means of non-additive probability measures or capacities, and subjective probabilities can be replaced by decision weights under a number of conditions (e.g., when dealing with gains and losses). Important and seminal CU models include Gilboa (1987), Schmeidler (1989) and Wakker (1990). In this paper, we focus on the MP and CU ambiguity specifications because of their overlapping features, their suitability for contingent-claims valuation, and the fact that they have shown sufficient reliability in explaining valuation behavior and economic choice under uncertainty (Hey et al. 2010; Abdellaoui et al. 2011). Other ambiguity frameworks used in decision theory include, amongst others, vector expected utility by Siniscalchi (2009), the expected uncertain utility of Gul and Pesendorfer (2014), and Bewley's (2002) incomplete preferences and unanimity rule (see Machina and Siniscalchi 2014 for an exhaustive review of the various models). The advantage of using the MP and CU specifications in our context is that we are able to link national culture and ambiguity to (closed-form) real options valuation through an ambiguity score *k*. This *k* score is a proxy for individual ambiguity perceptions or perceived ambiguity in our option appraisal setting and is indicative of one's propensity to deviate from Bayesian valuation (i.e., Bayesian benchmark or anchor score *k* = 0.5). Ambiguity is captured by means of a (sub-)family of priors under MP and through constant conditional capacities under CU throughout the rest of the paper.

2.2. Appraisal under multiple-priors ambiguity (MP)

Under multiple-priors ambiguity, real option value O_{MP} is derived from a (subjective subset of) multiple-priors Brownian motion(s)/specification(s) (e.g., Riedel 2009; Nishimura and Ozaki 2007) of the form:

$$dV(t) = (\mu + m\sigma)V(t)dt + \sigma V(t)dB_t \quad (\forall\, m \in\,]-1,1[\,, \forall\, k\ \in]0,1[\,) \qquad (3)$$

where $-1 < m < 1$ indicates the degree of parametric uncertainty or misspecification (due to ambiguity behavior) surrounding the mean rate or expected returns μ. Parameter *m* is a linear function of ambiguity score *k*, such that $m = 2k - 1$, where $0 < k < 1$ (see e.g., Kast and Lapied 2010 and the MP version of their ambiguity-based symmetric random walk). Score *k*, known as κ-ignorance in the MP literature, captures the level of ambiguity affecting appraisal outcomes. $m < 0$ and $m > 0$ (i.e., $k < 0.5$ vs. $k > 0.5$) can also be interpreted as reflecting more pessimistic vs. less pessimistic drift adjustments in the face of uncertainty (see e.g., Hackbarth 2009; Kajii and Ui 2005). $m = 0$ corresponds to the Bayesian case without ambiguity.

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[7] The latter is based on robust decision making principles which consist of accounting for model misspecification and ambiguity perturbations from a reference model through a penalty function (see e.g., Hung and So (2010) and their robust control contingent-claim model with risk aversion)

2.2.1. Ambiguous drift, MaxMin and MaxMax criteria (MP)

The MaxMin multiple-priors-based specification of call option value $O_{MAXMIN\text{-}MP}$ can be expressed as follows (see Riedel 2009; Miao and Wang 2011; Asano and Shibata 2014):

$$O_{MAXMIN-MP}(V) = \max \left\{ inf_{m\in[-1,1]} E^{Q^{MP}} \left[e^{-r'T}(V'_T - I, 0) \right] \right\} \quad (4)$$

where the MP-based subjective future asset value $V'_T = f'$ (V_0, T, r, μ, σ, m) and $E^{Q^{MP}}$ is the multiple-priors based expectation operator. r' is a subjective discount rate, which is a function of risk-free rate r and behavioral parameter m (determined linearly as in Eq. (3) by ambiguity score k), due to MaxMin-based ambiguous beliefs. Under this specification, economic agents give full consideration to the worst-case scenario (i.e., $k < 0.5$ and $m < 0$) - within a subset of priors - in their appraisal of uncertain prospects (Gilboa and Marinacci 2013). In line with Eq. (3), ambiguity is captured by k and influences the degree of misspecification surrounding expected returns μ. Ambiguity aversion is assumed throughout because of “extreme” pessimism in decision making; ambiguity and ambiguity aversion are correlated through k. The MaxMax version of the MP specification is the maximum O_{MP} value for any given k.

2.2.2. The α-MaxMin criterion (α-MP)

The α-MaxMin multiple-priors-based specification, also based on Equation. (3), of real option value $O_{\alpha\text{-}MP}$ can be expressed as:

$$O_{\alpha-MP}(V) = \alpha\, sup_{m\in[-1,1]} E^{Q^{MP}} \left[O_{MP} \right] + (1-\alpha) inf_{m\in[-1,1]} E^{Q^{MP}} \left[O_{MP} \right] \quad (5)$$

Under this framework, economic agents take something akin to a weighted average between their pessimistic and optimistic appraisals. Ambiguity is again captured by k, and as defined in Eqs. (3-4), m represents the degree of parametric uncertainty surrounding the mean rate of the Brownian motion in (3). Unlike the MaxMin MP criterion, the α-MaxMin MP aims to disentangle ambiguity attitudes α from ambiguity perceptions (Ghirardato et al. 2004; Chateauneuf et al. 2007). Variable α stands for the decision weights ($0 \leq \alpha \leq 1$) attributed to optimistic (MaxMax) and pessimistic (MaxMin) outcomes. Eq. (5) simplifies to Eq. (4) in the case with no optimism.

2.3. Appraisal under Choquet ambiguity (CU)

Under Choquet ambiguity, option value O_{CU} is derived from the more general (though still subjective) set of Choquet-based Brownian motions - involving ambiguous returns *and* ambiguous volatility - (e.g., see De Waegenaere et al. 2003; Agliardi et al. 2016) of the form:

$$dV(t) = (\mu + m\sigma)V(t)dt + n\sigma V(t)dB_t \quad (\forall\, m \in\,]-1{,}1[\,, \forall\, n\, \in]0{,}1]\,) \quad (6)$$

where $m = 2k - 1$ as defined before and n is a nonlinear function of ambiguity score k - such that $n = \sqrt{4k(1-k)}$ - altering the underlying variance process (see Kast and Lapied 2010; Agliardi and Sereno 2011 and Appendix A). Here m and n can take a number of functional forms, with the RN case meeting the condition $m = 0$ and $n = 1$ (see e.g., Kuhnen and Melzer 2018). The above CU specification is broader, overlaps with MP (i.e., Eq. (3)), and can accommodate ambiguity-seeking interpretations (Gilboa and Marinacci 2013). However, while ambiguity score k herein partly reflects the direction of ambiguity, it does not disentangle ambiguity perceptions from ambiguity attitudes (i.e., ambiguity and ambiguity aversion (-seeking) are correlated through k). The Choquet-based specification of call option value O_{CU} can be expressed as follows:

$$O_{CU}(V) = e^{-r''T}\, E^{Q^{CU}}\, max\,(V''_T - I, 0) \qquad (7)$$

where the Choquet-based subjective future asset value $V''_T = f''\,(V_0, T, r, \mu, \sigma, m, n)$ and $E^{Q^{CU}}$ is the Choquet expectation operator. r'' is a subjective discount rate, which is a function of the risk-free rate r and behavioral parameters m and n (the latter also accounting for uncertainty about volatility). As mentioned, m affects the drift of the Brownian motion and n is a variance scaling parameter determined by ambiguity score k (see Kast et al. 2014; Agliardi et al. 2016; Driouchi et al. 2018). Under this more general framework, economic agents appraise real option alternatives using non-additive probabilities (e.g., see Einhorn and Hogarth 1985; Abdellaoui et al. 2011 and their behavioral valuation theories). Ambiguity and model misspecification are captured by constant conditional capacity or ambiguity score k, which this time determines the degree of misspecification/miscalibration surrounding both the drift and volatility terms of (1) and (6) through m and n. Wakker (1990, 1991) indeed shows using convex/concave capacities that CU can express uncertainty-liking behavior (i.e., $k < 0.5$ vs. $k > 0.5$ for aversion and seeking, respectively). The MaxMax version of this specification is simply the maximum O_{CU} for any k. Variable k - alternatively known as c-ignorance in the CU literature - is important in these models because it defines the degree of partial ignorance surrounding asset value V, and influences individuals' appraisals of uncertain option-like opportunities.

The above frameworks suggest that while valuation à la Black-Scholes (RN) might be considered a benchmark in Bayesian real options analysis, individuals can also resort to using sophisticated criteria or ambiguity-based decision rules such as best case (MaxMax), worst-case (MaxMin), averaging (α-MaxMin) and non-additive probabilities (CU) in their cognitive appraisal processes when faced with uncertainty and incomplete information. This should be explained by mental anchoring, miscalibration and other behavioral considerations. This would especially be the case when studying cross-cultural settings and heterogeneous samples. This leads to the following proposition:

Proposition 1. *Individuals are more likely to intuitively appraise WTP and WTA real options situations using ambiguity-based criteria than relying on Bayesian valuation benchmarks.*

As a proxy for ambiguity, variable k should help us examine the extent to which call and put option values produced by our experimental survey participants are in accord with the intrinsic values given by Eqs. (2, 4-5, and 7). This is similar to testing whether individuals instinctively follow Bayesian RN/risk-based, or ambiguity-based MaxMin, MaxMax, α-MaxMin (MP) and non-additive probability schemes (CU) when appraising real options or investments with embedded contingent-claims. Using two-sample paired t-tests and multivariate regression analysis, we also identify empirically some of the key drivers and cultural factors that explain differences in heterogeneous real option values among participants (e.g., over- and undervaluation cases).

2.4. Literature and predictions on the antecedents of cognitive appraisal

Cultural, personal and situational attributes have been known to influence both risk and uncertainty preferences (see Li et al. 2013; Wang et al. 2017; Baillon et al. 2016). In accord with Hsee and Weber (1999) and their cushion hypothesis on the risk-prone, and possibly uncertainty-seeking, tendencies of individuals from collectivist Confucian societies, we test whether Hofstede's long-term orientation (individualism) increases one's propensity to overvalue (undervalue) uncertain real options. This has been previously attributed, in the context of standard lotteries, to the higher risk-seeking characteristics of the Chinese relative to Westerners and the fact that, unlike individualistic societies, Confucianist and collective-minded cultures have social networks that individuals can rely upon in cases of insolvency and other personal finance difficulties (i.e., social diversification phenomena) (Weber et al. 1998; Hsee and Weber 1999). Additionally, Hofstede (2001) documents that countries such as China, Singapore, Hong Kong and Vietnam have lower (higher) uncertainty avoidance (tolerance) levels than most Western countries. We verify if Chinese individuals in our sample are more tolerant of uncertainty than others when it comes to real options.

We also investigate the influence of personal characteristics on individuals' propensity to seek or avoid uncertainty. As proxies for broader life experiences, we examine the situational and personal factors (i.e., age, major of study, number of countries one has lived in, gender, etc) that affect appraisal processes. With age, individuals are expected to be more responsible and more cautious (Vroom and Pahl 1971; Figner et al. 2009). With more specific knowledge, less erratic or extreme values should be observed (Fox and Weber 2002). According to the cultural pluralism hypothesis, knowledge of more than one culture (e.g., through the number/diversity of countries one has lived in) can enhance both risk mitigation and uncertainty aversion (Earle and Cvetkovich 1997).[8] Because of gender differences in experience, social norms and values, women are predicted to be more risk averse, less overconfident and more ambiguity averse than men in the literature (Borghans et al. 2009; Faccio et al. 2016).

In terms of other national cultural effects, masculinity and power distance are known to influence someone's propensity to seek or avoid situations with uncertain prospects (Chui and Kwok 2008). Further, societies that promote achievement and competitiveness (i.e., high masculinity) can be more entrepreneurial (Hofstede 2001; Mihet 2013). Power distance (PDI) is predicted to be negatively associated with both risk and uncertainty loving because of trust considerations (Mihet 2013; Li et al. 2013). Some of these associations might be reversed, however, because of confounding effects from other cultural aspects and the cushion hypothesis (e.g., Sharp and Salter 1997; McGrath et al. 1992).

The aforementioned situational and cultural factors are investigated as potential determinants of real option value and ambiguity in our study of international postgraduate students. This leads to the following proposition regarding the antecedents of option appraisal and ambiguity behavior:

Proposition 2. *National culture, personal and situational attributes influence real option appraisal outcomes and individual ambiguity attitudes.*

We test our predictions concerning the role of cultural aspects in option appraisal using Hofstede's (2001) dimensions. Table 1 summarizes the basic predictions on the determinants of ambiguity (emphasizing aversion in the table) and other related literature. Overall, our research aims to verify whether option appraisal outcomes from experimental survey participants are in line with those of our ambiguity-based valuation frameworks (see Eqs. (2-7)), and understand how ambiguity behavior influences investment decisions. This will consist of i) examining the role of

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[8] This is in contrast to cosmopolitanism arguments which emphasize higher uncertainty tolerance and risk-taking.

cultural factors and personal attributes in investment appraisal, and ii) studying the antecedents of ambiguity in our sample by extracting ambiguity score *k* directly from respondents' option values[9].

Table 1. Explanatory variables and literature on the role of cultural and situational attributes in cognitive appraisal

Explanatory variable	Predicted sign (Option value)	Predicted sign (Ambiguity aversion)	Related literature
Situational			
Age	-	+	Vroom and Pahl (1971); Kahle et al. (2005); Figner et al. (2009).
Gender (Female)	-	+	Borghans et al. (2009); Faccio et al. (2016).
Chinese (China)	+	-	Bontempo et al. (1997); Weber et al. (1998); Hsee and Weber (1999); Xie et al. (2003); Pattaratanakun and Mak (2015).
Number of Countries (Ncountries)	-	+	Hollinger (1992); Earle and Cvetkovich (1997).
Knowledge & Experience	-	+	Abbink and Rockenbach (2006); Dwyer et al. (2002); List and Haigh (2010); Fox and Weber (2002).
Cultural			
Uncertainty avoidance (UAI)	-	+	Hofstede (2001); Wang et al. (2017).
Long-term orientation (LTO)	+/-	-/+	Bontempo et al. (1997); Hsee and Weber (1999); Weber and Hsee (1998).
Individualism (IDV)	+/-	-/+	Hsee and Weber (1999); Chui and Kwok (2008); Salter et al. (2013); Li et al. (2013).
Masculinity (MAS)	+	-	Hofstede (2001); Shao et al. (2013); Frijns et al. (2016).
Power distance (PDI)	-	-	Mihet (2013); McGrath et al. (1992); Li et al. (2013).

3. Data and methodology

3.1 Sample and participants

Our sample consists of 84 international postgraduate students mostly based in the UK. Of these, 42 are males and 42 are females. 59 majored in Accounting, Finance or Economics and can be considered specialists and familiar with option appraisal principles. The rest (30%) are generalists. 26 nationalities were represented overall,[10] although 45 respondents were Chinese thus allowing to examine predicted differences in appraisal and ambiguity tolerance of this important culture. While the majority of participants had learned about options in their university degree or through self-study, only 9 had prior industry experience related to financial options or other types of contingent-claims. 12 respondents indicated they had no previous knowledge in options analysis. The median age of respondents is 25. 78 had lived in more than one country, displaying meaningful international life experience. As

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[9] Our elicited ambiguity score *k* does not fully separate ambiguity attitudes from the overall degree of ambiguity perceptions. An interesting research extension could consist of decomposing our *k* indicator into an uncertainty score of likelihood insensitivity and a pure index of ambiguity aversion or pessimism (e.g., see Abdellaoui et al. 2011; Baillon et al. 2017), and study the decision-theoretic implications of each component.

[10] Namely: Albania, Austria, Bulgaria, Chile, China, Cyprus, France, Germany, India, Iran, Italy, Malaysia, Netherlands, New Zealand, Peru, Poland, Slovakia, Switzerland, Taiwan, Thailand, Turkey, Ukraine, UK, USA, Vietnam, former-Yugoslavia.

noted, the high proportion of Chinese participants[11] enables us to contribute to extant research that contrasts the risk and uncertainty preferences of the Chinese versus others (see Weber and Hsee 1998; Xie et al. 2003; Pattaratanakun and Mak 2015). While the survey methodology suits our purpose of obtaining a sizeable sample of respondents (in line with extant evidence on behavioral real options), it can suffer from sampling bias, lack of control over behavior and perceptual framing effects. An interesting extension of our study could consist of using lab experiments (e.g., see Abdellaoui et al. (2011); Baillon et al. (2017)) to further verify/validate our research predictions and mitigate some of the aforementioned survey-specific externalities.

3.2 Questionnaire

An anonymous online valuation questionnaire was sent to 245 postgraduate students from leading universities. The valuation questions are comparable to those developed by Miller and Shapira (2004) related to buying and selling call and put option investment plans. However, our questionnaire consisted of short cases that provided more conventional and explicit option appraisal questions (e.g., considering asymmetric payoffs and standard inputs: strike price I, riskless interest rate r, volatility σ, and maturity T) and focused primarily on the potential role of ambiguity in valuation. We added situational and demographic questions to the questionnaire to help better understand some of the key determinants of ambiguity and the drivers of cognitive options appraisal. Our questionnaire was thus composed of two main sections. 84 completed and usable questionnaires were obtained. The first section of the questionnaire contained demographic, cultural and situational information (i.e., age, gender, nationality, number of countries one had lived in, major of study, prior option experience, etc). The second part on valuation contained 10 questions involving short cases or situations of buying (WTP) and selling (WTA) call and put option investments (six: 4 WTP and 2 WTA calls vs. four: 2 WTP and 2 WTA puts) with different maturities, volatilities and moneyness levels (see Appendix B for illustration). As the focus was on practical and intuitive appraisal, participants were instructed not to use calculators when mentally assigning values to the WTP/WTA cases. In terms of wording and structure, the valuation part again resembles Miller and Shapira's (2004) though - as mentioned - questions were refined to account for explicit optionality, standard valuation input information, and to differentiate clearly between upside versus downside investment opportunities (call vs. put options). This aspect was more in line with the cases and questions used by Howell and Jägle (1997) and Brady (2014).[12]

The resulting sample was then subjected to statistical analysis for hypothesis validation. In the first part of the analysis, paired t-tests were conducted to examine the effects of ambiguity and cultural attributes on option valuation, while in the second part (two-stage) multivariate regression was performed to verify the determinants of ambiguity in the sample. For further validation and confirmation of our results, we extended our sample to a total of 142 participants (84 Chinese and 58 non-Chinese overall) using similar questions in an anonymous paper- and classroom-based survey of an additional 58 postgraduate Accounting & Finance students (specialists) from a leading

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[11] These proportions are roughly reflective of the current specialist postgraduate AFE student population in the UK. Potential sample bias and endogeneity are dealt with in Section 4 using two-stage multivariate analysis and Heckman-type regressions.

[12] The questionnaire and data are available from the authors upon request. Ethics approval for this research was obtained under project number 11-12_1546.

UK management school. The Heckman correction was also employed to control for endogeneity and small sample bias in the regressions.

4. Findings

4.1. Descriptive statistics and the role of situational attributes

Table 2 presents descriptive statistics for the 10 sets of call and put option appraisal outcomes obtained from participants. Values are different and, on average, higher than those from classical Black-Scholes prices (shown as a baseline in column 3: BSM value), confirming that respondents are far from risk- and uncertainty-neutral (see e.g., Howell and Jägle 1997; Miller and Shapira 2004; Devers et al. 2007).[13] This is valid for both WTP and WTA situations. In line with extant behavioral research (e.g., Plott and Zeiler 2005; Trautmann and Schmidt 2012), a positive gap exists between WTA and WTP average values.

Figure 1 provides comparative findings regarding the effects of situational attributes on real options appraisal for buying and selling prospects. Chinese respondents appear to value options higher than the rest of the sample participants for buying and selling opportunities. This might be explained by their higher propensity to tolerate or seek situations with uncertain prospects (Weber and Hsee 1998; Hofstede 2001), and is indicative of (optimistic) miscalibration. Figure 1 also suggests that age has a negative association with real option value in our dataset, consistent with the intuition that individuals become more conservative with age. Female respondents in our sample tend to value options more than males do for both out-of-the money (OTM) and at-the-money (ATM) prospects. This counterintuitive effect is reversed, however, when omitting Chinese respondents from the sample. In line with widespread evidence on the lower tolerance for both risk and uncertainty among women, non-Chinese female respondents in our sample seem to value options lower than non-Chinese men. This implies that Chinese female participants, as opposed to their non-Chinese counterparts, are not necessarily more ambiguity averse than Chinese men. This points to some moderating Chinese effects we explore further in Section 4.4. We find also that, in accord with the comparative ignorance hypothesis of Fox and Weber (2002), a lack of option knowledge or having a non-related major of study (i.e., generalist participants) can lead to higher or more erratic appraisals. Consistent with cultural pluralism arguments, the higher the number of foreign countries one has lived in (proxy for international life experience), the lower the option value relative to having lived in at most one foreign country. Similar to Abbink and Rockenbach (2006) and their knowledge/professional curse finding, prior industry experience in options seems to negatively affect option value in our dataset. The next section studies the role of cultural attributes in real option appraisal.

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[13] Less than 4.8% (4.2%) of respondents in the online survey (extended dataset with sample size N = 142) valued options exactly according to the BSM risk-neutral benchmark. Based on our elicited *k* scores in Section 4.4, about 71.4% (76.8%) of participants were ambiguity-seeking, while 23.8% (19.0%) displayed ambiguity aversion tendencies.

Table 2. Descriptive statistics: Participants' real option values (N = 84)

Cases/Questions	Mean	BSM value	S.D	Minimum	Maximum
1. Buy call (X = 1000, S = 1000, T = .75, r = .0485, σ = .15)	458.20	70.70	537.15	0.00	3453
2. Buy call (X = 1300 , S = 1000, T = 1.5, r = .0485, σ = .15)	481.45	15.78	642.72	0.00	4545
3. Buy call (X = 1000 , S = 1000 , T = .75, r = .0485 , σ = .30)	408.45	120.36	363.31	0.00	1050
4. Buy call (X = 1300, S = 1000 , T = 1.5, r = .0485 , σ = .30)	439.96	77.25	427.64	0.00	1340
5. Sell call (X = 1000 , S = 1000, T = 3, r = .0485 , σ = .45)	509.17	355.08	375.17	0.00	1300
6. Sell call (X = 1300 , S = 1000 , T = 3, r = .0485 , σ = .45)	547.16	263.49	473.26	2.00	1500
7. Buy put (X = 750 , S = 1000 , T = 1, r = .0485 , σ = .30)	403.48	16.58	338.83	0.00	1020
8. Buy put (X = 1000 , S = 1000 , T = 1, r = .0485 , σ = .45)	459.14	151.13	381.69	0.00	1230
9. Sell put (X = 750 , S = 1000 , T = 2, r = .0485, σ = .30)	414.32	34.25	361.64	0.00	1220
10. Sell put (X = 1000 , S = 1000 , T = 2, r = .0485 , σ = .45)	492.56	194.57	392.73	0.00	1590

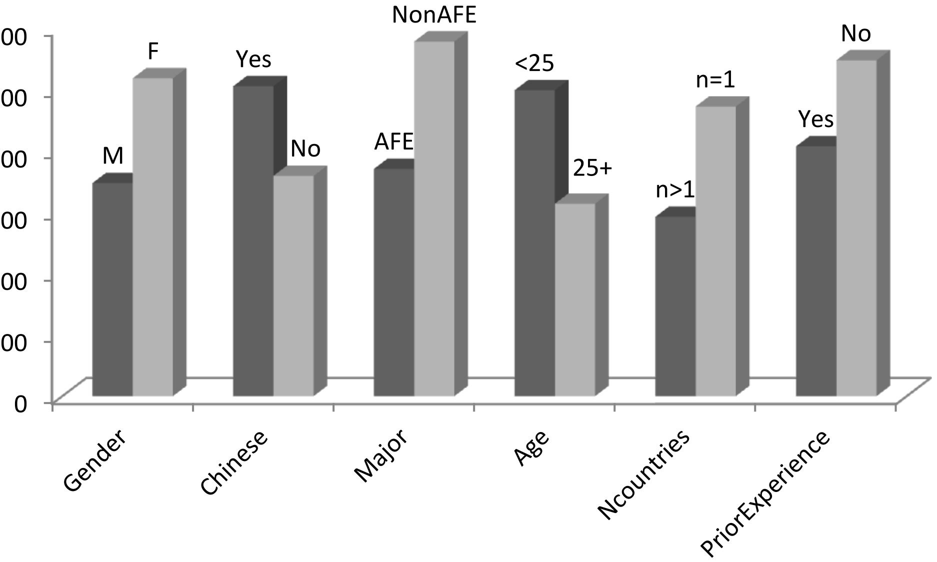

Figure1a. Average WTP values and personal attributes

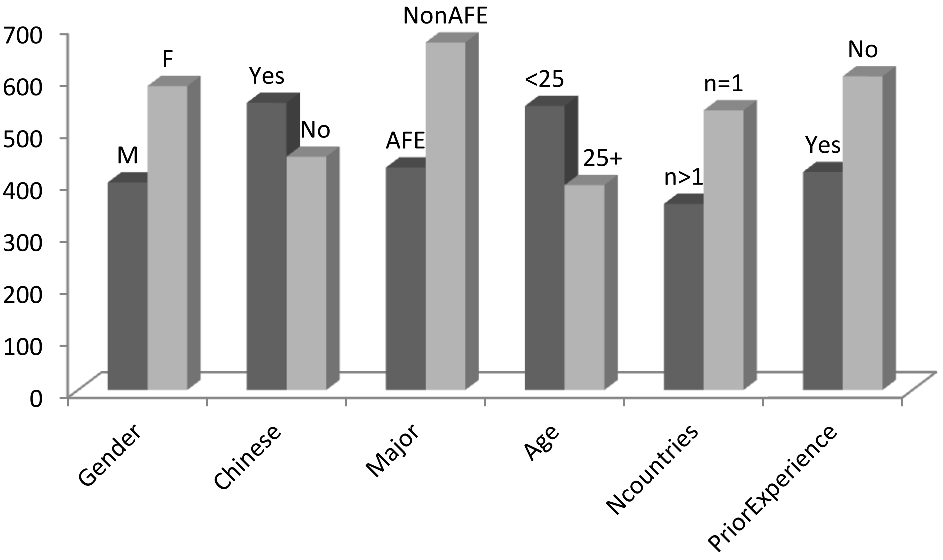

Figure 1b. Average WTA values and personal attributes

4.2. The role of national culture in real option appraisal

Extant literature documents evidence of individuals not following uniform rules to lottery and investment appraisal. This has been attributed to uncertainty preferences, culture and other personal characteristics (Chui and Kwok 2008; Wang et al. 2017; Baillon et al. 2017). Ambiguity and cultural factors should, therefore, help explain differences in subjective real options values among participants. We verify our cultural predictions using the Hofstede's (2001) classification. Findings on these important effects are presented in Table 3.

Hsee and Weber (1999), for example, show that long-term orientation and individualism help explain differences in risk, and possibly uncertainty preferences, between different cultural groups. Our two-sample t-tests confirm that Hofstede's UAI, LTO and IDV (though to a lower extent for the latter) generally have significant effects on real option values for the various questions examined. IDV tends to have a negative influence on option values but this association is more statistically significant for disinvestment and WTA situations (i.e., respondents from less individualistic countries are less cautious when disinvesting or selling) (t = -1.64, p = 0.052). UAI and LTO have consistently significant effects. Higher uncertainty avoidance is associated with lower value or under-investment ($p <$ 0.01) while higher long-term orientation is linked to higher real option value and over-commitment. This holds for both calls (t = 2.40, p = 0.01) and puts (t = 2.18, p = 0.016). We find that PDI does not significantly influence (p > 0.1) real option value but MAS does primarily for WTP call option investment situations (t = 1.95, p = 0.027). The relatively balanced composition of our sample in terms of Chinese vs. non-Chinese participants helps explain the above associations and levels of statistical significance. As the Hsee and Weber's (1999) hypothesis is driven by Chinese or Confucian effects, our multivariate results in Section 4.4 further verify if being Chinese affects the relationships between national culture and ambiguity in our sample.

Besides validating the role of national culture (and particularly that of the Chinese) in real option appraisal, the results in Table 3 confirm that Hofstede's uncertainty avoidance index UAI, as an ambiguity aversion indicator, can serve as a proxy for ambiguity score k in the ambiguity-based option appraisal frameworks presented in Section

2. Our UAI finding tends to be robust to more recent versions of the Hofstede's cultural classification and to using the uncertainty avoidance index of House et al. (2004) as an alternative ambiguity proxy.

Table 3. The role of cultural attributes in real options appraisal (N = 84)

	Hofstede's Cultural Dimensions				
Cases/Questions	**High vs. Low UAI**	**High vs. Low LTO**	**High vs. Low IND**	**High vs. Low MAS**	**High vs. Low PDI**
1. Buy call$_{ATM}$	-2.94***	2.37**	-0.92	1.96**	0.47
2. Buy call$_{OTM}$	-3.46***	2.01**	-1.52*	1.50*	0.61
3. Buy call$_{ATM}$	-2.77***	2.66***	-0.69	2.16**	0.84
4. Buy call$_{OTM}$	-3.04***	2.34**	-0.73	2.16**	0.86
5. Sell call$_{ATM}$	-1.49*	2.53***	-1.61*	1.29*	0.86
6. Sell call$_{OTM}$	-1.90**	2.46***	-1.55*	1.79**	0.73
7. Buy put$_{OTM}$	-3.03***	2.36**	-2.40***	0.41	1.13
8. Buy put$_{ATM}$	-2.95***	1.82**	-1.58*	0.74	1.05
9. Sell put$_{OTM}$	-1.71**	2.62***	-1.35*	1.55*	0.17
10. Sell put$_{ATM}$	-1.86**	1.91**	-1.35*	1.86**	0.16

one-tailed t-tests; ***p < 0.01, ** p < 0.05, * p < 0.1. Sample size *N* = 84 except for IND: Question 10, *N* = 80

The next section examines the extent to which option values by participants are consistent with our model-based behavioral values, using a rescaled UAI estimate as a proxy for ambiguity score k ($0 < k < 1$), in Eqs. (2, 4, 5 and 7) such that:

$$O(V) = g\ (V, I, r, T, \sigma, UAI) \tag{8}$$

4.3. The effect of ambiguity on real option appraisal

Table 4 summarises our findings on whether participants' intuitive or instinctive appraisals are in line with the model values of Eqs. (2, 4-5, and 7) and the degree to which individuals deviate from Bayesian valuation when assessing uncertain real options opportunities.

Table 4 presents the distribution of respondents according to their closest ambiguity specifications. To control for confounding Bayesian effects, we also test the CRRA-based option valuation model (RA) by Bartunek and Chowdhury (1997) in our dataset. Insignificant t-tests imply that our intrinsic model values are not statistically different than participants' observed values. Results, based on paired t-tests and reporting median absolute deviations (MAD), show that despite instances of multiple cognitive preferences which include appraisals near and around BSM/Bayesian values, survey participants regularly follow the optimistic MaxMax rule (under both MP and CU) when buying real options (WTP), and adopt pessimistic MaxMin, α-MP averaging, ambiguity-based CU and MaxMax schemes when selling options (WTA). The MaxMax criterion (i.e., best case scenario) dominates buying decisions for both calls and puts while α-MaxMin (i.e., "averaging" between best and worst case), MaxMin MP (i.e., worst case appraisal) and rank-dependent CU (i.e., non-additive probabilities) appraisals often characterize selling decisions especially those related to call options. This validates our Proposition 1. While the MaxMax and α-MP criteria are preponderant in the valuation (as participants deviate significantly from Bayesian values), we find that in terms of monetary loss implications the MaxMin MP and rank-dependent CU specifications produce the lowest monetary loss, on average, vis-à-vis the BSM risk-neutral benchmark.

The BSM- and risk aversion-related proportions shown in Columns 2-3 of Table 4 further point to some anchoring towards Black-Scholes (Bayesian) values and provide evidence of subjective valuation under risk, and not only ambiguity, in our cross-cultural sample. These outcomes also suggest that our respondents might be relatively more (less) ambiguous towards real options situations with potential losses (OTM) (gains: ATM). Such heterogeneity in appraisal and ambiguity is explained by national culture, demographic and situational factors. While Bayesian appraisal is present (moderate) when selling call (put) options, participants are also likely to take (follow) something akin to a weighted average between minimum and maximum values (MaxMax) with worst case appraisal and ambiguity-based non-additive probabilities also playing a role; especially in ATM cases for CU (OTM put case for the MaxMax criterion). This could consist of cautiously accounting for regret and uncertainty around the probability of getting a profitable price when selling/disinvesting. The fact that option-relevant knowledge has more influence on appraisal processes when selling is somewhat in line with the logics of averaging and non-additive probabilities. The aforementioned BSM and Bayesian anchored-based proportions also relate to this probabilistic sophistication explanation (i.e., transformation of probabilities: see Appendix A).

Evidence of multiple valuation approaches confirms the important role of subjective beliefs and lack of uniformity in the real option logic. This suggests that deviations from Bayesianism can be attributed to the ambiguity attitudes and ambiguity, not only aversion towards it, of participants. Whereas previous research has hinted that experimental options values might be either due to uncertainty averse or overconfident behaviors (see e.g., Miller and Shapira 2004; Devers et al. 2007; Leiblein et al. 2017), the findings in Table 4 imply that risk aversion, ambiguity aversion and ambiguity-seeking all influence investment appraisal and explicit real options valuation. Subsequent cluster and MANOVA analyses (unreported), indeed, corroborated the existence of at least six different behavioral groups in our dataset. In our context, heterogeneity in appraisal can be explained by international differences across groups and participants' national culture, situational attributes and ambiguity aversion (proxied herein by Hofstede's UAI). Our option valuation insights from Table 4 generally hold in the expanded dataset of 142 participants (see Supplementary Table S1 where sample size N = 142). They are also broadly in line with those of Hey et al. (2010) who examine the valuation of standard lotteries in a Knightian uncertainty experiment.

Table 4. Distribution of respondents' option values per behavioral specification (N = 84)

Cases/Questions	**Behavioral specifications**							
	Risk-based		**Ambiguity-based**					
	BSM	**RA**	**MaxMin$_{MP}$**	**α-MP**	**MaxMax$_{MP}$**	**CU**	**MaxMax$_{CU}$**	**t-stat (MAD)**
Q1. Buy call$_{ATM}$	5	24	1	8	30	3	13	0.85
	(5.95%)	(28.57%)	(1.19%)	(9.52%)	(35.71%)	(3.57%)	(15.48%)	(63.44)
Q2. Buy call$_{OTM}$	7	14	3	1	45	2	12	1.21
	(8.33%)	(16.67%)	(3.57%)	(1.19%)	(53.57%)	(2.38%)	(14.29%)	(163.81)
Q3. Buy call$_{ATM}$	6	29	1	2	22	3	21	-0.85
	(7.14%)	(34.52%)	(1.19%)	(2.38%)	(26.19%)	(3.57%)	(25.00%)	(95.70)
Q4. Buy call$_{OTM}$	5	19	10	6	28	1	15	0.36
	(5.95%)	(22.62%)	(11.90%)	(7.14%)	(33.33%)	(1.19%)	(17.86%)	(49.54)
Q5. Sell call$_{ATM}$	11	31	25	6	0	6	5	-0.19
	(13.10%)	(36.90%)	(29.76%)	(7.14%)	(0.00%)	(7.14%)	(5.95%)	(115.85)
Q6. Sell call$_{OTM}$	11	28	17	25	0	2	1	-0.36
	(13.10%)	(33.33%)	(20.24%)	(29.76%)	(0.00%)	(2.38%)	(1.19%)	(83.73)
Q7. Buy put$_{OTM}$	3	12	2	2	37	2	26	-0.32
	(3.57%)	(14.29%)	(2.38%)	(2.38%)	(44.05%)	(2.38%)	(30.95%)	(255.20)
Q8. Buy put$_{ATM}$	5	26	1	8	24	0	20	-0.91
	(5.95%)	(30.95%)	(1.19%)	(9.52%)	(28.57%)	(0.00%)	(23.81%)	(113.77)
Q9. Sell put$_{OTM}$	7	10	3	9	33	3	19	0.17
	(8.33%)	(11.90%)	(3.57%)	(10.71%)	(39.29%)	(3.57%)	(22.62%)	(126.94)
Q10. Sell put$_{ATM}$	9	21	10	11	19	13	1	0.19
	(10.71%)	(25.00%)	(11.90%)	(13.10%)	(22.62%)	(15.48%)	(1.19%)	(55.34)

Having shown that respondents' option values are not significantly different from the ambiguity-based option prices proposed in Eqs. (3-7), we next turn to studying the role of personal attributes in shaping ambiguity perceptions. Section 4.4 examines the antecedents of ambiguity in our main sample (N = 84) by obtaining implied ambiguity score *k* from respondents' real option appraisal outcomes. This is achieved by minimizing the absolute deviations between intrinsic model values $O^{intrinsic}$ and participant observed option values $O^{observed}$ such that:

$$k = \arg\min_{k|0<k<1}\left[\left|O^{intrinsic}(V, I, r, T, \sigma, k) - O^{observed}\right|\right] \tag{9}$$

We verify the effects of personal and cultural attributes on ambiguity score *k* and explain some of the determinants of ambiguity-seeking and aversion among participants. For ease of exposition and given the composition of our dataset, we rely on CU-based ambiguity interpretations (i.e., CU accommodates ambiguity-seeking and overlaps with MP) in our discussion of the below results. As noted, $k < 0.5$ ($m < 0$) and $k > 0.5$ ($m > 0$) implies increasing ambiguity aversion vs. increasing ambiguity-seeking, respectively in the CU ambiguity parlance.

4.4. Determinants of ambiguity

Table 5 summarizes descriptive statistics for ambiguity score *k*. We find that the ambiguity information inferred from participants is positively correlated with Hofstede's uncertainty avoidance index (UAI). We also observe that except for Questions 1-2, which are cases of low uncertainty, *k* is higher for OTM options than for ATM counterparts. This is valid for WTA and WTP situations. On average, respondents in the sample can be considered moderately ambiguity-seeking ($\bar{k}$ = .62).

Table 5. Descriptive statistics: Elicited ambiguity score *k* (N = 84)

Cases/Questions	**Mean**	**SD**	**Minimum**	**Maximum**
1. Buy call$_{\text{ATM}}$	0.63	0.27	0.07	0.86
2. Buy call$_{\text{OTM}}$	0.48	0.20	0.08	0.99
3. Buy call$_{\text{ATM}}$	0.58	0.21	0.09	0.76
4. Buy call$_{\text{OTM}}$	0.63	0.23	0.12	0.99
5. Sell call$_{\text{ATM}}$	0.58	0.16	0.24	0.82
6. Sell call$_{\text{OTM}}$	0.62	0.21	0.21	0.91
7. Buy put$_{\text{OTM}}$	0.76	0.21	0.12	0.94
8. Buy put$_{\text{ATM}}$	0.63	0.25	0.19	0.90
9. Sell put$_{\text{OTM}}$	0.65	0.28	0.03	0.89
10. Sell put$_{\text{ATM}}$	0.61	0.24	0.03	0.93

To identify the determinants of ambiguity score *k* (averaged over 10 questions to mitigate attenuation biases potentially caused by measurement errors, see e.g., Kuhnen and Melzer, 2018), we run a series of multivariate linear regressions accounting for multicollinearity, endogeneity and sample bias:

$$k_{\overline{q1-q10}} = \beta_0 + \beta_1 Age + \beta_2 Gender + \beta_3\ Gender \times China_{dummyv} + \beta_4 Ncountries + \beta_5 NationalCulture + \varepsilon \quad (10)$$

Table 6 presents the relevant relationships and findings (VIFs < 5). The results show that situational and personal attributes are significant determinants of ambiguity in options appraisal processes. As expected and consistent with conservatism theories (see e.g., Kahle et al. 2005), lower age - herein dummy variable = 1 if respondent age is below the sample median of 25 - is positively related to ambiguity score *k*, suggesting a positive (negative) effect of age on ambiguity aversion (seeking) in our sample ($p < 0.05$).[14] Due to potential endogeneity, this effect is re-examined in Table 7 using two-stage probit and Heckman regressions. In line with the cultural pluralism hypothesis and diversification principles, Ncountries is associated with a lower *k* score (i.e., higher ambiguity aversion) (Models 1-6, $p < 0.01$). This implies that knowledge of more than one culture make individuals in our sample less erratic and more cautious in their appraisal of uncertain real options prospects. Our regression output also suggests that women are

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[14] This effect might also be caused by the ambiguity-seeking characteristics of participants in our dataset and endogeneity, and is worth verifying in further research using larger and more heterogeneous samples. Extant literature tends to document a mixed or weak effect of age on ambiguity. For robustness, we run two-stage probit and Heckman regressions in Table 7 to account for endogeneity related to age and sample bias. Our findings are consistent.

overall more ambiguity averse (lower *k* score under CU) than men in our dataset. This result is moderated (association is reversed), however, by a Chinese subsample effect (Models 2, 3 and 6, $p < 0.01$) suggesting that Chinese women are more tolerant of ambiguity that non-Chinese men in the overall sample. This was reflected in Figure 1. More importantly we find the gender effect to be insignificant in the subsample of Chinese respondents, implying that Chinese women are not more ambiguous and ambiguity averse than Chinese men in our dataset. This can potentially be explained by the entrepreneurial predispositions of educated Chinese women or the status of East Asian women in business and society. An alternative explanation could simply relate to the lack of knowledge disparity between Chinese men and Chinese women in our sample (see Dwyer et al. 2002).

In terms of cultural attributes, results indicate that on their own PDI and MAS are positively related to ambiguity score *k* (Models 1 and 3). This is consistent with the notion that societies that encourage challenge and competition are more entrepreneurial. In line with Mihet (2013), the PDI association is negative and insignificant (significant at 10% level) when omitting (controlling for) Chinese respondents (interaction effects) from (in) the expanded sample. LTO is positively associated with ambiguity score *k* (Model 4). This effect is conditional on being Chinese and the association is reversed to negative when examining the sub-sample of non-Chinese participants. The same holds for the individualism variable. The latter tends to be positively related to ambiguity aversion, however, this effect is stronger when controlling for LTO effects (Model 5). This concurs with Hsee and Weber's (1999) propositions and the social diversification phenomenon. The overall results confirm that Chinese respondents are more tolerant of uncertainty than other individuals in the sample and national culture influences ambiguity behavior.

Personal attributes in the form of age, gender and international experience are also important determinants of ambiguity in our sample. Along with the findings in Section 4.2, the above validates Proposition 2.[15] Though influencing appraisal processes and option values, knowledge and major of study were found not to be significantly associated with ambiguity score *k*. Since the majority of survey participants had prior options knowledge, this is not unexpected. Being a specialist or generalist in our cross-cultural sample affects the option appraisal outcome but not necessarily the ambiguity tolerance. Extending our sample to a more heterogeneous population should provide further insights into the role of financial literacy and expertise in ambiguity aversion (see e.g., Kuhnen and Melzer 2018).

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[15] In further analysis that consists of regressing our ambiguity score *k* on Hofstede's UAI and using the residual-based ambiguity proxy from this regression as an alternative dependent variable in Eq. (10) (as another way to mitigate sampling bias), we find that most of our results on the role of personal and situational attributes in explaining ambiguity hold.

Table 6. Determinants of ambiguity score *k* (N = 84)

	Multivariate specifications					
Independent variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Cst.	.493***	.689***	.464***	.285***	.267***	.372***
	(5.381)	(6.980)	(4.846)	(3.911)	(3.629)	(4.479)
Agedummy	.143***	.128***	.116***	.085**	.081**	.092***
	(3.686)	(3.559)	(3.353)	(2.471)	(2.376)	(2.736)
Gender	-.032	-.168***	-.158***	-..040	-.034	-.119**
	(-.837)	(-3.368)	(-3.803)	(-1.288)	(-1.098)	(-2.598)
Chinese*Gender	-	.220***	.192***	-	-	.140**
	-	(3.846)	(4.092)	-	-	(2.464)
Ncountries	-.106***	-.111***	-.097***	-.106***	-.107***	-.115***
	(-3.836)	(-4.348)	(-3.919)	(-4.453)	(-4.620)	(-5.060)
PDI	.238**	.000	-	-	-	-
	(2.509)	(.131)	-	-	-	-
MAS	-	-	.004***	-	-	-
	-	-	(2.733)	-	-	-
LTO	-	-	-	.001**	-	-
	-	-	-	(2.099)	-	-
IDV	-	-	-	-	-.095**	-.016
	-	-	-	-	(-2.418)	(-.324)
LTO*IDV	-	-	-	.000***	.000***	.000***
	-	-	-	(4.994)	(6.830)	(4.324)
R^2	**32.4%**	**43.2%**	**48.1%**	**53.5%**	**54.3%**	**57.7%**
F	9.470	11.856	14.479	17.974	18.561	17.485

t-statistics in parentheses; ***p < 0.01, ** p < 0.05, * p < 0.1

For additional validation of our findings, two-stage probit and Heckman regressions were also implemented to control for endogeneity and sample bias, respectively associated with age (i.e., using gender, the Chinese subsample variable, MAS and PDI as instruments to age) and the proportion of Chinese respondents in our dataset. Regression estimates in Table 7 validate our above conclusions. Probit findings are reported in Models 1-2. Output from these two models confirms our previous results in Table 6 (adding cultural principal components CF1 and CF2 to the multivariate structure). The significant effects of age, gender, international life experience and national culture are generally preserved in the regressions.[16] The Heckman regressions in Models 3-6 (using WTP- and WTA-based ambiguity scores) further corroborate our main conclusions and the robustness of our findings. Our conclusions tend to also hold for OTM vs. ATM prospects and under restricted MP specifications. Our results are confirmed in the expanded sample of 142 participants; findings are documented in Supplementary Table S2 (combining online and offline surveys). The various relationships, associated significance and related signs are maintained despite the lower explanatory power. The latter is primarily due to a relatively less balanced expanded sample. The moderating effects of being Chinese on ambiguity score *k* were also confirmed in the expanded dataset. We found no significant statistical difference in ambiguity between online vs. paper-based appraisal questions. Finally, our results are robust when using the partial least squares (PLS) approach to account for further endogeneity, interrelationships and feedback effects in the samples.

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[16] The signs and effects of the individual cultural dimensions (i.e., PDI, LTO, IDV and MAS) were also consistent with those reported in Table 6.

Table 7. Determinants of ambiguity score *k*: Two-stage Probit and Heckman regressions (N = 84)

	Multivariate specifications					
Independent variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Cst.	.688***	.700***	-	-	-	-
	(16.910)	(17.380)	-	-	-	-
Agedummy	.206***	.134***	1.511***	1.162***	1.361***	.934***
	(5.310)	(3.160)	(5.790)	(4.730)	(4.140)	(2.950)
Gender	-.184***	-.140***	-1.616***	-1.217***	-1.040***	-.687**
	(-4.040)	(-3.590)	(-5.410)	(-4.800)	(-2.780)	(-2.080)
Chinese*Gender	.216***	.154***	1.738***	1.205***	1.383***	.900**
	(3.720)	(3.340)	(5.220)	(4.590)	(3.300)	(2.550)
Ncountries	-.142***	-.116***	-.696***	-.599***	-.666***	-.584***
	(-5.680)	(-4.890)	(-5.020)	(-4.420)	(-3.880)	(-3.430)
CF1	.037*	-	.263**	-	.275*	-
	(1.710)	-	(2.170)	-	(1.830)	-
CF2	-	.046**	-	.230**	-	.279*
	-	(2.570)	-	(2.000)	-	(1.870)
MillsRatio	-	-	-.051	.136	-.114	.251
	-	-	(-.223)	(.549)	(-.330)	(.592)
R^2	**51.5%**	**53.6%**	**40.4%**	**49.6%**	**35.1%**	**42.9%**
F	16.54	18.00	-	-	-	-
Log-likelihood	-	-	**-94.23**	**-94.50**	**-104.95**	**-104.75**
Wald	-	-	69.99	67.35	36.14	48.45

t-statistics in parentheses (Models 1-2); ***$p < 0.01$, ** $p < 0.05$, * $p < 0.1$
z-statistics in parentheses (Models 3-6); ***$p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5. Discussion and conclusions

Studying the role of national culture and ambiguity in real option logic, this paper provides experimental survey evidence of and explanations for the under/over-investment problem in decision making and presents empirical results on individuals' tendency to deviate from standard Bayesian option valuation. We find that survey participants appraise buying opportunities somewhat erratically according to the MaxMax best-case scenario, but are more likely to follow worst-case MaxMin, and α-MP and CU logics when selling or disinvesting. This implies that in their option purchase decisions participants instinctively account for ambiguity regarding upside prospects, whereas in their selling decisions they also consider ambiguous volatility dispersions and potential regret. Evidence of multiple cognitive preferences, which include Black-Scholes anchor-based as well as risk aversion-based values, confirms the presence of heterogeneity in individual appraisal processes. We also present findings on the conditional positive (negative) effect of long-term orientation (individualism) on real option value and show that Hofstede's uncertainty avoidance index and other national cultural dimensions can help explain international differences in real option appraisal patterns by respondents. We further verify the effects of personal and situational attributes (age, gender, number of countries one has lived in) on ambiguity behavior. We find that Chinese participants are, on average, relatively more ambiguity-seeking than the rest of the individuals in our sample and present new evidence on the lack of gender differences in ambiguity among highly educated Chinese individuals. We additionally find that age and international life experience have positive effects on ambiguity aversion (i.e., lower ambiguity score *k*) in our dataset. Our results are robust to a range of alternative specifications using multivariate and two-stage regressions with Heckman corrections.

Our evidence provides useful financial decision making insights into the heterogeneous behavior of individuals faced with uncertain economic prospects and call for the need to account for national culture, miscalibration and ambiguity in cognitive option appraisal processes. Our findings on the determinants of ambiguity can also serve as useful rules of thumb for negotiation, strategy, risk management and operational hedging (see e.g., Zhao and Huchzermeier 2017; Caldentey et al. 2017; Oliveira and Costa 2018), and international decision making under uncertainty. Results can further help managers and other decision makers anticipate potential biases in real options appraisal within teams and firms, avoid under/overinvestment fallacies (i.e., type 1 and type 2 errors), learn about (the consequences of) national variations in uncertainty preferences, and appreciate better the roles of national culture, country differences and ambiguity - as uncertainty beyond risk - in investment decision making.

Limitations to the study relate to the relatively small international sample analyzed and the fact that participants were mainly based in the UK. Although our sample extension of 142 participants qualitatively corroborates our valuation conclusions plus some of our findings are in line with Dimmock et al. (2015) regarding the determinants of MP ambiguity among U.S. households, and accord with those of Baillon et al. (2016) concerning the appraisal of stock market lotteries in a dataset of undergraduate students from the Netherlands, more data or larger surveys would be needed to generalize to other international and less specialist samples. Other personal and international attributes can also be considered as potential determinants of ambiguity. These may include psychological characteristics, family background, income, religion or morality among other dimensions. Studying such dynamics on managers and executives using larger surveys and lab experiments can help elucidate further issues of miscalibration, learning and overconfidence in industry (Howell and Jägle 1997; Sautner and Weber 2009; Ben-David et al. 2013; Pikulina et al. 2017). Highlighting the role of ambiguity in investment appraisal processes, our results nonetheless validate our ambiguity-adjusted valuation frameworks and confirm that individuals follow a number of (non-Bayesian) decision rules when assessing uncertain real options opportunities. This corroborates the presence of ambiguity and subjective beliefs in the real options logic and underlines the role of national culture, personal and situational attributes in investment appraisal.

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Appendix A – Option Valuation Models

Option value under risk-neutrality and risk aversion (Bayesian benchmarks):

$$O_{RN} = V_0 e^{-\delta T} N(d_1) - I e^{-rT} N(d_2) \tag{A.1}$$

where:

$$d_1 = \frac{\ln\left(\frac{v_0}{I}\right) + \left(r - \delta + \frac{1}{2}\sigma^2\right)T}{\sigma\sqrt{T}} \text{ and } d_2 = d_1 - \sigma\sqrt{T} \tag{A.2}$$

$$O_{RA} = e^{-rT} \left(E^{Q^{RA}}[(max\,(V_T - I, 0)^{1-\gamma})] \quad ^{1/(1-\gamma)}\right) \tag{A.3}$$

O_{RA} is computed using 10000 iterations of 5000-step Monte Carlo simulation with γ = .2 (following Bartunek and Chowdhury (1997)). Dividend yield δ = 0 in our setting and for all valuation specifications. *N(.)* is the standard cumulative normal distribution function.

Option value under multiple-priors:

$$O_{MP} = V_0 e^{-\varepsilon' T} N(d'_1) - I e^{-r' T} N(d'_2) \quad (\forall\, k \ \in]0,1[) \tag{A.4}$$

where:

$$d'_1 = \frac{\ln\left(\frac{V_0}{I}\right) + \left(r' - \varepsilon' + \frac{1}{2}\sigma^2\right)T}{\sigma\sqrt{T}} \text{ and } d'_2 = d'_1 - \sigma\sqrt{T} \tag{A.5}$$

$$r' = r + m\frac{[r - (\mu + m\sigma)]}{\sigma} \ , \ \varepsilon' = \delta - \frac{m[(\mu + m\sigma) - r]}{\sigma} \text{ and } -1 < \mathrm{m} < 1$$

Option value under α-MaxMin multiple-priors:

$$O_{\alpha-MP} = \alpha\, max\, O_{MP} + (1-\alpha)\, min\, O_{MP} \quad (\forall\, k \ \in]0,1[, \forall\, \alpha \ \in]0,1[) \tag{A.6}$$

Hofstede's UAI is used as a proxy for ambiguity and ambiguity attitudes.

Option value under Choquet ambiguity:

$$O_{CU} = V_0 e^{-\varepsilon'' T} N(d''_1) - I e^{-r'' T} N(d''_2) \quad (\forall\, k \ \in]0,1[) \tag{A.7}$$

where:

$$d''_1 = \frac{\ln\left(\frac{V_0}{I}\right) + \left(r'' - \varepsilon'' + \frac{1}{2}(n\sigma)^2\right)T}{n\sigma\sqrt{T}} \text{ and } d''_2 = d''_1 - n\sigma\sqrt{T} \tag{A.8}$$

$$r'' = r + m\frac{[r - (\mu + m\sigma)]}{n^2\sigma} \text{ and } \varepsilon'' = \delta - \frac{(m + n^2\sigma - n\sigma)[(\mu + m\sigma) - r]}{n^2\sigma}$$

$$m = 2k - 1 \text{ and } n = \sqrt{4k(1-k)}$$

As the CU model sometimes produces extreme values for very high (very low) k values, we cap the intrinsic MaxMax$_{CU}$ model value per question to: mean + 3*stdev.

Eq. (A.7) can also be rewritten as:

$$O_{CU} = V_0 e^{(-\delta T)} N(d_1) \cdot w_1 - I e^{-rT} N(d_2) \cdot w_2$$

where *w₁* and *w₂* are defined as follows:

$$w_1 = \frac{N\left(\frac{1}{n} d_1 + \varphi_1\right)}{N(d_1)} \cdot e^{\left(\frac{(m+n^2\sigma-n\sigma)[(\mu+m\sigma)-r]}{n^2\sigma} T\right)}; \; w_2 = \frac{N\left(\frac{1}{n} d_2 + \varphi_2\right)}{N(d_2)} \cdot \frac{1}{e^{\left(m \frac{[r-(\mu+m\sigma)]}{n^2\sigma} T\right)}}$$

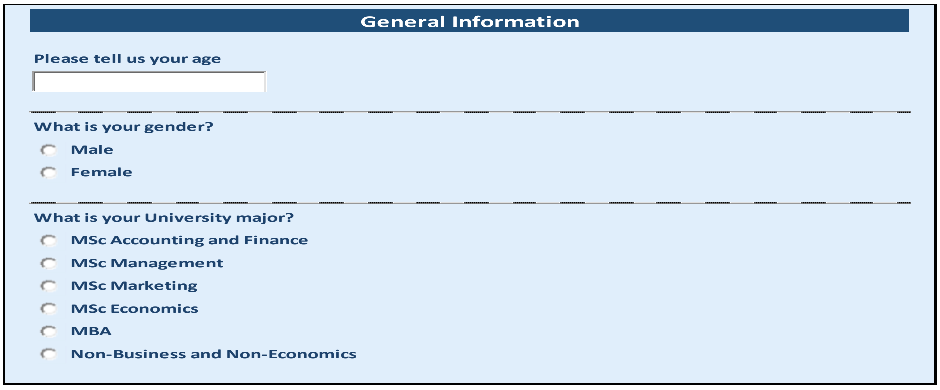
$$\varphi_1 = \frac{T\{m[r-(\mu+m\sigma)] + (m+n^2\sigma-n\sigma)[(\mu+m\sigma)-r]\}}{n^3\sigma^2\sqrt{T}} + \frac{0.5\sigma\sqrt{T}(n-1)}{n}$$

$$\varphi_2 = \varphi_1 - \frac{\sigma\sqrt{T}(n-1)}{n}$$

m, *n*, *d₁* and *d₂* are as defined above. In the absence of ambiguity (meaning *k* = 0.5, *w₁* = *w₂* = 1 and under

additive probabilities), this version of (A.7) simplifies to (A.1).

Appendix B – Questionnaire Illustration



General Information

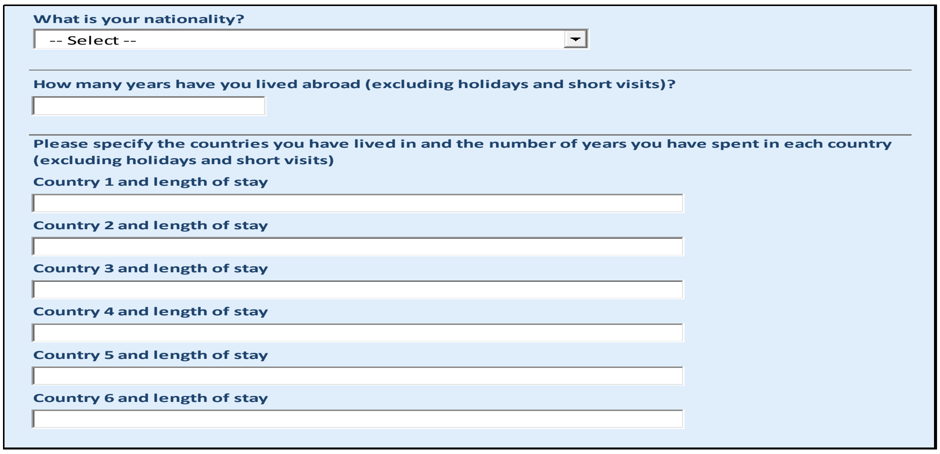
Please tell us your age

What is your gender?

○ Male
○ Female

What is your University major?

○ MSc Accounting and Finance
○ MSc Management
○ MSc Marketing
○ MSc Economics
○ MBA
○ Non-Business and Non-Economics



What is your nationality?

-- Select --

How many years have you lived abroad (excluding holidays and short visits)?

Please specify the countries you have lived in and the number of years you have spent in each country (excluding holidays and short visits)

Country 1 and length of stay

Country 2 and length of stay

Country 3 and length of stay

Country 4 and length of stay

Country 5 and length of stay

Country 6 and length of stay

Reminder:

* A *call option* is a contract that gives the buyer the right, but not the obligation, to *purchase* the specified asset (in this questionnaire, the asset is the investment) at a specified price of a certain day.
* When you buy the call option, you are purchasing the right to buy the specified asset.

* When you sell the call option, you are selling the right to buy the specified asset to an option buyer.
* *Volatility* is a measure of variation in asset price (in this questionnaire, the asset is the investment) over time.

* In a call option, the *exercise price* means the cost at which the specified asset can be bought.

Buying a call option

01. You are offered a call option on an investment that has a volatility of 15%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $1000. The option can only be exercised in *9 months*. For this option, I would be willing to pay:

02. You are offered a call option on an investment that has a volatility of 15%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $1300. The option can only be exercised in *18 months*. For this option, I would be willing to pay:

03. You are offered a call option on an investment that has a volatility of 30%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $1000. The option can only be exercised in *9 months*. For this option, I would be willing to pay:

04. You are offered a call option on an investment that has a volatility of 30%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $1300. The option can only be exercised in *18 months*. For this option, I would be willing to pay:

Buying a put option

07. You own an investment that has a volatility of 30%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $750. The option can only be exercised in *12 months*. For buying the option to transfer the outcome of this investmetn to someone else, I would be willing to pay:

08. You own an investment that has a volatility of 45%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $1000. The option can only be exercised in *12 months*. For buying the option to transfer the outcome of this investmetn to someone else, I would be willing to pay:

Selling a put option

09. You are selling to someone the option to transfer to you the outcome associated with an investment that has a volatility of 30%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $750. The option can only be exercised in *24 months*. To sell this option, I would have to receive:

10. You are selling to someone the option to transfer to you the outcome associated with an investment that has a volatility of 45%. The investment opportunitiy value today is $1000. The interest rate is 4.85%. The exercise price of the option is $750. The option can only be exercised in *24 months*. To sell this option, I would have to receive:

Appendix C – Supplementary Material

Table S1. Distribution of respondents' option values per behavioral specification (sample size N = 142)

	Behavioral specifications							
	Risk-based		**Ambiguity-based**					
Cases/Questions	**BSM**	**RA**	**MaxMin$_{MP}$**	**α-MP**	**MaxMax$_{MP}$**	**CU**	**MaxMax$_{CU}$**	**t-stat (MAD)**
Q1. Buy call$_{ATM}$	5	41	1	15	56	3	21	1.23
	(3.52%)	(28.87%)	(0.70%)	(10.56%)	(39.44%)	(2.11%)	(14.79%)	(56.67)
Q2. Buy call$_{OTM}$	7	16	9	3	83	3	21	1.59
	(4.93%)	(11.27%)	(6.34%)	(2.11%)	(58.45%)	(2.11%)	(14.79%)	(146.81)
Q3. Buy call$_{ATM}$	6	49	5	5	36	3	38	-1.11
	(4.23%)	(34.51%)	(3.52%)	(3.52%)	(25.35%)	(2.11%)	(26.76%)	(87.20)
Q4. Buy call$_{OTM}$	7	31	16	10	44	2	32	-0.02
	(4.93%)	(21.83%)	(11.27%)	(7.04%)	(30.99%)	(1.41%)	(22.54%)	(49.54)
Q5. Sell call$_{ATM}$	20	56	37	10	0	7	12	-0.55
	(14.08%)	(39.44%)	(26.06%)	(7.04%)	(0.00%)	(4.93%)	(8.45%)	(140.25)
Q6. Sell call$_{OTM}$	19	48	22	44	0	5	4	-0.44
	(13.38%)	(33.80%)	(15.49%)	(30.99%)	(0.00%)	(3.52%)	(2.82%)	(84.33)
Q7. Buy put$_{OTM}$	3	13	6	4	67	2	47	-0.80
	(2.11%)	(9.15%)	(4.23%)	(2.82%)	(47.18%)	(1.41%)	(33.10%)	(212.73)
Q8. Buy put$_{ATM}$	6	46	6	11	39	0	34	-0.97
	(4.23%)	(32.39%)	(4.23%)	(7.75%)	(27.46%)	(0.00%)	(23.94%)	(109.77)
Q9. Sell put$_{OTM}$	11	12	9	13	56	8	33	0.12
	(7.75%)	(8.45%)	(6.34%)	(9.15%)	(39.44%)	(5.63%)	(23.24%)	(126.94)
Q10. Sell put$_{ATM}$	13	41	13	19	32	21	3	0.03
	(9.15%)	(28.87%)	(9.15%)	(13.38%)	(22.54%)	(14.79%)	(2.11%)	(57.57)

Table S2. Determinants of ambiguity score *k* (sample size N = 142)

Independent variables	**Multivariate specifications**							
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Cst.	0.522***	0.700***	0.488***	0.330***	0.388***	0.451***	0.738***	0.725***
	(7.534)	(9.649)	(5.493)	(4.944)	(5.648)	(6.642)	(21.410)	(21.420)
Agedummy	0.075**	0.070**	0.069***	0.057**	0.061**	0.063**	0.102**	0.087**
	(2.524)	(2.575)	(2.610)	(2.179)	(2.281)	(2.444)	(2.310)	(2.010)
Gender	-0.021	-0.158***	-0.136***	-0.035	-0.032	-0.126***	-0.193***	-0.180***
	(-0.682)	(-4.088)	(-3.738)	(-1.285)	(-1.156)	(-3.436)	(-4.320)	(-4.230)
Chinese*Gender	-	0.218***	0.182***	-	-	0.164***	0.169***	0.171***
	-	(5.121)	(4.757)	-	-	(3.681)	(3.320)	(4.360)
Ncountries	0.086***	0.090***	0.080***	-0.083***	-0.090***	-0.092***	-0.099***	-0.088***
	(-3.772)	(-4.254)	(-3.841)	(-4.072)	(-4.372)	(-4.621)	(-4.540)	(-4.080)
PDI	0.003***	0.000	-	-	-	-	-	-
	(3.055)	(0.131)	-	-	-	-	-	-
MAS	-	-	0.003***	-	-	-	-	-
	-	-	(2.704)	-	-	-	-	-
LTO	-	-	-	0.001***	-	-	-	-
	-	-	-	(3.556)	-	-	-	-
IDV	-	-	-	-	-0.002***	0.000	-	-
	-	-	-	-	(-2.844)	(-0.204)	-	-
LTO*IDV	-	-	-	0.000***	0.000***	0.000***	-	-
	-	-	-	(4.388)	(6.394)	(4.063)	-	-
CF1	-	-	-	-	-	-	0.007	-
	-	-	-	-	-	-	(.630)	-
CF2	-	-	-	-	-	-	-	0.036***
	-	-	-	-	-	-	-	(2.680)
R^2	**17.5%**	**30.8%**	**34.4%**	**35.4%**	**33.4%**	**39.4%**	**30.3%**	**33.6%**
F	7.260	12.124	14.233	14.897	13.607	14.644	11.810	13.750

t-statistics in parentheses (Models 1-6); ***p < 0.01, ** p < 0.05, * p < 0.1
z-statistics in parentheses (Models 7-8); ***p < 0.01, ** p < 0.05, * p < 0.1