Strategic Ambiguity and Decision-making: An Experimental Study*

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Abstract

We conducted a set of experiments to compare the effect of ambiguity in single person decisions and games. Our results suggest that ambiguity has a bigger impact in games than in ball and urn problems. We find that ambiguity has the opposite effect in games of strategic substitutes and complements. This confirms a theoretical prediction made by Eichberger and Kelsey (2002). The experiments also test whether subjects' perception of ambiguity differs when faced by a local opponent as opposed to a foreign one. Our results show that there is little evidence of more influence of ambiguity on behaviour when faced by foreign subjects.

Keywords: Ambiguity; Choquet expected utility; strategic complements; strategic substitutes; Ellsberg urn.

JEL Classification: C72, **C**91, **D**03, D81

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1 Introduction

We report an experimental study on the effects of ambiguity in single person decisions and games. Risks are said to be ambiguous if the probabilities of possible outcomes are unknown and it is difficult or impossible to assign subjective probabilities to them. There exists a substantial body of experimental literature which shows that ambiguity affects single person decisions. Most economic decisions, however, are not made by individuals, but by groups of individuals involved in strategic interactions. There is a small experimental literature studying ambiguity in games.[1] However, most of these papers do not test specific theories of behaviour in ambiguous games. Since many economic problems can be represented as games we believe this research will be useful for understanding how ambiguity affects the behaviour of economic systems.

Our paper is an experimental test of Eichberger and Kelsey (2002), which predicts that ambiguity has opposite effects in games of strategic complements and substitutes. In the case of strategic substitutes, increasing the level of ambiguity would shift the equilibrium strategies in an ex-post Pareto improving direction, whereas for strategic complements, an increase in ambiguity would have the opposite effect.[2] Thus it was hypothesised that ambiguity had an adverse effect in games with strategic complements, but was helpful in attaining an ex-post Pareto efficient outcome in games with strategic substitutes. In order to implement this, we need to find a way of introducing ambiguity into a game setting, without lying to the subjects.

We adapt the experimental design of Kilka and Weber (2001) who find that subjects are more ambiguity-averse when the returns of an investment are dependent on foreign securities than when they are linked to domestic securities. In our games, subjects were either matched with a local opponent or with a foreign one who was intended to be the analogy of the foreign securities. We hypothesised that subjects will be more ambiguity-averse with the foreign opponents. In order to test this, we recruited subjects both locally at the University of Exeter as well as

[1] See for instance Calford (2016), Eichberger, Kelsey, and Schipper (2008), Greiner (2016), Ivanov (2011) Kelsey and le Roux (2015) or Di Mauro and Castro (2011).

[2] We refer to an ex-post Pareto improvement since this efficiency measure does not take into account any ex-ante losses in utility due to ambiguity-aversion.

overseas in St. Stephen's College, India.

In addition we also alternated the games with Ellsberg Urn type decision problems. This was done in order to test whether there was any difference in ambiguity-attitude between the types of decision. Moreover, it allowed us to elicit an independent measure of subjects' ambiguity-attitudes. Finally it acted to erase subjects short term memory.

We find that behaviour broadly supports our hypotheses. However, subjects do not display an increase in ambiguity when faced by foreign opponents. This is in line with findings reported in Kelsey and le Roux (2016). Another interesting observation from the data is that even though subjects display ambiguity-aversion when faced by other opponents (whether local or foreign), they often are ambiguity seeking when faced by nature in single-person decisions. This is consistent with an earlier study Kelsey and le Roux (2015), where subjects showed differences in ambiguity-attitudes based on the scenario they were facing.

Organisation of the Paper In Section 2, we describe the theory being tested. Section 3 and 4 describe the experimental model and design employed, Section 5 consists of data analysis and results, Section 6 reviews related literature and Section 7 provides a summary of results together with future avenues of research.

2 Preferences and Equilibrium under Ambiguity

In this section we shall explain how we model ambiguity in games. Our notation is as follows. A 2-player game $\Gamma = \langle \{1,2\}; X_1, X_2, u_1, u_2 \rangle$ consists of players, $i = 1, 2$, finite pure strategy sets X_i and payoff functions $u_i(x_i, x_{-i})$ for each player. The notation, x_{-i}, denotes the strategy chosen by i's opponent and the set of all strategies for i's opponent is X_{-i}. The space of all strategy profiles is denoted by X.

We shall model ambiguity by neo-additive preferences which have been axiomatised by Chateauneuf, Eichberger, and Grant (2007). These preferences may be represented by the function:

$$V_i\left(x_i\right)=\delta_i\alpha_i\min_{x_{-i}\in x_{-i}}u_i\left(x_i,x_{-i}\right)+\delta_i\left(1-\alpha_i\right)\max_{x_{-i}\in X_{-i}}u_i\left(x_i,x_{-i}\right)+\left(1-\delta_i\right)\mathbf{E}_{\pi_i}u_i\left(x_i,x_{-i}\right),$$

where $\mathbf{E}_{\pi_i}$ denotes conventional expectation with respect to the probability distribution π_i. This expression is a weighted average of the highest payoff, the lowest payoff and an average payoff. The response to ambiguity is partly optimistic represented by the weight given to the best outcome and partly pessimistic. These preferences are a special case of Choquet expected utility (CEU), Schmeidler (1989). Thus they may also be represented in the form

$$V_i\left(x_i\right)=\int u_i\left(x_i,x_{-i}\right)d\nu_i\left(x_{-i}\right),$$

where ν_i is a neo-additive capacity on X_{-i} and the integral is a Choquet integral, Choquet (1953-4).[3] We define the support of a neo-additive capacity to be the support of the additive probability on which it is based, i. e. $\operatorname{supp}\nu_i=\operatorname{supp}\pi_i$.[4]

A player has a possibly ambiguous belief about what his/her opponent will do. In games, π_i is determined endogenously as the prediction of the players from the knowledge of the game structure and the preferences of others. In contrast, we treat the degrees of optimism, α_i and ambiguity, δ_i, as exogenous. Define the best-response correspondence of player i given that his/her beliefs are represented by a neo-additive capacity ν_i by $R_i(\nu_i)=\operatorname{argmax}_{x_i\in X_i}V_i\left(x_i\right)$. We can now define equilibrium under ambiguity.

Definition 2.1 (Equilibrium under Ambiguity) *A pair of neo-additive capacities* (ν_1^*,ν_2^*) *is an Equilibrium Under Ambiguity (EUA) if for* $i=1,2$, $\operatorname{supp}\left(\nu_i^*\right)\subseteq R_{-i}(\nu_{-i}^*)$.

An EUA will exist for any given ambiguity-attitude of the players, (see Eichberger and Kelsey (2014) for a proof). In equilibrium each player uses a strategy which is a best response given his/her beliefs. A player perceives ambiguity about the strategy of his/her opponent.

[3] A *neo-additive*-capacity ν_i on X_{-i} is defined by $\nu_i\left(X_{-i}|\alpha_i,\delta_i,\pi_i\right)=1$, $\nu_i\left(\varnothing|\alpha_i,\delta_i,\pi_i\right)=0$ and $\nu_i\left(A|\alpha_i,\delta_i,\pi_i\right)=\left(1-\alpha_i\right)\delta_i+\left(1-\delta_i\right)\pi_i\left(A\right)$ for $\emptyset\subsetneqq A\subsetneqq X_{-i}$, where $0\leqslant\delta_i<1$, π_i is an additive probability distribution on X_{-i}.

[4] For a justification of this definition and its relation to other support notions see Eichberger and Kelsey (2014).

This is represented by an ambiguous belief, in the form of a capacity over the opponent's strategy space. The support of a player's beliefs is itself an ambiguous event. This reflects some uncertainty about whether or not his/her opponents play best responses. Players respond to this ambiguity partly in an optimistic way by over-weighting the best outcome and partly in a pessimistic way by over-weighting the worst outcome.

Consistency between beliefs and actions is achieved by requiring that all strategies in the support of a player's beliefs be a best response for his/her opponent. This is a weaker notion of consistency than that used in Nash equilibrium. However Greiner (2016) has experimental evidence which shows that behaviour does not satisfy stronger notions of consistency even in relatively simple games. Moreover the violations of consistency he finds are compatible with our theory.

A common interpretation of NE is that each player chooses a strategy which maximises his/her utility given the strategy of the other players. However it is also possible to view NE as an equilibrium in beliefs. From this viewpoint each player has a subjective belief about the actions of his/her opponents and chooses a best response to this belief. Definition 2.1 extends the interpretation of NE as an equilibrium in beliefs, by allowing these beliefs to be non-additive. We interpret the deviation from additivity as representing ambiguity about the opponent's strategy choice.

3 Experimental Model

In this section, we introduce the games used in our experiments, followed by the Ellsberg-style decision problems being studied by us. Henceforth we will use male pronouns he, his etc. to denote the Row Player, while female pronouns she, hers etc. will be used to denote the Column Player.[5]

[5] This convention is for the sake of convenience only and does not bear any relation to the actual gender of the subjects in our experiments.

3.1 The Games

The games used in our experimental sessions can be seen in Figure 1. Games ($SC1$) and ($SC2$) (as labelled in Figure 1) are games with strategic complements and positive externalities; while Games ($SS1$) and ($SS2$), were games with strategic substitutes. Game SS1 also has negative externalities.

Figure 1: The Games

(SC1)	Left	Middle	Right
Top	90, 85	90, 95	90, 0
Centre	0, 90	110, 95	110, 0
Bottom	5, 105	105, 95	105, 110

(SC2)	Left	Middle	Right
Top	115, 95	115, 100	115, 0
Centre	0, 95	135, 100	135, 0
Bottom	5, 105	105, 100	105, 135

(SS1)	Left	Middle	Right
Top	0, 0	70, 0	170, 150
Centre	100, 70	165, 165	165, 150
Bottom	150, 170	150, 165	150, 150

(SS2)	Left	Middle	Right
Top	95, 5	5, 0	5, 90
Centre	0, 5	100, 100	100, 90
Bottom	90, 95	90, 100	90, 90

The following result is the main theoretical prediction, which our experiments are designed to test. In the appendix we provide two examples illustrate it. These are based on our experimental games. A formal proof can be found in Eichberger and Kelsey (2014).

Proposition 3.1 *If both players are ambiguity averse, i.e.* $\alpha = 1$, *and have neo-additive preferences then*[6]*:*

1. *In the case of games with strategic complements and positive (resp. negative) externalities, the equilibrium strategy under ambiguity of an agent with neo-additive beliefs, is decreasing (resp. increasing) in ambiguity.*

2. *In the case of games with strategic substitutes and negative (resp. positive) externalities, the equilibrium strategy under ambiguity of an agent with neo-additive beliefs, is decreasing (resp. increasing) in ambiguity.*

[6]It might be worth noting that Eichberger and Kelsey (2014) present a stronger result for more general CEU preferences.

Games ($SC1$) and ($SC2$) are games with strategic complements and positive externalities. This can be verified if we fix the order $T < C < B$ and $L < M < R$. Both games have one pure Nash equilibrium: (C, M). The equilibrium under ambiguity for these games is (T, M).

Game ($SS1$) is a strategic substitutes game with negative externalities and multiple Nash equilibria, if we fix $T > C > B$ and $L > M > R$. The game has three pure Nash equilibria: (T, R), (C, M) and (B, L), none of which are focal. The equilibrium under ambiguity for this game is (B, R). Game ($SS2$) is a strategic substitutes game if we fix $T > C > B$ and $L > M > R$. The game has a unique Nash equilibrium: (C, M). The equilibrium under ambiguity for this game is (B, R). For both strategic substitutes games the Nash equilibrium Pareto dominates the equilibrium with ambiguity.

3.2 Ellsberg Urn Experiments

The game rounds were alternated with single person decision problems similar to the Ellsberg Urn experiment. Subjects were presented with an urn containing 90 balls, of which 30 were labelled X, and the remainder were an unknown proportion of Y or Z balls. The decisions put to the subjects took the following form:

"An urn contains 90 balls, of which 30 are labelled X. The remainder are either Y or Z.

Which of the following options do you prefer?

a) Payoff of λ if an X ball is drawn.

b) Payoff of 100 if a Y ball is drawn.

c) Payoff of 100 if a Z ball is drawn."

Payoff "λ" attached to the option X was changed from round to round, with $\lambda = 95$, $90, 80, 100$, 105 (in that order), to measure the ambiguity threshold of subjects. If $\lambda = 100$ this is equivalent to the 3-ball version of the Ellsberg Paradox. In the case $\lambda = 105$ we are testing whether some subjects would choose to bet on an ambiguous ball even though it has a lower expected return, (according to a uniform prior). This is a feature not present in many previous experimental tests of the Ellsberg Paradox.

In our Ellsberg urn experiments, we use balls labelled X, Y and Z, rather than following the traditional practice of using Red, Blue and Yellow coloured balls.[7] This is because in a previous set of experiments Kelsey and le Roux (2015), we used coloured balls and found that subjects often chose Blue (the ambiguous option), simply because they had a fondness for the colour blue. Similarly, we found a large number of Chinese subjects chose Red, because it was considered "auspicious" in Chinese culture. In this study we use balls labelled X, Y and Z, in order to avoid biases of this sort.

4 Experimental Design

The games described above were used in paper-based experiments, conducted at St. Stephen's College in New Delhi, India, and at the Finance and Economics Experimental Laboratory in Exeter (FEELE), UK. All the subjects recruited at St. Stephen's College were Indian nationals, who (by assumption) had an Indian sociocultural upbringing. While sending out the invitations to recruit subjects at the University of Exeter, we took particular care to weed out any foreign students who were Indian. As such, the subjects recruited at FEELE had a different sociocultural upbringing. We expected this difference in backgrounds would create ambiguity on the part of Exeter subjects.

The experiments were conducted with three different treatments.

- In Treatment I, subjects were matched against other local subjects (this treatment analyses data from Delhi vs. Delhi and Exeter vs. Exeter sessions).[8]
- Treatment II consisted of matching Exeter subjects against an Indian opponent. Subjects were told that the same experiments had been run in India and that they would be matched up against an Indian subject whose responses had been already collected.[9]

[7] The traditional Ellsberg urn contains Red, Blue and Yellow coloured balls. The number of Red balls in the urn is known, while the remaining Blue and Yellow coloured balls are ambiguous in number.

[8] A probit regression showed that the dummy variable for location (*Delhi*/*Exeter*) does not have a significant impact on choosing the ambiguity safe option. Thus for the purpose of analysing subject behaviour in Treatment I, we have combined the data from sessions where Delhi subjects played against other Delhi subjects (local vs. local) with data from the Exeter vs. Exeter session, without the loss of efficiency.

[9] Subjects knew that their choice would not affect the actual payoff of foreign players, while this was the case when they played the games against local opponents. As a result, when comparing behaviour in the games to test the role of ambiguity, we note that there may be a social preferences confound: subjects might have behaved differently when playing against foreign opponents simply because their choices did not affect the payoff

Cultural studies conducted in the past have shown that western societies are individual-oriented, while Asian cultures tend to be collectivist. Members of Asian cultures have larger social networks that they can fall back upon in the event of an emergency/loss. This makes them more risk/ambiguity-seeking than their western counterparts, Weber and Hsee (1998). Kelsey and Peryman (2015) find that British subjects in particular, act in a way that indicates they believe Asian opponents will behave more cautiously than other British opponents. As such, we expected that subjects would be more ambiguous when matched against opponents who are from a different sociocultural background than themselves.

- In Treatment III, subjects were matched against both internationally as well as locally recruited subjects, for the purpose of payment.

Treatments I and III consisted of 60 subjects each and Treatment II had 61 subjects. In total there were 181 subjects who took part in the experiment, 81 of whom were males and the remaining 100 were females. Each session lasted a maximum of 45 minutes including payment.

Subjects first read through a short, comprehensive set of instructions at their own pace, following this the instructions were also read out to all the participants in general.[10] The subjects were asked to fill out practice questions to check that they understood the games correctly. Once the practice questions had been answered and discussed, the actual set of experimental questions were handed out to the subjects. Subjects were randomly assigned the role of either a Row Player or a Column Player at the beginning of the experiment, for the purpose of matching in the games, and remained in the same role for the rest of the experiment.

Each subject had to select one option per round: Top/Centre/Bottom if they were a Row Player or Left/Middle/Right if they were a Column Player, and in case of the Ellsberg urn rounds X, Y or Z. In the Ellsberg urn rounds, the pay-offs attached to drawing a Y or Z ball were held constant at 100, while those attached to drawing an X ball varied as 95, 90, $80, 100, 105$.

of somebody else.

[10] The experimental protocols can be found at the following link: http://saraleroux.weebly.com/experimental-protocols.html

Once subjects had made all decisions, a throw of dice determined *one* game round and *one* Ellsberg urn round for which subjects would be paid. Subjects in India were paid a show-up fee of $Rs.200$ (£2.50), together with their earnings from the chosen round, where $100ECU = Rs.200$. Exeter subjects were paid a show-up fee of £3, together with their earnings from the chosen round, where $100ECU = £2$.[11] In order to prevent individuals from self-insuring against payoff risks across rounds, we picked one round at random for payment, see Charness and Genicot (2009).[12] Players' decisions were matched according to a predetermined matching, and pay-offs were announced.

Instead of using a real urn we used a computer to simulate the drawing of a ball from the urn.[13] The computer used a normal distribution to randomly assign the number of Y and Z balls in the urn so that they summed to 60, while keeping the number of X balls fixed at 30 and the total number of balls in the urn at 90.[14] The computer then simulated an independent ball draw for each subject. If the label of the ball drawn by the computer matched that chosen by the subject, it entitled him to the payoff specified in the round chosen for payment.

5 Data Analysis and Results

5.1 Row Player Behaviour

See Figure 2, for a summary of row player behaviour. In Treatment I, we find that a large majority of our subjects, 63% in $SC1$ and 73% in $SC2$, chose the ambiguity-safe option T in our experiments. In comparison, only 13% ($SC1$) and 17% ($SC2$) of subjects chose C, the choice under Nash. *Binomial Test A* (See Table 1) finds that subjects chose the ambiguity-safe

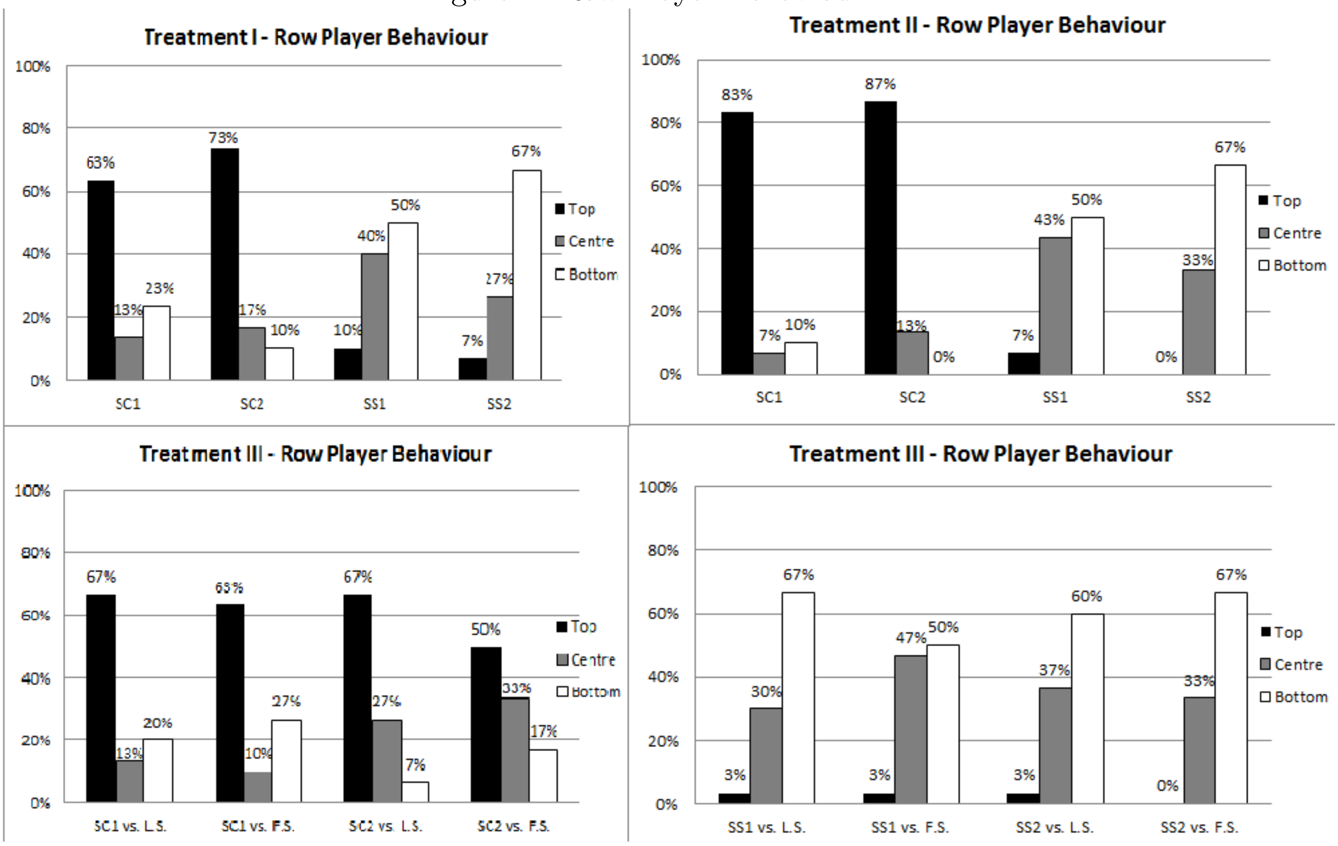
[11] The experiments were conducted between November 2010 - February 2011. The exchange rate during the period was 1 GBP = 80 INR. Our aim was that the average earnings from our experiment which lasted a maximum of 30 minutes, should be able to afford subjects (university students) the chance purchase a meal and a non-alcoholic drink. The purchasing power parity that we were aiming for was a burger meal.

[12] If all rounds count equally towards the final payoff, subjects are likely to try and accumulate a high payoff in the first few rounds and then care less about how they decide in the following rounds. In contrast, if subjects know that they will be paid for a random round, they treat each decision with care.

[13] The computer simulated urn can be found at the following link: http://saraleroux.weebly.com/experimental-protocols.html

[14] The number of Y balls in the urn were determined using the MSExcel command "=ROUNDDOWN(RAND()*61,0)", and the number of Z balls in the urn were simply = (60 minus the number of Y balls).

Figure 2: Row Player Behaviour



option significantly more often than either of the other options. Similarly, in $SS1$ and $SS2$ we find that 50% and 67% of subjects chose the ambiguity-safe option B. It is interesting to note that when multiple Nash equilibria are present (in $SS1$), 40% of the subjects select the Nash $(C, M)-$ which gives an equal payoff to both players. This might indicate that *fairness constraints* affect these subjects more than ambiguity. As such, *Binomial Test B* finds that subjects choose the ambiguity-safe option B, significantly more often in $SS2$, but fails to reject this hypothesis for $SS1$ (See Table 1, Row 5).

In Treatment II, we find that 83% and 87% of subjects chose the ambiguity-safe strategy T in $SC1$ and $SC2$, respectively, compared to 7% (2) and 13% of subjects who chose C (the choice under Nash equilibrium). When compared to the base treatment, it is clear that subjects perceived greater ambiguity in this situation (when faced by the foreign subject). As can be seen in Table 1 (Row 6), subjects chose the ambiguity safe option significantly more often than the other two options available to them. In the strategic substitutes game $SS1$ and $SS2$, 50% and 67% of subjects chose B, the choice under EUA. Even though we perceive heightened ambiguity on the part of the subjects, about half of them (43%), opt for the Nash outcome which would result in equitable pay-offs for both players. *Binomial Test B* cannot be rejected for $SS1$, however, we do reject the null at a 5% level of significance for $SS2$.

Table 1: Binomial Tests A and B - Results

Test:	*Z-score for Binomial Test A*		*Z-score for Binomial Test B*	
Null Hypothesis (H_0):	$prob(T) = prob(C+B) = 0.5$		$prob(B) = prob(T+C) = 0.5$	
Alt. Hypothesis (H_1):	$prob(T) > prob(C+B)$		$prob(B) > prob(T+C)$	
Game:	$SC1$	$SC2$	$SS1$	$SS2$
Treatment I	1.465059**	2.55604***	0	1.82574**
Treatment II	3.65148***	4.01663***	0	1.82574**
Treatment III vs. LS	1.82574**	1.82574**	1.82574**	1.09544
Treatment III vs. FS	1.46505*	0	0	1.82574**
*, **, *** indicate significance levels of 10%, 5% and 1% respectively.				

In Treatment III, Exeter subjects were asked to make decisions versus both the local (Exeter) as well as the foreign (Indian) opponent. They were allowed to choose different actions against the foreign opponent and the domestic one. See the bottom half of Figure 2, for a summary of Row Player behaviour. We find that *fewer* subjects chose the ambiguity-safe option T, against the foreign opponent than against the local opponent, in both $SC1$ and $SC2$. It is interesting to note that subjects chose the ambiguity-safe option significantly more often against the local opponent, but not against the foreign subject (See Table 1, Rows 7 and 8). We find similar behaviour in game $SS1$, where fewer subjects took the ambiguity-safe option versus the foreign subject than against the local subject. Play in $SS2$, was closer to our expectations, and subjects chose the ambiguity-safe option more against the foreign subject than the local one.

Table 2: Correlation in Row Player Behaviour between Games Rounds

Game/Action:	$SC1\_ASO$	$SC2\_ASO$	$SS1\_ASO$	$SS2\_ASO$
$SC1\_ASO$	1.000			
$SC2\_ASO$	0.724	1.000		
$SS1\_ASO$	0.504	0.484	1.000	
$SS2\_ASO$	0.637	0.619	0.559	1.000

We find that there is a significant amount of correlation between subjects' choice of the ambiguity-safe option (ASO) between the four games (See Table 2). However, when we investigate whether there is any correlation between row players who consistently choose the ambiguity-safe option in the game rounds, with their choice in the Ellsberg Urn rounds, we find a weak negative correlation. The row players seemed to display a pessimistic attitude towards ambiguity in the game rounds, but displayed an optimistic attitude towards ambiguity in the Urn rounds.

5.2 Column Player Behaviour

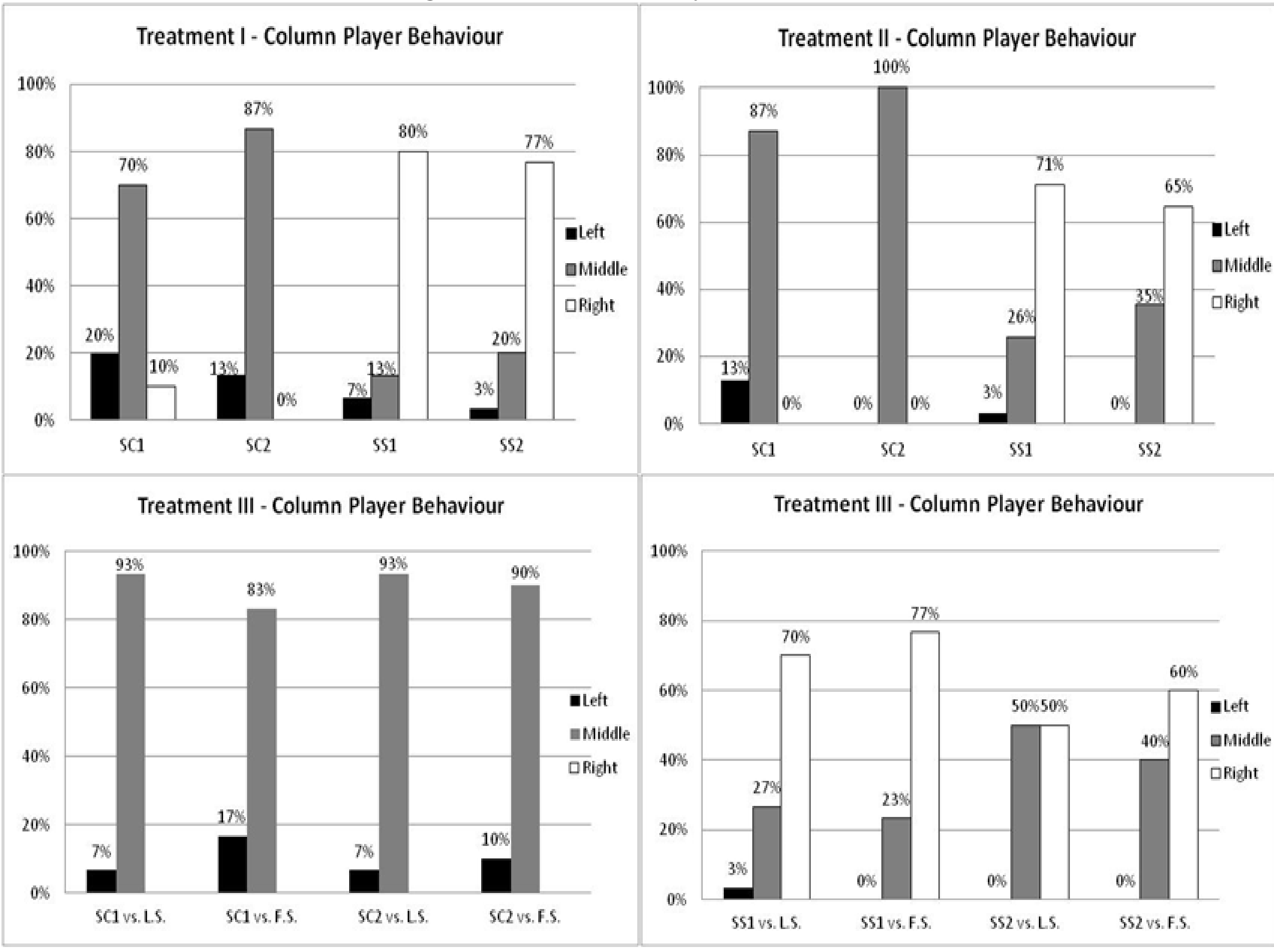
See Figure 3, for a summary of Column Player behaviour. In Treatment I, we find that 70% and 87% of subjects chose the Nash strategy M in $SC1$ and $SC2$, respectively.[15] *Binomial Test C* finds that subjects choose the Nash/EUA option significantly more often than either of the other two choices (See Table 3, Row 5). In the strategic substitutes games $SS1$ and $SS2$, we find that 80% and 77% of subjects choose the ambiguity-safe strategy R, in comparison to 13% and 20% of subjects that chose M (the choice under Nash). *Binomial Test D* finds that subjects choose the ambiguity-safe option M, significantly more often than $L + R$ (Table 3, Row 5).

In Treatment II, 87% and 100% of subjects choose the Nash/EUA strategy M, in $SC1$ and $SC2$ respectively. As might be expected, *Binomial Test C* can be rejected at a 1% level for both $SC1$ and $SC2$ (See Table 3, Row 6). In games $SS1$ and $SS2$,we find 71% and 65% of subjects chose the ambiguity-safe strategy R. *Binomial Test D* is rejected at 1% for $SS1$ and at 5% for $SS2$ (Table 3, Row 5). As such, we do see evidence that subjects seek to take the ambiguity-safe option against the foreign subject. Moreover, we encouraged subjects to write a short account at the end of the experiment, about their reactions and what they were thinking about when they made their choices. A number concluded that they preferred to stick with a safe (but definite) payoff rather than take a chance and lose out, since they were not sure what prompted the foreign opponent's decision choices. Thus these subjects were willing to forego the possibility of a higher payoff, in order to avoid an option which they perceived as ambiguous.

In Treatment III, subjects were matched against both local as well as foreign opponents. We

[15] Note in the case of $SC1$ and $SC2$, the equilibrium action under ambiguity coincides with the Nash strategy, for the Column player.

Figure 3: Column Player Behaviour



expected the subjects to perceive more ambiguity with a foreign opponent. See Figure 3 (lower half of figure), for a summary of Column Player behaviour in Treatment III. It is clear that a large majority of the subjects are choosing the Nash in $SC1$ and $SC2$; however, fewer subjects chose it against the foreign subject. *Binomial Test C* shows that the Nash/EUA option was the significant choice of subjects, in both $SC1$ and $SC2$, and against both local and foreign opponents. In game $SS1$, we find that 70% and 77% of subjects chose the ambiguity-safe strategy R, against the local and foreign subject respectively. In $SS2$, half the subjects chose the ambiguity-safe strategy while the other half chose the Nash against the local opponent. When faced with the foreign opponent, 60% chose the ambiguity-safe option while 40% chose it under Nash. It can be noted that in both the strategic substitutes rounds, the ambiguity-safe option was chosen more often against the foreign subject. As before, we conduct *Binomial Test D* and reject the null at 5% against the local opponent and 1% against foreign opponents for $SS1$. We fail to reject the null for $SS2$, since the decisions were very close to the $50-50$ mark.

Table 3: Binomial Tests C and D - Results

Test:	*Z-score for Binomial Test C*		*Z-score for Binomial Test D*	
Null Hypothesis H_0:	$prob(M) = prob(L+R) = 0.5$		$prob(R) = prob(L+M) = 0.5$	
Alt. Hypothesis H_1:	$prob(M) > prob(L+R)$		$prob(R) > prob(L+M)$	
Game:	$SC1$	$SC2$	$SS1$	$SS2$
Treatment I	2.19089**	4.01663***	3.28633***	2.92119***
Treatment II	4.13092***	5.56776***	2.33487***	1.61645**
Treatment III vs. LS	4.74693***	4.74693***	2.19089**	0
Treatment III vs. FS	3.65148***	4.38178***	2.92119***	1.09445
*, **, *** indicate significance levels of 10%, 5% and 1% respectively.				

However, it is clear in both $SS1$ as well as $SS2$, that the ambiguity-safe option was chosen more often against the foreign subject.

We ran probit regressions to ascertain what factors influenced subjects in their choice of the ambiguity-safe option. Dummy variables were defined to capture the characteristics of the data such as: $Quant = 1$, if the subject was doing a quantitative degree ($Quant = 0$, for degrees like English, History, Philosophy, Politics etc.); $Male = 1$, if gender is male (0, otherwise); and various dummies for the separate treatments and games ($T1$, $T2$ or $T3LS/T3FS$ for the various treatments and SC_1, SC_2, SS_1 and SS_2 for the different game rounds).

A probit regression of Amb_Safe_Option (choice of the ambiguity safe option) was on the various dummies found that "$Quant$", and the various treatment dummies were insignificant. Thus, we note that there was no significant difference in the number of people choosing the ambiguity-safe option between the treatments. A probit regression of Amb_Safe_Option on $Male$ and the dummies for the game rounds, has a chi-squared ratio of 45.51 with a p-value of 0.0000, which shows that the model as a whole is statistically significant.[16] Regression results are seen below.[17]

$$Amb\_Safe\_Option = 0.502 - 0.207(Male) + 0.671(SC\_1) + 1.101(SC\_2) + 0.336(SS\_1)$$

We note that subjects are more likely to choose the ambiguity-safe option in games with strate-

[16]The dummy for SS_2 was dropped from the probit regression, in order to avoid the dummy variable trap.

[17]The coefficients from a probit regression do not have the same interpretation as coefficients from an Ordinary Least Squares regression. From the probit results, we can interpret that males are less likely to choose the ambiguity safe option. If a subject is male, their z-score decreases by 3.01. Moreover, subjects are more likely to choose the ambiguity-safe option in $SC1$: the z-score increases by 3.73, in $SC2$: the z-score increases by 5.42, and for $SS1$: the z-score increases by 1.97, when compared to the base which is game $SS2$.

gic complements than those with strategic substitutes. Moreover, males are significantly less likely to take the ambiguity-safe option than females.

Table 4: Correlation in Column Player Behaviour between Games Rounds

Game/Action:	$SC1\_ASO$	$SC2\_ASO$	$SS1\_ASO$	$SS2\_ASO$
$SC1\_ASO$	1.000			
$SC2\_ASO$	0.801	1.000		
$SS1\_ASO$	0.622	0.725	1.000	
$SS2\_ASO$	0.537	0.619	0.729	1.000

Once again we found a strong correlation between subjects' choice of the ambiguity-safe option (ASO) between the four games (See Table 4). However, the correlation choices in the game rounds and the Ellsberg Urn rounds, was weakly negative. Column player behaviour was consistent with row player behaviour, in that subjects displayed pessimism towards ambiguity in the game rounds, and optimism towards ambiguity in the Urn rounds.

5.3 Behaviour in Ellsberg Urn Rounds

The strategic complement and substitute games were alternated with Ellsberg Urn decisions, in order to elicit an ambiguity threshold of the subjects. Moreover, it enabled us to evaluate whether the ambiguity-attitude of subjects remained consistent between single person decisions, and situations where they were faced by ambiguity created by interacting with other players. The payoff on drawing X (the unambiguous event) was varied as $\lambda = 95,\ 90, 85, 100$ or 105 ECU, depending on the round being played.

As can be seen in Figure 5, for $\lambda = 100$ (the standard Ellsberg urn decision problem), 73% (133) of subjects chose X, while 27% (48) chose to bet on Y and Z.[18] This result is consistent with previous studies.

When there is a premium attached to X, i.e., when $\lambda = 105$, a majority of subjects (73%) opt for X. However, what is more interesting to note is that 27% of subjects opt for $Y + Z$. These subjects are willing to take a lower payoff, in order to choose Y or Z - the balls whose

[18] We consider the sum of the people who chose Y and Z, rather than the number of people who chose Y or Z balls individually, in order to negate any effect of people choosing Y just because it appeared before Z on the choice set.

Figure 4: Subject Behaviour in Ellsberg Urn Rounds

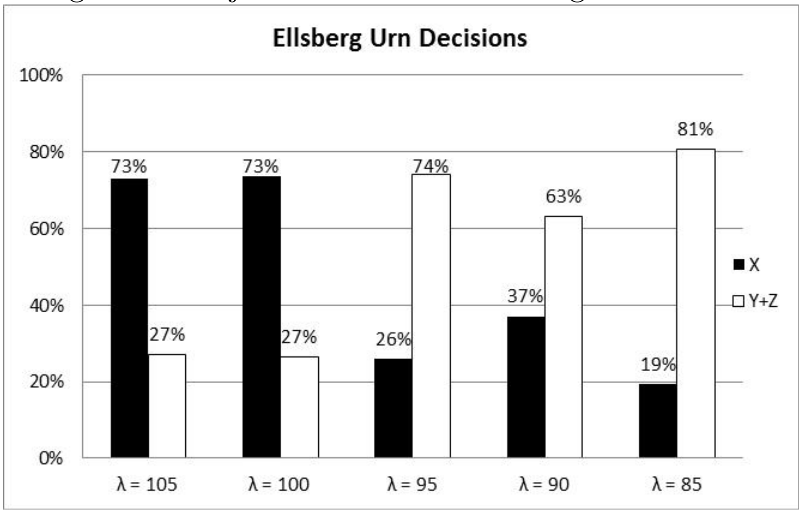


Figure 5:

proportion is unknown! We believe this captures ambiguity-seeking behaviour on the part of the subjects.

Even a small penalty on X from $\lambda = 100$ to $\lambda = 95$, leads to a big rise in the number of subjects choosing $Y + Z$. When $\lambda = 95$, 74% (134) of subjects choose $Y + Z$. This goes up substantially to 81% (146) of subjects choosing $Y + Z$, when $\lambda = 85$. Most subjects are not ambiguity-averse enough to bear a small penalty, in order to continue choosing X (the unambiguous event). It is significant that 19% (35) of subjects chose X, even when $X = 85$, thus displaying strong ambiguity-averse behaviour.

We ran probit regressions to ascertain what factors influenced subjects in their choice of X (the unambiguous ball). Dummy variables were defined to capture the characteristics of the data such as: $Quant = 1$, if the subject was doing a quantitative degree ($Quant = 0$, otherwise.); $Male = 1$, if gender is male (0, otherwise); L_105, L_100, L_95, L_90, $L\_85 = 1$, depending on the value "λ" took in that particular round.

A probit regression of X on the various λ-value dummies L_105, L_95, L_90, L_85, has a chi-squared ratio of 201.29 with a p-value of 0.0000, which shows that our model as a whole is statistically significant.[19] Regression results are seen below.[20]

$$X = 0.627 - 0.033(L\_105) - 1.27(L\_95) - 0.96(L\_90) - 1.49(L\_85)$$

There was no significant difference in the choice of X when $\lambda = 105$ and 100. However, for $\lambda = 95, 90$ and 85, subjects chose X significantly less often than when $\lambda = 100$.

At the individual level, of the 133 subjects that chose X when $\lambda = 100$, 68 switched to $Y + Z$ at $\lambda = 95$, 7 switched to $Y + Z$ at $\lambda = 90$, 5 switched to $Y + Z$ at $\lambda = 85$, while 21 subjects chose X for all values of λ. Looking more closely at the choices of the subjects who always chose X, we find that 9 of them always chose the ambiguity-safe options in the game rounds.[21] Thus, a very small subset of our subject pool (5%), showed strong ambiguity-averse behaviour.

Looking at the 49 subjects who chose $Y + Z$ when $\lambda = 105$, we find that 11 of them never chose X in the Urn rounds. However, 12 of these 49 subjects always chose the ambiguity-safe options in the game rounds – these subjects seem to have a context-dependant ambiguity-attitude: ambiguity-loving in single person decisions and ambiguity-averse in the game environment.

Table 5: Binomial Tests E and F - Results

Test:	*Z-score for Binomial Test E*	*Z-score for Binomial Test F*
Null Hypothesis H_0:	$prob(X) = prob(Y+Z) = 0.5$	$prob(X) = prob(Y+Z) = 0.5$
Alt. Hypothesis H_1:	$prob(X) > prob(Y+Z)$	$prob(Y+Z) > prob(X)$
$\lambda = 105$	6.169***	
$\lambda = 100$	6.318***	
$\lambda = 95$		6.467***
$\lambda = 90$		3.493***
$\lambda = 85$		8.251***
*, **, *** indicate significance levels of 10%, 5% and 1% respectively.		

We conducted *Binomial Tests E* and *F* as described in Table 5. We find that subjects choose the unambiguous ball X significantly more often for $\lambda = 105$ and 100, but prefer the ambiguous balls $Y + Z$ for lower values of λ. On the whole, subjects seem to prefer "betting" on

[19] The dummy for L_100 was dropped from the probit regression, in order to avoid the dummy variable trap. Dummies for *Quant* and *Male* were found to be insignificant, and were thus dropped from the final regression.

[20] From the probit results, we can interpret that when $\lambda = 105$: the z-score decreases by 0.03, for $\lambda = 95$: the z-score decreases by 1.27, for $\lambda = 90$: the z-score decreases by 0.96, for $\lambda = 85$: the z-score decreases by 1.49, when compared to the base which is $\lambda = 100$.

[21] Of these, 7 were Column Players and the remaining 2 were Row Players.

Y and Z. Responses gathered from the subjects showed that subjects viewed the urn rounds as "gambles". The justification given for this was that the computer could have picked any of the three options - thus Y or Z balls could have been more in number than X balls, that were capped at 30 balls. The subjects thus displayed an optimistic attitude towards ambiguity. Moreover, some subjects treated these rounds as based on luck rather than reasoning.[22]

6 Related Literature

6.1 Ambiguity in games

Our study builds upon the theoretical paper by Eichberger and Kelsey (2002). They find that in a game with positive (resp. negative) externalities, ambiguity prompts a player to put an increased (resp. decreased) weight on the lowest of his opponent's actions. The marginal benefit that the player gets from his own action gets decreased (resp. increased) in the case of a game with strategic complements (resp. substitutes). In the presence of positive externalities, players often have the incentive to use a strategy below the Pareto optimal level, and so, the resultant Nash equilibrium is inefficient. In the case of strategic substitutes, increasing the level of ambiguity would cause a shift in equilibrium strategies towards an ex-post Pareto efficient outcome, whereas for strategic complements, an increase in ambiguity would cause a shift in equilibrium, away from the ex-post Pareto efficient outcome. Hence it was hypothesised that ambiguity had an adverse effect in case of games with strategic complements, but was helpful in the case of games with strategic substitutes. Ambiguity thus causes a decrease in equilibrium actions in a game of strategic complements and positive externalities or the opposite case, i.e., strategic substitutes and negative externalities. This result can be applied to a model of voluntary contributions to a public good. It implies that if the good is produced under decreasing returns to scale then an increase in ambiguity should increase contributions and thus provision of the public good.

[22] One subject in particular noted that– "The urn question is pure luck, because majority of the unmarked balls are either Y or Z, and choosing either is a gamble."

Di Mauro and Castro (2011) conduct a set of experiments designed to test whether ambiguity or altruism causes an increase in contribution to the public good in the above case. In order to negate the chance that altruism, or a feeling of reciprocation prompted the subjects' actions, the subjects were informed that their opponent would be a virtual agent and the opponent's play was simulated by a computer. Subjects played in two scenarios, one with risk, the other with ambiguity. It was noted that contributions were significantly higher when the situation was one of ambiguity. The results showed that there was indeed evidence that ambiguity was the cause of increased contribution. This is akin to the results found in our paper that ambiguity significantly affects the decisions made by individuals, in a manner that depends directly on the strategic nature of the game in consideration.

Another paper that studies strategic ambiguity in games experimentally, is Eichberger, Kelsey, and Schipper (2008). In common with the present paper, it used the identity of the opponent to introduce ambiguity in the experiment. They studied games in which subjects faced either the experimenter's grandmother (who was described as being ignorant of economic strategy), a game theorist (who was described as a successful professor of economics), or another student as an opponent. The key hypothesis being tested was that ambiguity has the opposite effect in games of strategic complements and substitutes. Ambiguity averse actions were chosen significantly more often against the granny than against the game theorist, irrespective of whether the game was one of strategic complements, strategic substitutes or one with multiple equilibria. When the level of ambiguity the subjects faced while playing the granny was compared to that of the subjects faced playing against each other, it was found that the players still found the granny a more ambiguous opponent.

The paper also tested whether ambiguity had the opposite effect in games of strategic complements and substitutes. This is similar to Eichberger, Kelsey, and Schipper (2008) who also conclude that comparative statics broadly support the theoretical prediction. Subjects were also found to react to variations in the level of ambiguity, which was tested by altering the cardinal payoff in the game while keeping the ordinal payoff structure unchanged. It can thus be seen that subjects react not only to ambiguity on the part of the opponent, but also to subtle changes in the payoff structures of the experiment.

Kelsey and Peryman (2015) study experiments with stag hunt and bargaining coordination games. They use a between-subjects design to vary the identity of the opponent to see whether cultural norms or identity play a part in coordination decisions. They find that players do appear to use cultural stereotypes to predict behaviour, especially in the bargaining game. In particular, British subjects act in a manner that indicates they believe Asian subjects will behave more cautiously. In our experiments we failed to see subjects react more ambiguously towards foreign opponents and as such, our subjects did not vary their actions on cultural stereotypes.

Ivanov (2011), discusses the findings of a series of experiments on normal form games run to distinguish between eighteen types of players. A person was classified on the basis of his attitude to ambiguity - as being either ambiguity averse, ambiguity neutral, or ambiguity loving; on the basis of his attitude to risk - as being risk averse, risk neutral or risk loving; and whether he played strategically or naively. A person who played in a naive manner was modelled as having a uniform belief in every game he played, whereas if he played strategically, his beliefs were different for every game and were thus unrestricted. The study finds that about 32% of the subjects taking part in the experiment were ambiguity loving, as opposed to 22% who were ambiguity averse. The majority of subjects (46%) were found to be ambiguity neutral. While being tested on the basis of their attitude to risk, 62% of the subjects were found to be risk averse, 36% to be risk neutral, and a mere 2% were risk loving. 90% of the subjects played in a strategic manner, while 10% played naively. These results are opposite to ours, since we find more subjects who are ambiguity averse than those who are ambiguity seeking, in the game rounds.

The study by Ivanov (2011) questions the fact that there are more subjects who are ambiguity loving/neutral, than those who are ambiguity averse, given that on average a majority of them play strategically. This is attributed to players' altruistic behaviour, i.e., they played in a manner that would maximise the sum of both players' pay-offs. This may be because a player is willing to compromise with his opponent, in order to do well himself.

While our study concentrated on investigating individual behaviour in the presence of ambiguity, Keller, Sarin, and Sounderpandian (2007) investigate whether individuals deciding together as pairs (termed dyads in the paper) display ambiguity averse behaviour. Participants were initially asked to state how much they were willing to pay for six monetary gambles. Five of the six gambles put before the subjects involved ambiguity, while the sixth involved no ambiguity. Once the participants had all disclosed their individual willingness to pay, they were randomly paired with another subject and each pair had to re-specify how much they were willing to pay for the six gambles. It was found that the pairs displayed risk averse as well as ambiguity averse preferences. It was observed that the willingness-to-pay among pairs of individuals deciding together, was lower than the average of their individual willingness-to-pay for gambles. They thus conclude that ambiguity averse behaviour is prevalent in group settings.

In our experiments, we did not allow subjects to interact with each other. We believed that this would reduce the level of ambiguity they would perceive, when asked to make decisions against each other. In contrast, Keck, Diecidue, and Budescu (2012), conduct an experiment in which subjects made decisions individually, as a group, and individually after interacting and exchanging information with others. Subjects were asked to make binary choices between sure sums of money and ambiguous and risky bets. They found that individuals are more likely to make ambiguity neutral decisions after interacting with other subjects. Moreover, they find that ambiguity seeking and ambiguity averse preferences among individuals are eliminated by communication and interaction between individuals; and as such, groups are more likely to make ambiguity neutral decisions.

Greiner (2016) studies the effect of strategic ambiguity in five kinds of bargaining games - The dictator game, the ultimatum game, the standard and two variants of the impunity game. The study finds significant aversion to strategic uncertainty even with regard to strategies which are very unlikely to be chosen. In particular, if the second mover has the ability to reject a fair offer, it has an effect on the first mover, even though in practice participants do not reject offers of equal splits. This behaviour is inconsistent with rational beliefs and consistency in strategies, but it was found to be robust across the different games and subject pools. In our experiments.

we found that subjects were motivated by fairness criteria, especially in SS1 where 40% of the subjects select the Nash equilibrium $\langle C, M\rangle$, which gives an equal payoff to both players.

Calford (2016) presents an experiment which aims to disentangle the effects of risk and ambiguity on behaviour in games. In addition, the paper also seeks to separate the effects of subject's own beliefs over her opponent's preferences from the effects of her own preferences. The data is gathered though laboratory experiments and finds that risk and ambiguity both affect subject behaviour. It is interesting to note that subjects' reported beliefs of their opponent's preferences are independent of their behaviour in the normal form game.

6.2 Ambiguity in Single Person Decisions

Our Ellsberg urn experiments investigated whether there was any correlation between ambiguity attitude in games and single person decisions. Moreover, we wanted to evaluate whether there was any threshold at which individuals switched from being ambiguity averse to being ambiguity neutral (or seeking). For an extensive survey of the literature on Ellsberg experiments, see Trautmann and van de Kuilen (2015).

Eliaz and Ortoleva (2011) study a three-colour Ellsberg urn with increased ambiguity, in that the amount of money that subjects can earn also depends on the number of balls of the chosen colour in the ambiguous urn. The subjects thus face ambiguity on two accounts: the unknown proportion of balls in the urn as well as the size of the prize money. In their experiment, both winning and the amount that the subject could possibly win were both perfectly correlated - either positively or negatively, depending on which of the two treatments was run by them. In the experiment, most subjects preferred betting in the positively correlated treatment rather than the negative one. Moreover, subjects also showed a preference for a gamble when there was positively correlated ambiguity, as opposed to a gamble without any ambiguity. This behaviour of the subjects, is compatible with our findings that subjects preferred betting on Y/Z where there was ambiguity, rather than on X, the known choice.

Binmore, Stewart, and Voorhoeve (2012), test whether subjects are indeed ambiguity averse. They report that behaviour in their experiments is inconsistent with the Hurwicz criterion.

Instead, they find that the principle of insufficient reason has greater predictive power with respect to their data, than ambiguity aversion. This may also explain why behaviour in games appears different to that in Ellsberg urn type experiments. It is harder to apply the principle of insufficient reason to games. Our results are consistent with these findings, since we find that subjects are not willing to pay even a moderate penalty to avoid ambiguity in the Ellsberg urn rounds where the payoff attached to X were $95/90/85ECU$. This might be because in the absence of information, subjects use the principle of insufficient reason and attach a $50:50$ probability to the remaining 60 Y and Z balls left in the urn. The principle of insufficient reason would imply that the probability distribution attached to the X, Y and Z balls in the urn is $(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$. It would thus be more rational to choose Y or Z and get a payoff of $100ECU$, than to choose X and suffer a penalty, i.e., get pay-offs $95/90/85ECU$.

In our experiments we did not allow the subjects to communicate or interact with each other. Charness, Karni, and Levin (2013), test whether individuals display a non-neutral attitude towards ambiguity, and given a chance to interact, can subjects persuade others to change their ambiguity attitude. They find that though a number of their subjects displayed an incoherent attitude towards ambiguity, a majority of subjects displayed ambiguity neutral preferences. A small minority (smaller than the number who were ambiguity-incoherent) displayed ambiguity averse and ambiguity seeking behaviour. More interestingly, they find that if subjects are allowed to interact with each other, given the right incentives, ambiguity neutral subjects often manage to convince ambiguity seeking and ambiguity incoherent subjects to change their mind and follow ambiguity neutral behaviour.

7 Conclusions

Behaviour in our experiments was found to be consistent with many of our hypotheses. Nash equilibrium was a poor predictor of subject behaviour and the deviations from Nash behaviour were in the direction expected. In the games we find that subjects do indeed choose the equilibrium action under ambiguity more often than either of the other actions. As predicted ambiguity had the opposite effect in games of strategic complements and substitutes.

We tested whether subjects display a greater level of ambiguity-averse behaviour when faced by a foreign opponent. Although there were some signs of this, the evidence was weak and not statistically significant. These results are consistent with an earlier study, where subjects' perception of ambiguity in a public goods setting was analysed Kelsey and le Roux (2016).

One would expect that the ambiguity-safe option would be chosen more often against the foreign subject and not otherwise. Moreover, it is interesting that our findings are opposite to those of Kilka and Weber (2001), who found that subjects are more ambiguity-averse when the returns of an investment are dependent on foreign securities than when they are linked to domestic securities. One can note that decisions regarding financial markets are much more complex than the act of dealing with other people. It is easier for subjects to conceptualise another person whom they may be faced against, rather than investments in known/unknown financial markets. Follow-up experiments may be run, where subjects are given a choice of whether they would like to face a foreign opponent in a game, or invest in a foreign security.

It can be noted that the behaviour in game $SS2$ supports our hypothesis that when faced by both the foreign subject and the local subject simultaneously, the safe act would be taken more often against foreign subject. One of the reasons for not picking the ambiguity-safe option more often against the foreign subject, may be that subjects were trying to be consistent when making their choices. Alternatively, subjects could see the other local subjects sitting in the experimental laboratory, whereas the foreign subject seemed very far away. They thus chose to play cautiously against the local subject, while taking their chances against the foreign subject.

Another reason for subjects choosing the same action against both foreign and local opponents, may be that some students were afraid that if they chose a different option against the foreign subject, they might appear racist.[23] In an attempt to appear fair, subjects may have chosen the same option against both opponents. We could avoid this complication in future experiments, by comparing different groups of a similar race, such as African-Americans and Africans. In future experiments, we could have treatments where subjects are allowed to

[23] This was part of an overheard conversation between subjects, who were talking to each other at the end of the experiment.

choose which opponent they would like to face, local or foreign. Furthermore, we could check if they are willing to pay a penalty in order to avoid facing the foreign opponent. It would be interesting if subjects were willing to pay a penalty, to avoid an ambiguous foreign opponent, since this would contrast with what we observed in the single person decisions.

In the Ellsberg Urn rounds we find that for $\lambda = 105$ and $\lambda = 100$ subjects prefer to opt for X rather than Y or Z, but even the smallest reduction in λ leads to subjects choosing Y or Z (which is the ambiguous choice). When the payoff attached to X was 95, 90, or 85, $Y + Z$ was chosen significantly more often than X. We notice that the subjects are unwilling to bear even a small penalty in order to stick with X balls (the unambiguous choice). At the individual level, we found steep drops in the number of subjects choosing X, for every reduction in the value of λ. A very small subset of our subject pool (5%), showed strong ambiguity-averse behaviour always choosing the ambiguity-safe option in the game rounds and X in the Urn rounds, while 27% of our subjects showed mildly ambiguity-seeking behaviour by opting for $Y + Z$ when $\lambda = 105$.

Our subjects appear to perceive more ambiguity and exhibit more ambiguity-aversion in games. In addition,we note that ambiguity attitudes appear to be context dependent: ambiguity-loving in single person decisions and ambiguity-averse in games. This is consistent with our earlier study, Kelsey and le Roux (2015), where we found that the ambiguity-attitude of subjects was dependent on the scenario they were facing. It might be interesting to elicit subjects' preferences on whether they would like to face an opponent or an Ellsberg urn.

It is our belief that subjects find it more ambiguous to make decisions against other people than against the random move of nature, over which everyone is equally powerless. This might even explain why people are more concerned with scenarios involving political turmoil or war - situations dependent on other people, but appear to discount the seriousness of possible natural disasters - which are beyond anyone's control.

A Appendix

We shall illustrate Proposition 3.1 by two examples. One a game of strategic complements and the other a game of strategic substitutes.

Example A.1 *Consider Game* $(SC2)$ *in Table 6.*

Table 6: Game SC2

	L	M	R
T	$115, 95$	$115, 100$	$115, 0$
C	$0, 95$	$135, 100$	$135, 0$
B	$5, 105$	$105, 100$	$105, 135$

The game has one pure Nash equilibrium: (C, M). Moreover, if we order the strategy spaces as follows: $T < C < B$ and $L < M < R$, the game is one of strategic complements and positive externalities.

Let the Row Player have the following beliefs : $v^{RP}(L) = 1 - \delta^{RP}$ and $v^{RP}(M, R) = 0$. Then the Choquet expected pay-offs for the Row Player would be: $V^{RP}(T) = 115, V^{RP}(C) = 135\delta^{RP}$ and $V^{RP}(B) = 5 + 100\delta^{RP}$. Thus, T is the best response for the Row Player if $\delta^{RP} \geq \frac{115}{135} \simeq 0.85$. Hence if the Row Player is sufficiently ambiguous about the opponent's behaviour, he would opt for T, which is the ambiguity safe choice.

Similarly, if the Column Player has the following beliefs : $v^{CP}(B) = 1 - \delta^{CP}$ and $v^{CP}(T, C) = 0$. Then the Choquet expected payoff for the Column Player would be: $V^{CP}(L) = 100 + (95 - 105)\delta^{CP}, V^{CP}(M) = 100$ and $V^{CP}(R) = 135\left(1 - \delta^{CP}\right)$. Thus, M is the best response for the Column Player if $\delta^{CP} \geq \frac{135-100}{135} \simeq 0.26$. Hence if the Column Player perceives sufficient ambiguity about the opponent's behaviour, he would choose M, which is the ambiguity safe option.

The illustrates the proposition that the equilibrium strategy for both players in a game with strategic complements and positive externalities, decreases with ambiguity. $\square$

We use Game $(SS2)$ in Table 7 below, to illustrate the implications of ambiguity in a game with strategic substitutes.

Example A.2 *In the Game* $(SS1)$*, in Table 7 below, an increase in ambiguity will result in both players using lower strategies in equilibrium.*

Table 7: Game SS2

	L	M	R
T	$0, 0$	$70, 0$	$170, 150$
C	$100, 70$	$165, 165$	$165, 150$
B	$150, 170$	$150, 165$	$150, 150$

The game has one pure Nash equilibrium: (C, M). Moreover, if we order the strategy spaces as follows: $T > C > B$ and $L > M > R$, the game is one of strategic substitutes and negative externalities.

Let the Row Player have the following beliefs : $v^{RP}(R) = 1 - \delta^{RP}$ and $v^{RP}(L, M) = 0$. Then the Choquet expected payoff for the Row Player would be:

$V^{RP}(T) = 170\left(1 - \delta^{RP}\right) + 0.\delta^{RP} = 170 - 170\delta^{RP}$,

$V^{RP}(C) = 165\left(1 - \delta^{RP}\right) + 100.\delta^{RP} = 165 - 65\delta^{RP}$, $\qquad V^{RP}(B) = 150$.

Thus, B is the best response for the Row Player if $150 \geqslant 165 - 65\delta^{RP} \Leftrightarrow \delta^{RP} \geqslant \frac{3}{13} \simeq 0.23$, and $150 \geqslant 170 - 170\delta^{RP} \Leftrightarrow \delta^{RP} \geqslant \frac{2}{17} \simeq 0.12$.

This means that if the Row Player is sufficiently ambiguous (i.e. $\delta^{RP} > 0.23$) about the opponent's behaviour, he would choose B, which is the ambiguity safe option.

Assume the Column Player has the following beliefs : $v^{CP}(B) = 1 - \delta^{CP}$ and $v^{CP}(T, C) = 0$. Then his Choquet expected pay-offs are: $V^{CP}(L) = 170 - 170\delta^{CP}$, $V^{CP}(M) = 165 - 165\delta^{CP}$, $V^{CP}(R) = 150$.

The Column Player would thus prefer R to M if, $150 \geqslant 165 - 165\delta^{CP} \Leftrightarrow \delta^{CP} \geqslant \frac{15}{165} = \frac{1}{11} \simeq 0.09$. He would prefer R to L if, $150 \geqslant 170 - 170\delta^{CP} \Leftrightarrow \delta^{CP} \geqslant \frac{2}{17} \simeq 0.12$.

Hence if the Column Player perceives sufficient ambiguity (i.e. $\delta^{CP} > 0.12$) about the opponent's behaviour, he would choose the ambiguity safe option, R. □

This illustrates that the equilibrium response for both players in a game with strategic substitutes and negative externalities, given sufficient ambiguity decreases ambiguity.

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