An experimental study of financial options markets and the "overpriced puts puzzle" [1]

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Abstract

TBA

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I. Introduction

A long tradition in economics and finance has emphasized the importance of emotions in the economy and in financial markets, starting with Keynes's (1936) discussion of the concept of "animal spirits." However, there is still a lack of controlled laboratory studies on the effect of emotions in financial markets. In this paper, we restrict our attention to a medium-intensity emotion, fear (*e.g.* Plutchik, 1994 and Ekman, 1992), and to the wearing effect of this emotion on decisions circuits, what is commonly called stress (Selye, 1976). We plan to study both experimenter-induced stress through a stress-induction protocol, as well as stress that is likely to arise endogenously in response to adverse conditions arising in financial markets. This study is based on laboratory experiments with (undergraduate) students.

We restrict our attention to a specific financial instrument, financial options. Since options are priced on the basis of *ex ante* risks, they give a privileged view of the way in which risks are perceived by investors (Santa Clara and Yan, 2010). There are two types of options traded in financial markets. Call (put) options give a right to buy (sell) an underlying asset at a predetermined price, called the strike price, at or until a particular date, called the maturity of the option. Options that are exercised at the maturity date are called European options, while those that can be exercised until the maturity date are called American options. For tractability reasons we focus our analysis only on European options. At the maturity date, options are exercised or not depending on the value of the underlying asset. A call (put) option is exercised when it is "in-the-money" (ITM) which means that the price of the underlying asset is above (below) the strike price at the maturity date. A call (put) option is not exercised when it is "out-of-the-money" (OTM), i.e. when the price of the underlying is below (above) the strike price at the maturity date.

Historically, the prices of OTM put options (OTM puts in short) in adverse periods in the economy have been too high and incompatible with the canonical asset-pricing models, such as CAPM and the Rubinstein (1976) model. This has given rise to the "OTM put puzzle" in finance (*e.g.* Bondarenko, 2004). An hypothesis regarding the relationship between emotions (fear in particular) and overpriced OTM puts can be the following: fear induces the trader to revise upwards his or her expectations of negative

tail events, which are pushed to a level eventually too high. This condition leads to increased demand and/or less supply of OTM put options (OTM puts for short), which at last results in the (excessive) increase of the market price of these derivative instruments.[4] While these three elements, fear, revision of beliefs and increased price for OTM puts, are in a symbiotic relationship, a laboratory experiment approach should help us establishing whether there is a causal link between artificially induced stress levels and an increased demand for OTM puts. The implications of this inquiry are important to understand the psychophysiological correlates of behavior in options markets and in particular of the demand and supply of insurance against extreme negative events, provided by the OTM puts.

We plan to collect three measures of stress: salivary cortisol (C)[5], skin conductance, and self-reported stress. The stress itself can be elicited through a stress-induction protocol or the volatility of the underlying asset, which we both control experimentally. The cortisol measurement is key because we wish to control for the fact that the effects of stress might be asymmetrically distributed across participants because of different cortisol responses (cf. Kandasamy *et al.*, 2014). Buckert et al. (2014) find that fear and stress produce behavioral effects only in those subjects who show a cortisol response to stress. Measuring cortisol gives us also a physiological measure of the level of stress in the group of participants, a variable that might be important in explaining asset pricing.

2. Options

2.1 Price dynamics: some empirical evidence

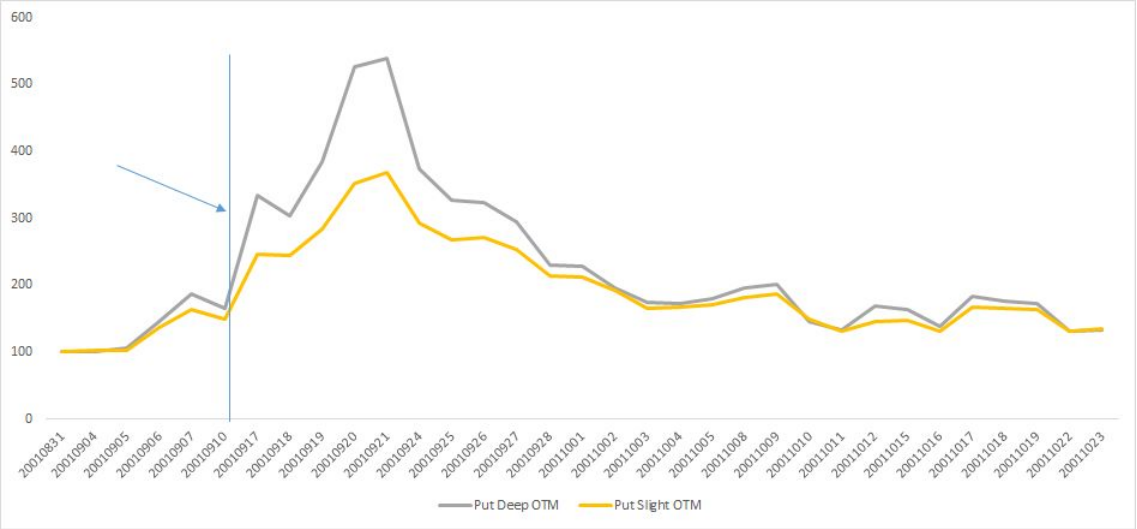
The prices of put options, particularly the OTM ones, are strongly affected by market conditions (*e.g.* Bondarenko, 2004; Santa Clara and Yan, 2010; Constantinides *et al.*, 2013). Increased stress in financial markets is typically associated with spikes in the price of OTM put options. This is evident if one looks *e.g.* at the dynamics of the prices

[4] This reasoning is in line with Constantinides and Lian's (2015) modeling of the endogenous supply and demand of index puts, where market makers sell "overpriced" puts while the risk-averse investors buy those index puts to maximize their utility and hedge their exposure to downside risk. Cf also Yang *et al.* (2016).

[5] We also plan to collect testosterone to test for the well-know "dual hormone hypothesis" (Mehta and Prasad, 2015), according to which the interaction term between cortisol and testosterone might be more important in explaining behavior than each hormone on its own.

of the S&P500 index OTM put options following the 9/11 terrorist attacks and the collapse of Lehman Brothers (Figure 1 and 2, respectively) and compares those movements with the price dynamics of S&P500 index OTM put options during a period of relative calm (Figure 3)[6]. After a stress event the price of "deeper" OTM puts increase in a much more spectacular way than the price of slightly OTM put options. During periods of calm the prices of slight and deep OTM puts seem to follow a much closer path.

Figure 1: options price dynamics around the 9/11 events



[6] These figures plot the daily price dynamics of two selected out-of-the-money (OTM) S&P500 put options, with fixed maturity date, for each of three different time periods. For each period, one of the puts is deeply OTM and the other is slightly OTM. The reference to define the level of moneyness (i.e. degree of OTM) is the S&P500 index level at the beginning of each period. Option prices are calculated as the bid-ask midpoint. Graphs are presented with rebased series, with the base being the level of each variable at the first day of each period. Three time periods are considered. In Figure 1, the time period is from 2001:08:31 until 2001:10:23, including the 9/11 events. The S&P500 index closing level at 2001:08:31 was 1133.58. The deep and slight OTM S&P500 put options plotted are ID11906147 (strike 950) and ID11906155 (strike 1100), both with maturity 2001:12:22. In Figure 2, the time period is from 2008:09:02 until 2008:10:21, including the Lehman Brothers event. The S&P500 index closing level at 2008:09:02 was 1277.58. The deep and slight OTM S&P500 put options plotted are ID31800109 (strike 900) and ID33526030 (strike 1260), both with maturity 2008:12:20. In Figure 3, the time period is from 2014:02:28 until 2014:03:31 representing a calm period. The S&P500 index closing level at 2014:02:28 was 1859.45. The deep and slight OTM S&P500 put options plotted are ID101252084 (strike 1500) and ID101252096 (strike 1800), both with maturity 2014:06:30. Option prices are collected from Optionmetrics.

Figure 2: options price dynamics around the Lehman Brothers events

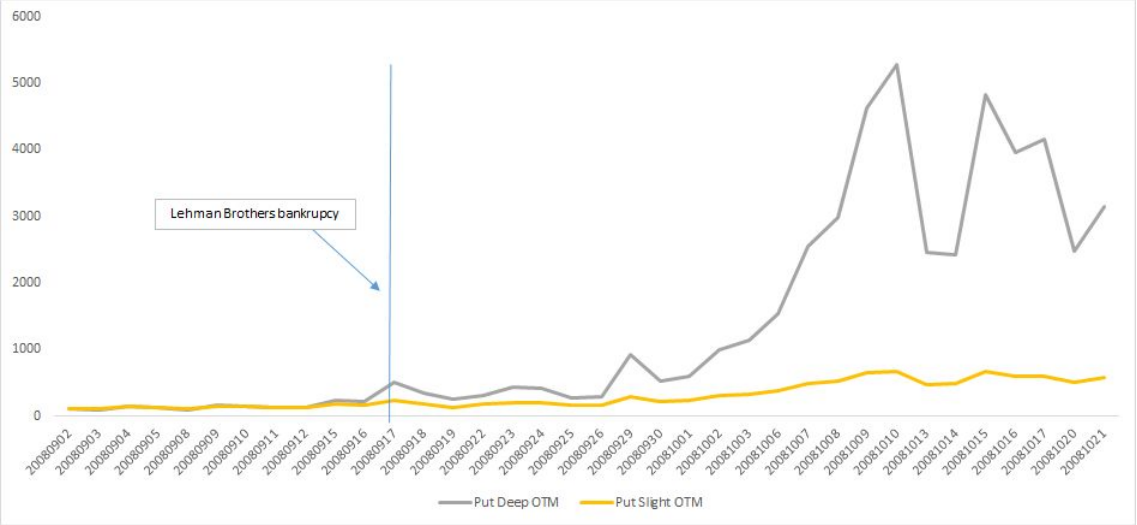


Figure 3: options price dynamics in a period of "calm"

The fact that the prices of OTM put options are on average higher than expected under classic asset-pricing models (*e.g.* Bondarenko, 2014), suggests that the *ex-ante* expectations of the market operators regarding negative tail events are, on average, greater than the realized *ex-post* prices (an instance of "peso problem"[7]). This mismatch

[7] 'Peso problem' was coined by Milton Friedman to describe the situation in which the forward-looking return distribution is more left skewed than an empirical distribution from past realizations. Historically, the intuition and name for the peso problem come from the Mexican Peso pegging versus the US dollar in the early 1970s. As the Mexican economy deteriorated, investors expected that the peg would not hold and such expectation was reflected in the large difference between spot and forward exchange rates. The widely expected abolition of the fixed exchange rate did not occur until 1976, when the Peso was allowed to float and plummeted by 46%. Such tail events that were expected to happen but did not happen until much later are known as Peso events.

might be explained by the role of emotions, stress and cognitive biases in shaping the investors' perceptions of the ambiguity in financial markets in "puzzling" ways. We have remarked that the difference between theoretical and empirical prices of deep OTM puts is amplified during periods of negative shocks in markets. This determines our focus on stress and fear and how these two psychophysiological states shape the demand and supply for OTM puts.

2.2 Experiments on options

The experimental literature on options is scarce. Kluger and Wyatt (1995) find that asset markets where options are available and traded aggregate the traders' dispersed information faster compared to asset markets without options. Ross (1976) shows the important function of options in decreasing the degree of incompleteness of financial markets and increasing efficiency. Abbink and Rockenbach (2006) in an experimental study of options find (i) no significant difference in monetary performance between students and employees of a bank and (ii) that the latter learn how to exploit arbitrage opportunities better than the students. No paper in the existing literature has to the best of our knowledge taken a psychophysiological approach to the study of options trading and pricing. Andrade et al. (2015), in a related contribution, use video clips to induce emotional states such as fear or excitement. They find that the videos inducing excitement were associated with bigger "bubbles" a phenomenon when asset prices significantly depart from their fundamentals. The type of financial instrument we analyze in this paper is, however, different, and with a stronger documented connection to fear and stress.

2.3 Inducing stress

Recently, Bali and Jaqqi (2016) reviewed several stress induction methods devised for humans used in the literature. Namely: (i) Cold Pressor Test (CPT), (ii) Trier Social Stress Test (TSST), (iii) Montreal Imaging Stress Task (MIST), (iv) Maastricht Acute Stress Test (MAST), (v) CO_2 challenge test, (vi) Stroop test, (vii) Paced Auditory Serial Addition Task (PASAT), (viii) noise stress, and (ix) Mannheim Multicomponent Stress Test. Skoluda et al. (2015) tested whether the Stroop test, CPT, TSST, and a bicycle

ergometer test differ in the likelihood, magnitude and time-course of the induced psychophysiological stress response pattern. Among all tasks, the TSST is the task that elicits the largest changes of response in cortisol immediately after the stress-induction test. Cortisol peaks 15 min after the stress-test and that the changes in cortisol seem to approach baseline levels from 45 minutes onwards. Smeets et al. (2012) and Giles et al. (2014) also found that the TSST elicits superior or equivalent stress and cortisol responses, compared with other stress-induction protocols.

The TSST was first developed by Kirschbaum et al. (1993). It consists of 3 stages: (1) a 10-minute preparatory stage, (2) a 5-minute public speaking task, and (3) a 5-minute mental arithmetic task in which participants receive negative feedback in case of mistakes. Cahlíková & Cingl (2016) who investigate whether participants undergoing the TSST and having a cortisol increase that exceeds 2.5 nmol/l are more risk averse. The authors find a strong difference in risk preferences between men who were under stress and men who were not, but no significant difference for women. Given the extensive use of the TSST in the literature, and its proven effectiveness in inducing stress compared to other protocols, the TSST, in the version for groups (TSST-G) devised by Von Dawans et al. (2011), is our stress-induction method of choice. The TSST-G was operationalized in this way: (i) an introduction, preparation, and anticipation phase (10 minutes overall); (ii) a public speaking task of 2 minutes per participant. The duration of this part of the TSST-G was of 2 minutes times the number of group members (6 members in the Von Dawans et al., 2011, study); (iii) a mental arithmetic task (serial subtraction) of 8 minutes. Participants were asked to prepare an application for a job of their choice and to introduce themselves to the selection committee in a free speech of 2 minutes. They were asked to convince the committee that they were the most suitable candidates for this position. As in the original TSST, the two members of the evaluation committee (one man and one woman wearing white laboratory coats; same evaluators for all participants) were trained to withhold verbal and non-verbal feedback and were presented as experts in the evaluation of nonverbal behavior. Moreover, the participants were told that a video analysis of their performance would be conducted. In addition, participants were informed that the panel could come back to them at any time throughout the speech to ask questions. The written

instructions ended with a remark about an unspecified second task that would follow the speech. After reading these instructions, the participants were given 10 min for preparation and were provided with a paper and pencil to outline their speech; however, they were not allowed to use their notes for their speech in the interview room (room B). After the preparation phase, all participants were guided to room B and had to stand in a row in front of the committee, who sat behind a table, and two conspicuous video-cameras. Participants are separated by mobile dividing walls that restricted any eye contact and social interaction with the other participants. The committee called on each of the participants in random order to start their speech. Whenever a participant finished his speech in less than 2 min, the committee responded in a standardized way. After all participants had given their 2-min speech, the committee asked the subject to serially subtract the number 16 from a given number as quickly and accurately as possible (e.g., 4878, 4862, etc.). Each participant received an individual starting number to avoid learning effects. If they made a mistake, they had to restart at their personal number with one member of the committee interrupting, ‘‘Stop. Please start again.’’

Bali and Jaqqi (2016) describe the methods used in the literature to measure stress, such as (i) self-reported anxiety measures, like questionnaires; (ii) biochemical markers such as cortisol, cortisol awakening response, dexamethasone suppression test, salivary α-amylase, plasma/urinary norepinephrine, norepinephrine spillover rate, and interleukins; (iii) physiological and behavioral changes: galvanic skin response, heart rate variability, pupil size, and muscle and/or skin sympathetic nerve activity (microneurography) and cardiovascular parameters such as heart rate, blood pressure. We have already pursued the first path, i.e., self-reported measures of stress. The second and third avenues are in the planning stage.

3. **Materials and Methods**

Groups of 10-15 participants entered the lab room and picked a code with their computer number. The interval for the number of participants was chosen to ensure that the market was reasonably “big.” We left the exact number of participants open, depending on subject availability in each session. Participants provided informed

consent[8]. We then administered three standard questionnaires designed to capture self-reported levels of stress: the STAI-State, the VAS-A, and the STAI-Trait. The participants filled the questionnaires in paper and pencil in the local language. The experimenter then read the instructions in the local language. The instructions, available upon request in English translation from the corresponding author, stated that the participants would be placed in the same group, and that everyone had the opportunity to buy and sell put and call options. All participants started with 2 put options, 2 call options, and a cash endowment of 100 experimental points. All options had as a maturity the last round, in which no trading occurred. The exact number of rounds, and therefore also the maturity of the options, was not communicated to the participants. Across all sessions, participants traded for 12 periods lasting 2 minutes each, and the "maturity" was, therefore, period 13. Subjects were told in the ad that we used for recruiting purposes that the experiment would last on average 1h45m. Participants could, therefore, reasonably infer the maturity of the options, once they started trading. The strike prices for the options were 20 and 45 experimental points for the put options (traded in Markets 1 and 2, respectively), and 45 and 80 for the call options (traded in Markets 3 and 4, respectively). We explained that the "underlying" was a generic asset, whose price varied in each period between and including 0 and 100. All subjects saw the value of the underlying on the screen in each period. Subjects were told that they could not trade the underlying asset, wich was, therefore, simply a parameter from the point of view of the participants. In one treatment (RISK) subjects were instructed that the value of the underlying was drawn from a uniform distribution between and including zero and one hundred; in another treatment, participants were told that the underlying was drawn between 0 and 100, without any further information about the distribution from which the number was drawn (AMBIGUITY). These two treatments were meant to replicate a situation of risk, where the value of the underlying is random, but drawn from a known distribution, versus a situation of ambiguity, where the distribution is unknown. In the ambiguity sessions, the values of the underlying were actually drawn from a cloud of points around a negatively sloped line[9]. It was common

[8] The study was reviewed and approved by the Ethics Lab of the Catholic University of Portugal (Porto).

[9] Those points are evenly distributed random real numbers around a negatively sloped line. We used the rand() function in Excel to generate those points. The only restriction imposed was that generated numbers stayed between 0 and 100.

knowledge that all participants saw the same value of the underlying in each period. Also, the value of the underlying in each period was the same in all sessions of the same treatment.[10]

As in a continuous double auction, participants could buy or sell the 4 options in separate markets. We explained to the participants the concept of an option, and the concepts of an out-of-the money and in-the-money option. The payoff was thus calculated: the number of points that participants had in the last round, plus the proceeds from exercising the in-the-money options. The out-of-the-money options were worthless. The participants were also informed that there was no compensation for any of the questionnaires they completed. We explained that the "moneyness" of the options the participants carried to the last period was determined by the value of the underlying in the last period (round 13).

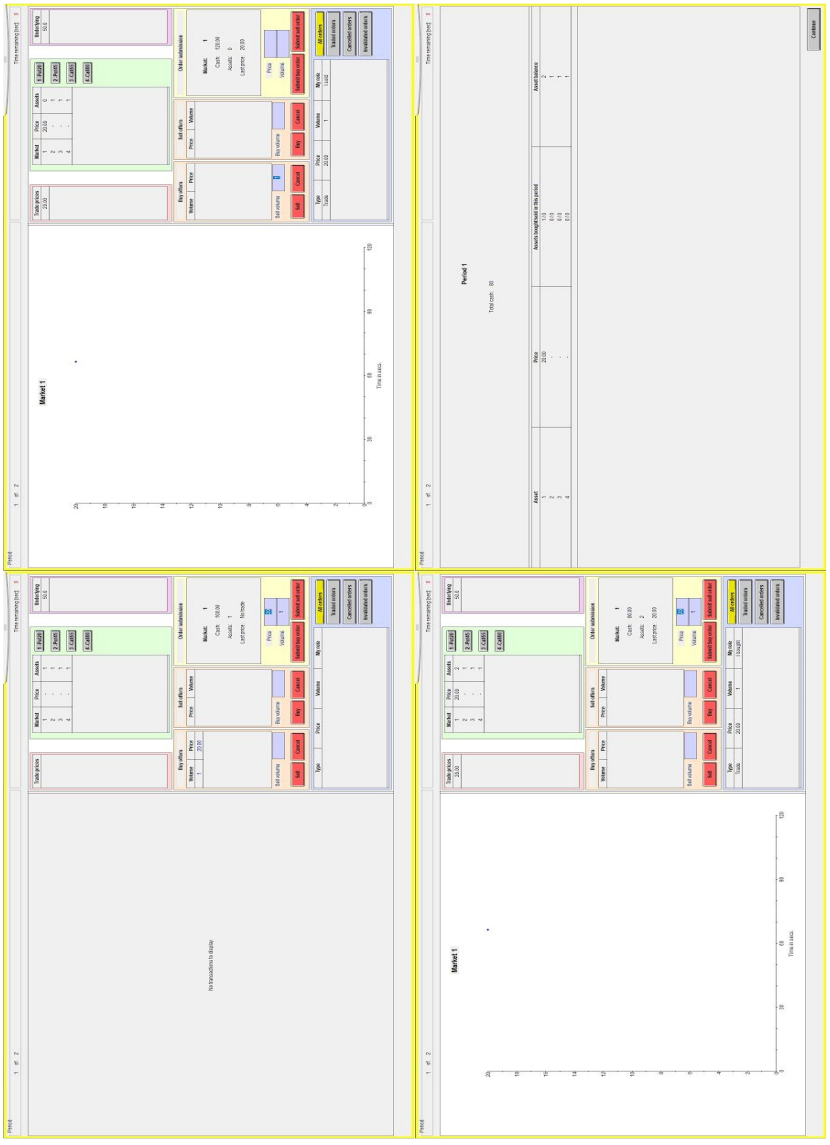
After reading the instructions, the participants were shown a video. This video introduced the participants to the asset trading platform. It also showed how to go from one market to another. The video was introduced in response to a common concern in pilot sessions that the participants started the experiment without any acquaintance with the trading platform. Participants then completed a comprehension test, which was individually checked by the experimenter. Questions were privately answered by the experimenter.

The trading then started. The trading was conducted through The Graz-Innsbruck Market System (GIMS), a platform for (multiple) asset market experiments in zTree (Fischbacher, 2007; Palan, 2017). We tailored the platform to an experiment in which rights to buy and sell an asset were traded, rather than the assets themselves being traded. The changes introduced in the software were, however, minimal, in an effort to ensure easy replicability of our results through the GIMS platform. We translated the messages and most of the "transition screens" in the local language. Just before the trading started, the participants completed a Holt and Laury task (coded in GIMS), to capture their levels of risk aversion. Because we intend to conduct the study in different countries, the trading screen was kept in English. Several screenshots of the trading

[10] Operationally, we placed the values of the underlying in a spreadsheet, which was read by GIMS. The same spreadsheet was used for all sessions of the same treatment.

platform are provided in Figure 2. In the example shown, a transaction in market 1 (the market for the put option with strike price of 20 points, Put20) was concluded at a price of 20. The value of the underlying asset in each period is shown in the top right corner.

Figure 4: the trading platform



The platform shows in real time the transactions concluded/open for each participant, as well as the average trading price in each of the four markets. In the left-hand side of the screen, subjects were shown in each trading period the evolution of the prices in each market. GIMS also gives the participants the ability to cancel their orders. A summary of all buy/sell/invalidated orders is shown to the participants in the bottom of the screen.

Participants could submit sell orders as they pleased in terms of price, but were constrained by the number of assets they possessed. In terms of buy orders, the participants could try to buy any number of assets at any price, as long as they were able to afford buying the entire "portfolio" (composed of several assets of the same type, i.e. 2 puts with strike price of 20). In response to buy orders of multiples units, sellers could chose to sell as many units as they wished, in accordance with their endowment of options. The same happened for buy orders of multiples units. The rules for submitting sell and buy orders were the customary ones: sell orders had to be descending in terms of the lowest outstanding sell order price; buy orders had to be ascending in terms of the highest outstanding buy order price. Borrowing or lending was not allowed. At the end of each trading period, the system showed the cash and the options holdings of each participant.

After the feedback stage of period 12, the platform showed the value of the underlying in period 13, which determined the moneyness of the options held by each participant, and the final payoff.

The participants then completed several questionnaires. In order: 5 questions of the financial literacy test incorporated in GIMS; the STAI-State and the VAS-A questionnaires (in paper and pencil); the questionnaire provided as part of the GIMS package, which contains standard socio-demographic questions, some questions related to the risk attitudes of the participants (such as smoking habits), the possibility to leave feedback to the experimenter, information on the mistakes participants might have made. Participants were then privately paid their earnings in gift cards of FNAC, a large retailer that sells, among other things, music items, electronics and books. Earning were rounded up to multiples of 5 euros.

Market 1, where the put option with strike price of 20 was traded, given the value of the underlying in period 1 (50 in the RISK treatment, and 57 in the AMBIGUITY treatment), was the market for the "out of the money" option. It is therefore the market that is most interesting for the purposes of the present inquiry. To gain insights into the demand and supply for this specific option, we introduced some alternative possibilities for trading, hence the other three markets.

Our working hypotheses are that: (i) the volume traded and price for the Put20 exceeds the volumes and prices of other assets. Stress and ambiguity result in higher prices and volumes for the Put20; (ii) female participants have a greater demand for Put20, due to higher risk aversion.

4. Results

We recruited 80 subjects, all undergraduate and graduate students of Católica Porto Business School in Porto (Portugal). No participant took part more than once in our study. Subjects received a 5 euros show-up fee, plus their earnings from the trading in the options markets. Sessions lasted on average 1h45m. The average payment, taking into account the rounding of the vouchers to multiples of 5 euros, was 18 euros, including the show-up fee. The exchange rate was set at ten euro-cents for one experimental point. The subjects started the game, as mentioned in the previous section, with 100 experimental points (10 euros), and one option of each type. Figure 5 shows the median price across sessions in each market, and in every trading period, for our RISK treatment. In the market for the Put20 a slight negative trend is visible, but the price appears to be quite stable. The price dynamics in the other four markets shows no clear pattern, and a high degree of experimentation on the side of the participants. Figure 6 shows the same variable for the AMBIGUITY sessions. Again in the market for the Put20 a slight negative trend is visible. Negative trends are now visible also in the market for the Put45 and the Call55. No clear pattern is visible in the market for the Call80.

Figure 5: Median prices, RISK treatment

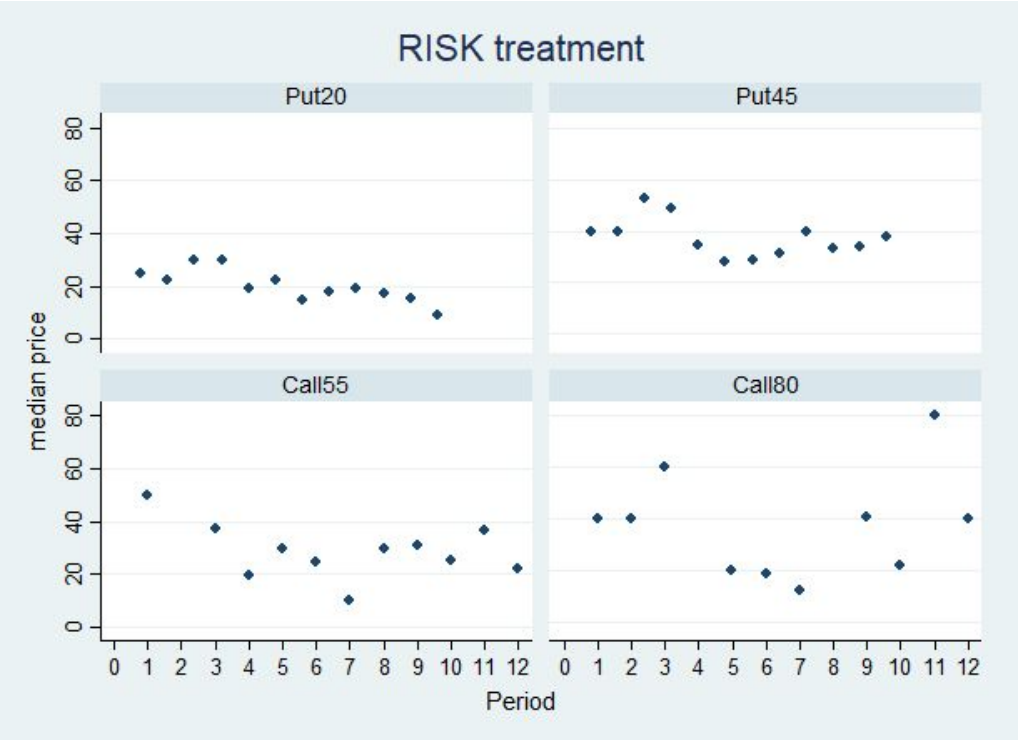


Figure 6: Median prices, AMBIGUITY treatment

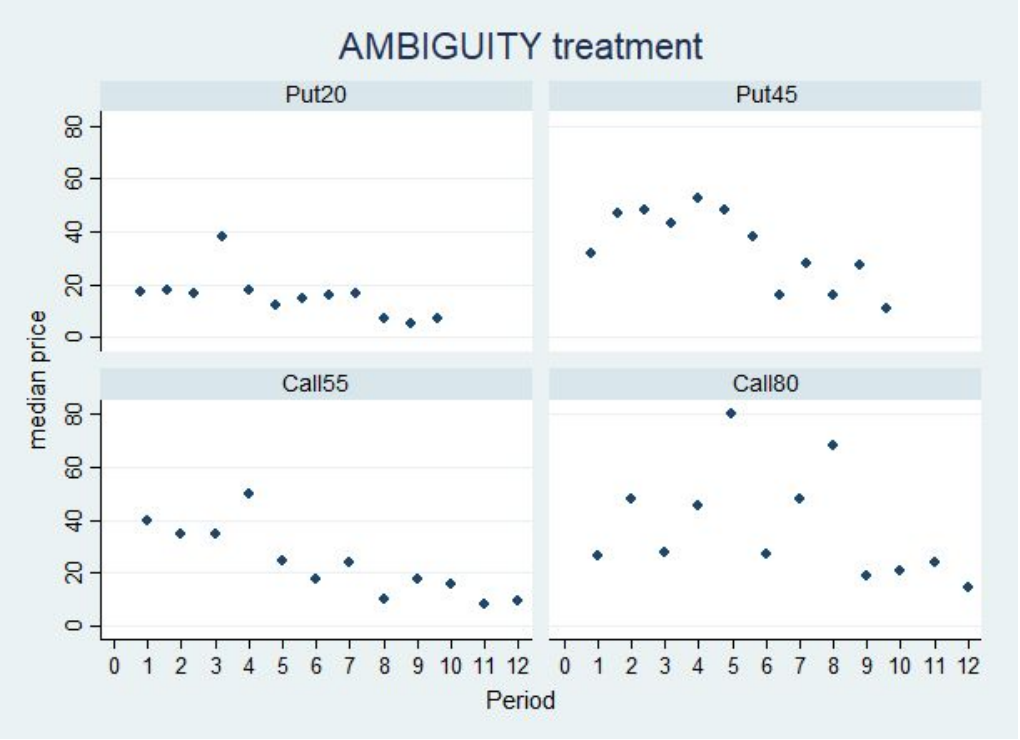


Figure 7: Median volume traded, RISK treatment

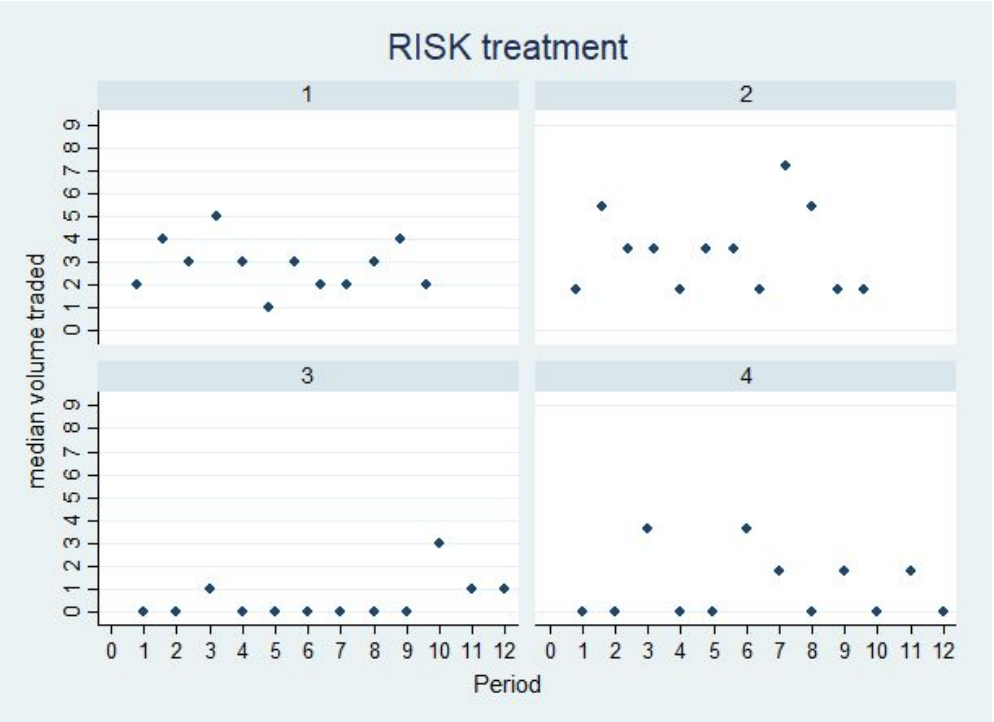


Figure 8: Median volume traded, AMBIGUITY treatment

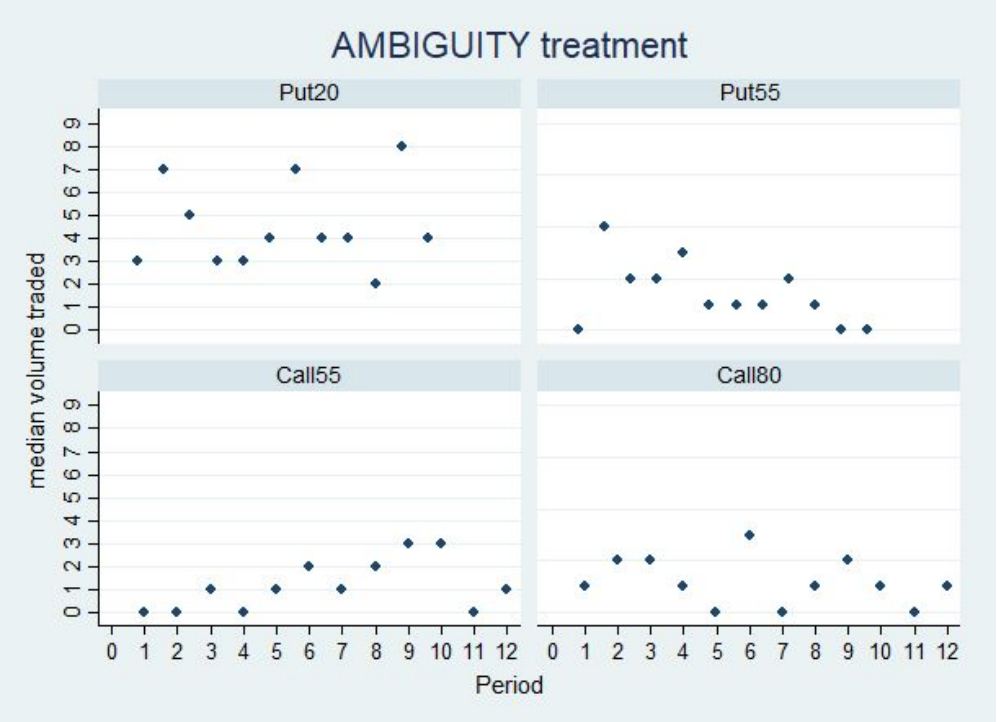


Figure 7 shows the median number of assets traded in each market, in each period, for the RISK treatment. No clear pattern is visible in the market for the Put20 which, together with the other put option, appears to be the market with the highest level of activity. Trading volumes in the market for the Call55 appear modest. Figure 8 shows the same variable for the AMBIGUITY sessions. No clear pattern is visible. The Put20 appears again the most traded asset.

Tables 1 and 2 show descriptive statistics for the median prices and volumes traded in each market, pooling observations from the two treatments together. Regarding the prices, we set the value of the median price to missing whenever no transaction was concluded in a particular round and market. In those cases there was in fact no price for the asset, resulting either from the lack of of buy/sell orders, or from a lack of "coincidence of wants," i.e. in a particular round the reservation prices of the sellers exceeded the reservation prices of the buyers. In all those sessions in which no transaction was concluded, we set the volume traded to zero. This explains the different number of observations in the two tables[11]. The two most valued assets, according to Table 1, are the Put45 and the Call80. As already hinted by the number of observations for these two markets, these were, however, the less active ones. Table 2 shows that the market for the Put20 was, by far, the most active one, with volumes that are roughly the double of those in the other markets.

Table 1: summary statistics (across rounds and the two treatments) for the median price in each market

Median prices	Obs	Mean	Std. Dev.	Min	Max
Put 20	70	17.87143	7.911048	0	40
Put 45	57	26.41167	9.969024	7	49
Call55	40	24.5375	11.42612	5.5	50
Call 80	41	26.17073	18.34448	6	85

[11] The number of observations for the variable volume is 72, thus obtained: 7 sessions*12 rounds.

Table 2: summary statistics (across rounds and the two treatments) for the volume traded in each market

Volume	Obs	Mean	Std. Dev.	Min	Max
Put20	72	3.722222	2.278016	0	10
Put45	72	1.916667	1.75828	0	8
Call55	72	1.194444	1.478855	0	6
Call80	72	1.027778	1.150287	0	4

A nonparametric test on the median number of volumes traded in the 4 markets (pooling observations from the two treatments) finds significant differences (Pearson chi2(3) = 59.6015 Pr = 0.000). A Jonckheere-Terpstra Test for Ordered Alternatives also finds that volumes decrease as we go from Market 1 to Market 4 (Pr(Z > J*) = 0.0000). A two-sample Wilcoxon rank-sum (Mann-Whitney) test on the volumes traded in market 1 only, in the two treatments, finds marginally significant differences across the two treatments (z = 1.986, Prob > |z| = 0.0470).

A nonparametric test on the median of the median prices in the 4 markets (pooling observations from the two treatments), finds significant differences (Pearson chi2(3) = 24.6574 Pr = 0.000). A Jonckheere-Terpstra Test for Ordered Alternatives finds that median prices increase as we go from Market 1 to Market 4 (Pr(Z < J*) = 0.0010). A two-sample Wilcoxon rank-sum (Mann-Whitney) test on the median price in market 1 only, in the two treatments, finds significant differences across the two treatments (z = -2.177, Prob > |z| = 0.0295). Given the small sample size at this point of our inquiry, we do not make a final call regarding the effect of the different information that was provided regarding the path of the underlying asset (risk vs. ambiguity). So far we have only been looking at concluded deals. There, were, however, many buy and sell orders that were not concluded. Concentrating on the most active, and most interesting, market, i.e. the market for the Put20, we construct a panel in which, for every round we sum the number of buy and sell orders of each participant.

5. Discussion

TBA

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