Supporting Online Material for

How psychological framing affects economic market prices in the lab and field

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S1: Study 1: Short Lab Experiment

1.1. Instructions for the Experiment "Stock Market in the Laboratory" (translated from German; original German Instructions available from the Authors)

Welcome to this experiment and thank you very much for taking the time to support our research.

Your task for approximately the next two hours will be to trade assets on a computer based trading system.

Before starting the experiment, we would like to familiarize you with the experiment and how the trading software that you will use works.

Therefore we would like to fully explain the three following questions:

- What will be traded?
- How does the trading system work?
- How will you be paid?

In studies like this one it is standard to provide the participants with written instructions and to go through them together, in order to guarantee that every group has exactly the same information about how the experiment works. Please keep general questions until the end of the introduction, as they may be answered during the following explanations. Although if there is something which you do not understand at all, please ask the people in charge, so that they can explain the point in further detail.

1. What will be traded?

In this experiment you will trade very simple assets which you can probably better imagine as bets on the occurrence of a certain future event (e.g. „Germany will be European Soccer Champion 2008“). Depending on whether the event occurs or not the asset will pay the owner either 100 or 0 monetary units (MU). Due to the fact that the outcome of the event is uncertain during the trading period, the price usually varies between the two extremes.

In a market you can always trade three assets simultaneously which all depend on the same basic event. At the end of the event, only one of the three assets will pay 100 MU. To clarify this, we will give you an example which will also be used later in a practice trading round:

Example. The uncertain future event is what share of votes the SPD party will receive in the next election of the German “Bundestag“. The three assets relating to this event can be described in the following way:

Asset 1: SPD.[0-29.9]	This asset will pay exactly 100 MU if the SPD share of votes is smaller than 30.0 % or will expire worthless otherwise. The final outcome for this, and the following assets, is based on all valid secondary votes (indirect votes for the party), which is determined by the “Bundeswahlleiter.”

Asset 2: SPD.[30.0-34.9]	This asset will pay exactly 100 MU if the SPD share of votes is between 30.0 % and 34.9 % or will expire worthless otherwise.

Asset 3: SPD.[35.0+]	This asset will pay exactly 100 MU if the SPD share of votes is equal to or more than 35.0 % or will expire worthless otherwise.

Please note that after the election of the German “Bundestag” only one out of the three assets will pay 100 MU, while the other two assets will expire worthless (since the intervals cover every possible outcome of the event, but at the same time do not overlap).

Before you start trading you should think about how much you are willing to pay for these assets and for how much you are willing to sell them for in the market. Trading will only occur between the participants of each experimental session. There are no external and/or computer-controlled participants in the market (one small exemption is the unit-portfolio, which will be explained later). Transaction costs do not exist for these assets.

During the experiment you will not trade assets on political events, but on events concerning financial markets, weather and sports. The order in which you will deal with these three topics will be determined randomly and varies for each group.

Furthermore, for each topic the groups will not trade the exact same three assets, since there are two different partitions (i.e. subset of assets), which will be assigned to your experiment session randomly. In order to guarantee that each participant has the same information, the following table shows all groups of three assets used in this study (even those that you will not be dealing with) including an accurate description of the payment conditions.

Financial markets ---- Event: DAX-closing in 2 weeks		
Asset definition: An asset will pay 100 cents, if the outcome of the underlying event exactly fits the definition of the asset. The other two assets will expire worthless. Relevant for the payment of the assets in the financial markets domain is the Xetra-DAX closing (incl. final auction) in two weeks from today (i.e., on May 8, 2007). Xetra-DAX closing as of April 23, 2007 was 7335.62.		
	Partition 1	Partition 2
Asset 1	DAX.[0 - 7248.99]	DAX.[0 - 7415.99]
Asset 2	DAX.[7249 - 7415.99]	DAX.[7416 - 7563.99]
Asset 3	DAX.[7416+]	DAX.[7564+]

Weather ---- Event: Maximum Temperature in Münster at the end of May		
Asset definition: An asset will pay 100 cents, if the outcome of the underlying event exactly fits the definition of the asset. The other two assets will expire worthless. Relevant for the payment of the assets in the weather domain is the maximum temperature two meters above ground-level (abbreviation: TX) at the weather center Muenster/Osnabrueck (station no.: 10315) on May 31st, 2007 in degrees Celsius determined by Germany's National Meteorological Service ("Deutscher Wetterdienst").		
	Partition 1	Partition 2
Asset 1	Temp.[up to 15.9]	Temp.[up to 19.9]
Asset 2	Temp.[16.0 - 19.9]	Temp.[20.0 - 23.9]
Asset 3	Temp.[20.0+]	Temp.[24.0+]

Sports ---- Event: Total number of goals scored on the 34th game day of German 1. Bundesliga (Season 2006/2007)		
Asset definition: An asset will pay 100 cents, if the outcome of the underlying event exactly fits the definition of the asset. The other two assets will expire worthless. Relevant for the payment of the assets in the sports domain is the total number of goals scored on the final game day of German 1. Bundesliga in the season 2006/2007 (soccer/men).		
	Partition 1	Partition 2
Asset 1	Goals.[0 - 20]	Goals.[0 - 25]
Asset 2	Goals.[21 - 25]	Goals.[26 - 30]
Asset 3	Goals.[26+]	Goals.[31+]

At the beginning of each trading round, you will receive an initial endowment of 2000 MU, which partly consists of assets and partly consists of cash. If you spend all your liquid funds or sell all your assets, you are not able to buy or sell any more; i.e. debts or short selling are not permitted. However, in order to obtain liquidity in cash or assets you can use a so called "unit-portfolio", which will be explained in the next paragraph.

Unit-portfolio („Unit-PF“)

The unit-portfolio is based on the idea that a full set—consisting of all 3 assets of one event—will always lead to a certain payment of 100 MU. This is independent of the outcome of the uncertain event, since one of the assets will always pay an amount of 100 MU, while the other two assets will expire worthless.

Therefore the person in charge of the experiment changes 100 MU for a complete set of assets at any time during the experiment. This trade takes place via the so called unit-portfolio, which can be bought or sold like the other assets via the trading system. However, the trading partner for this kind of deal is always the person in charge of the experiment and the price is fixed at 100 MU, i.e. it does not depend on bids and asks. In particular it should be clear that this deal does not depend upon the value of a single asset, but the fact that all 3 assets combined represent a certain payment of 100 MU. To clarify this, we return to our example. If you buy one “unit-PF”, one asset of each of the available assets is added to your portfolio. Thus, exactly one asset of type SPD.[0-29.9], one asset of SPD.[30.0-34.9] as well as one asset of type SPD.[35.0+] will be added, while your cash balance will be lowered by 100 MU. After the purchase of the „unit-PF“, you are able to trade and sell these assets in the market independently.

By selling a “unit-PF”, 100 MU will be added to your account, while simultaneously your portfolio will be reduced by one of each type of asset (of course, this sale is only permitted if you own at least one asset of each type). Hence, by using the “unit-PF” you can either acquire liquidity in assets, if you have enough cash or liquidity in cash, as long as you own a positive quantity of all types of assets.

In addition, by using the “unit-PF” you can exploit arbitrage opportunities in the market more directly. Arbitrage means completing a transaction, which results in a sure profit.

Arbitrage opportunity 1. If the market prices for individual assets enable you to purchase a complete set of assets for less than 100 MU, you can obtain a certain profit by buying these 3 assets for less than 100 MU and selling them via the “unit-PF” for 100 MU to the person in charge of the experiment.

Arbitrage opportunity 2. Alternatively, you can obtain a certain profit, if it is possible to sell the 3 assets individually in the market for more than 100 MU. Then you can purchase a complete set of assets via the “unit-PF” for 100 MU and sell them in the market as individual assets for a higher price afterwards.

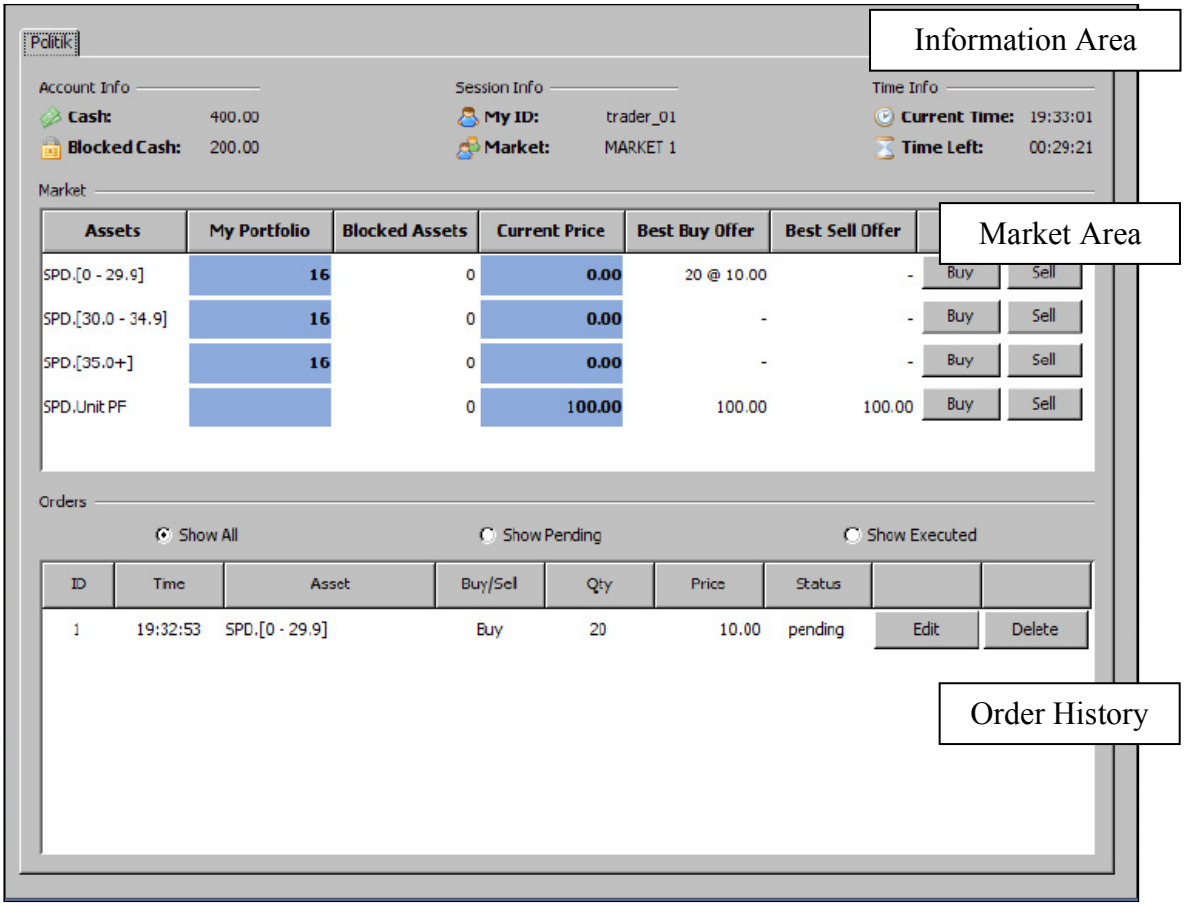
Such arbitrage opportunities are not excluded by the trading system automatically. Therefore, you should be aware that arbitrage may be possible!

2. How does the trading system work?

The trading system is a so called continuous double auction, i.e. at any time during the trading round you can act as buyer or seller. After a test trading phase you will trade a total of 6 rounds, each of 10 min. Each scenario appears twice, so you will deal with 3 different scenarios in total.

We will now explain the trading software in detail.

Trading screen



The trading screen is divided into three areas:

1. “Information Area“:

In this area you can find “account info”, “session info” and “time info”. The “account info” shows information on your cash balance and blocked cash which will be explained in more detail later on.

2. “Market Area“:

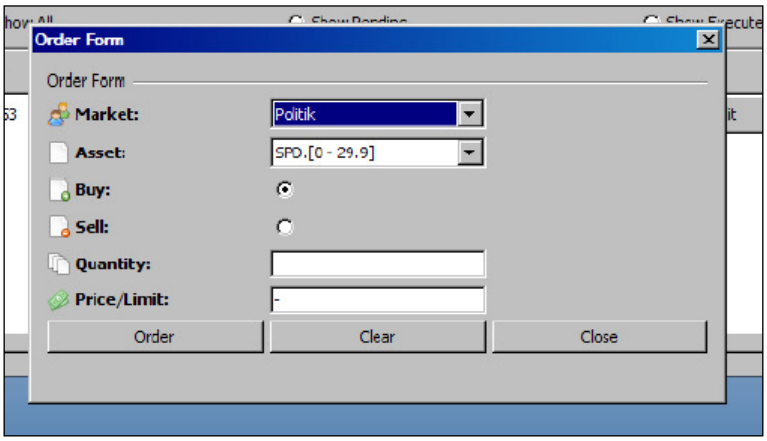
This area gives an overview about the tradable assets, your own portfolio, blocked assets, the recent market price (“current price”) and the best (highest) buy and the best (lowest) sell quote. The best buy order (sell order) indicates the volume and the price limit of the highest buy order (lowest sell order) at present, separated by an “@” symbol. For example, the display “20 @ 10” means, that one or more traders are ready to buy a quantity of 20 assets SPD.[0 - 29.9] at a price of 10 MU each.

3. “Order History”:

This area shows all of your orders which are pending or executed (currently there is a quantity of 1 order in the system). By pushing the “delete” button an outstanding order will be deleted. Using the “edit” button means all data regarding this order will be transferred into the “edit form” which subsequently appears.

Order placement

You can place an order by pushing one of the “buy”/”sell” buttons in the market area. Thereupon the “order form” appears:



You can complete your order by adding/modifying how many assets you would like to trade and for which price limit. By pushing the “clear” button you will delete all values previously entered, by pushing the “order” button you will confirm your order and it will be processed by the system (“order accepted”).

The “order form” remains active until you press the “close” button. While the “order form” is still active you can configure and submit further buy or sell orders.

After confirming your order, it will be processed by the system. When trading, this can last for 1-2 seconds. Your trading screen will be blocked during this time.

Regarding order placement, you should pay particular attention to the following two error messages:

Error “not enough cash” and error “short selling restriction”:

These error messages will appear, if you:

1. do not possess enough cash and/or if you have already placed too many active buy orders (“not enough cash”), or, if you

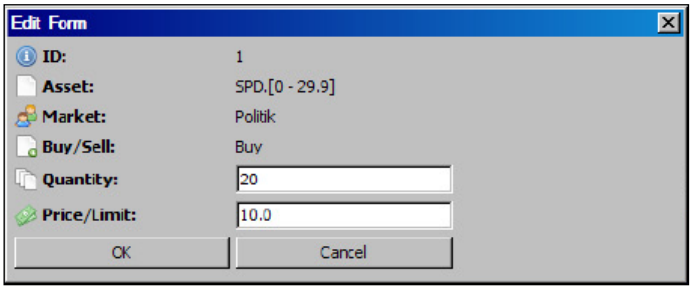
2. do not possess enough assets and/or if you have placed too many active sell orders (“short selling restriction”).

This is because any order placed will block your cash or assets until the orders are executed or cancelled. Blocked cash will be shown in the "account info", blocked assets will be displayed in the associated column of the market area. This prevents you from placing orders which cannot be executed. Current orders can be cancelled or edited anytime, in order to access the blocked cash/assets again.

In addition, the error message "*do not trade with yourself*" may occur. This happens if you try to place a buy and a sell order for the same asset simultaneously and if the limit price of the buy order is the same or higher than the limit price of your own sell order.

Order editing and cancelling

Orders not yet executed can be cancelled and edited anytime, in order to do this; pick a current order, which is marked as "pending" in the section "orders", and push one of the related buttons "edit" or "delete" which correspond to this order. "Delete" immediately deletes the order from the system, "edit" removes the order from the system as well, but at the same time inserts the data into the "edit form" that appears:



In this "edit form" you can modify the quantity and the limit price of your order. By pressing "OK" the modified order will be placed to the trading system, by pressing "cancel" the original order will be placed to the system again.

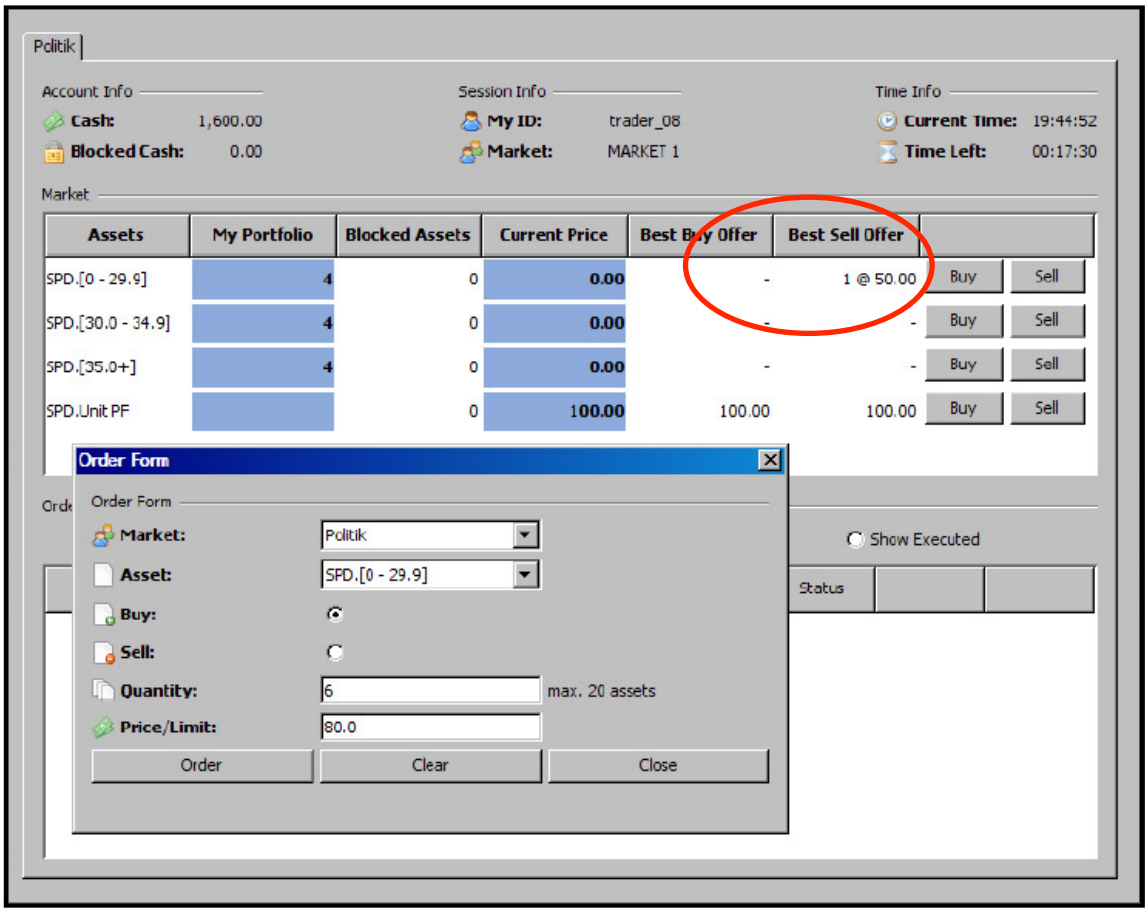
Order execution

As previously mentioned, the trading system is based on a continuous double auction. Two orders will be executed against each other simultaneously, only if the buy order has the same or a higher price limit as the corresponding sell order. Please look at the following order book, i.e. the data sheet of current buy and sell orders, which are entered into the system but not yet executed:

buy order	***sell order***
	1 @ 60 MU
	1 @ 56 MU
	1 @ 50 MU
-none entered-	

Assume you would like to buy assets and enter a buy order "6 @ 80" MU into the trading system, i.e. you are willing to buy a quantity of 6 assets with a price limit of 80 MU each.

You definitely know that you are going to buy 1 asset as you can see on your “trading screen” that a quantity of 1 asset is offered at a price of 50 MU in the market (best sell order).



The remaining part of the order book is not visible on the trading screen. Due to the fact that you are willing to pay up to 80 MU per asset, you will buy a quantity of 3 assets in total (see order book).

Politik

Account Info
Cash: 1,434.00
Blocked Cash: 240.00

Session Info
My ID: trader_08
Market: MARKET 1

Time Info
Current Time: 19:47:50
Time Left: 00:14:32

Market

Assets	My Portfolio	Blocked Assets	Current Price	Best Buy Offer	Best Sell Offer		
SPD.[0 - 29.9]	7	0	60.00	3 @ 80.00	-	Buy	Sell
SPD.[30.0 - 34.9]	4	0	0.00	-	-	Buy	Sell
SPD.[35.0+]	4	0	0.00	-	-	Buy	Sell
SPD.Unit PF		0	100.00	100.00	100.00	Buy	Sell

Orders

Show All Show Pending Show Executed

ID	Time	Asset	Buy/Sell	Qty	Price	Status		
13	19:47:43	SPD.[0 - 29.9]	Buy	3	80.00	pending	Edit	Delete
8	19:47:42	SPD.[0 - 29.9]	Buy	1	50.00	executed		
10	19:47:42	SPD.[0 - 29.9]	Buy	1	56.00	executed		
12	19:47:42	SPD.[0 - 29.9]	Buy	1	60.00	executed		

Important: Your original order quantity of 6 has been split up, so that 3 orders, each consisting of 1 asset, have been completed, while one order of 3 assets remains in the trading system. The price which is shown in the "price" column is your limit price (for the pending order) or the trading price (for the executed orders).

The part of your order which was not yet executed (3 @ 80) now appears as the best buy offer in the order book. Therefore, an amount of 240 MU was blocked and is displayed as "blocked cash" in your "account info".

If two orders can be executed against each other, the transaction will always take place at the price limit of the previously requested buy or sell order (time priority).

3. How will you be paid?

To encourage you to carefully think about your decisions, your compensation/payment will be incentive-compatible. This means, your trading performance (as well as a little bit of luck) will determine your payment.

For each experimental group we will randomly select one out of the six trading rounds and use this as the basis for your payment. For this round we will determine the value of your portfolio and add it to your cash balance (to decide which asset will pay 100 MU and which assets will be worthless, we have to wait until the relevant uncertainty (financial markets, weather, or sports) is resolved).

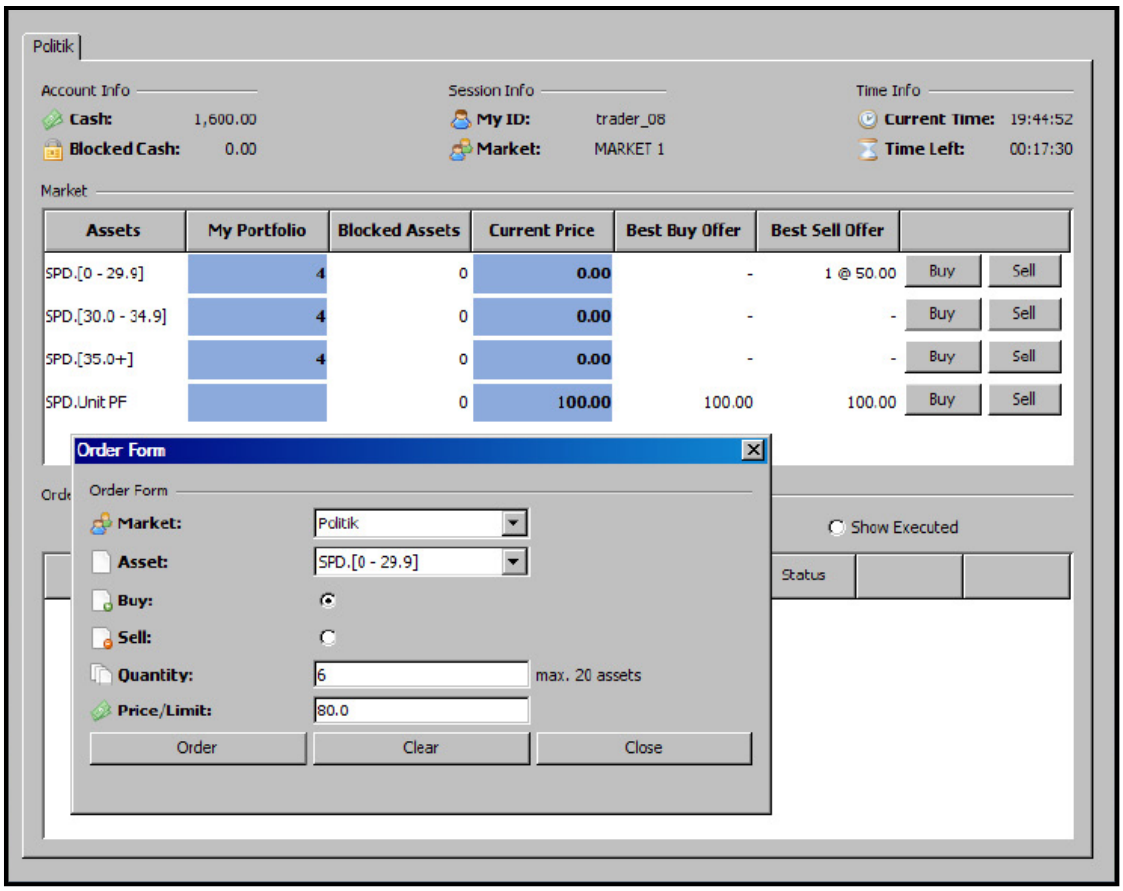
The total value of your portfolio will be divided by 100 and equals your payment in Euro!

We will inform you by e-mail about how much you earned. At a later date, you will be able to pick up your money from room 263 during office hours (daily 10 till 12) and you will need to bring identification (student ID, identity card, etc.).

Good luck!

1.2. SCREENSHOT AND FURTHER INFORMATION ON THE TRADING SOFTWARE

The trading software was exclusively developed for the study. It is based on Java Runtime Environment technology and was set up on a web-based client-server structure. The graphical user interface (GUI) was divided into three areas: information area, market area and order history (see screenshot below). Participants could submit, edit or cancel buy or sell orders via an order form. Orders were processed and executed by the system within split seconds; the trading screen was updated real-time.



1.3. TRADING VOLUME IN STUDY 1

	No. of trades per market			Average No. of assets per trade			Total assets traded per market		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Finance	21	43.08	62	1.93	3.37	5.42	81	144.17	284
Sports	25	44.00	66	2.07	3.31	4.37	78	143.92	210
Weather	26	41.40	64	2.31	3.49	5.90	85	143.48	242
All	21	42.83	66	1.93	3.39	5.90	78	143.85	284

1.4. MEAN PRE-TRADING INDIVIDUAL PROBABILITY JUDGMENTS.

Probability judgments are surveyed before the first trading round of the finance, sports and weather event domains. Partition dependence (PD) difference is defined as $p(I_1) + p(I_2) - p(I_1 \cup I_2)$ and $p(I_3) + p(I_4) - p(I_3 \cup I_4)$, respectively.

Treatment	Pre-Trading Individual Judgment	Event Domain		
		Finance ($N_1 = N_2 = 96$)	Sports ($N_1 = N_2 = 96$)	Weather ($N_1 = N_2 = 95$)
		Mean	Mean	Mean
1	$p(I_1)$	0.219	0.279	0.144
1	$p(I_2)$	0.497	0.398	0.333
	$p(I_1)+p(I_2)$	0.717	0.678	0.477
2	$p(I_1 \cup I_2)$	0.405	0.417	0.199
	PD difference	*0.312*	*0.261*	*0.278*
2	$p(I_3)$	0.397	0.378	0.349
2	$p(I_4)$	0.198	0.205	0.451
	$p(I_3)+p(I_4)$	0.595	0.583	0.801
1	$p(I_3 \cup I_4)$	0.283	0.322	0.523
	PD difference	*0.312*	*0.261*	*0.278*

All reported differences are statistically highly significant (Kruskal-Wallis test, $p<.0001$).

1.5. MEAN EQUILIBRIUM PRICES (2ND TRADING ROUND) AND INDIVIDUAL JUDGMENTS (POST-TRADING) FOR THE FINANCE, SPORTS AND WEATHER EVENT DOMAINS

Treatment		Mean Judged Probability/Equilibrium Prices					
		Finance		Sports		Weather	
		Equilibrium Market Prices (Round 2)	Post-Trading Individual Judgment	Equilibrium Market Prices (Round 2)	Post-Trading Individual Judgment	Equilibrium Market Prices (Round 2)	Post-Trading Individual Judgment
1	I_1	0.152	0.205	0.230	0.252	0.048	0.116
1	I_2	0.561	0.494	0.490	0.432	0.256	0.307
	$I_1 + I_2$	0.713	0.699	0.720	0.684	0.303	0.422
2	$I_1 \cup I_2$	0.424	0.442	0.439	0.428	0.149	0.196
	PD difference	*0.289*	*0.257*	*0.281*	*0.256*	*0.154*	*0.226*
	(Pre-Trading Judgm.)		*(0.312)*		*(0.261)*		*(0.278)*
2	I_3	0.404	0.382	0.416	0.403	0.354	0.352
2	I_4	0.177	0.176	0.152	0.169	0.496	0.452
	$I_3 + I_4$	0.581	0.558	0.568	0.572	0.850	0.804
1	$I_3 \cup I_4$	0.336	0.301	0.391	0.316	0.707	0.578
	PD difference	*0.245*	*0.257*	*0.177*	*0.256*	*0.143*	*0.226*
	(Pre-Trading Judgm.)		*(0.312)*		*(0.261)*		*(0.278)*

1.6. MEDIAN EQUILIBRIUM PRICES (2ND TRADING ROUND) AND INDIVIDUAL JUDGMENTS (PRE-TRADING AND POST-TRADING)

Median values to be compared with the mean values in Tables in sections 1.4. and 1.5. of SOM. The comparison is useful for checking whether means are influenced by a modest number of subjects.

Treatment		Median Judged Probability/Equilibrium Prices								
		Finance			Sports			Weather		
		Pre-Trading Individual Judgment	Equilibrium Market Prices (Round 2)	Post-Trading Individual Judgment	Pre-Trading Individual Judgment	Equilibrium Market Prices (Round 2)	Post-Trading Individual Judgment	Pre-Trading Individual Judgment	Equilibrium Market Prices (Round 2)	Post-Trading Individual Judgment
1	I_1	0.200	0.129	0.200	0.250	0.244	0.250	0.120	0.051	0.100
1	I_2	0.500	0.563	0.500	0.400	0.469	0.400	0.320	0.244	0.300
	I_1+I_2	0.700	0.714	0.700	0.700	0.716	0.700	0.500	0.271	0.400
2	$I_1 \cup I_2$	0.400	0.453	0.400	0.400	0.422	0.400	0.200	0.130	0.200
	PD difference	*0.300*	*0.261*	*0.300*	*0.300*	*0.294*	*0.300*	*0.300*	*0.141*	*0.200*
2	I_3	0.400	0.417	0.400	0.360	0.385	0.400	0.350	0.361	0.350
2	I_4	0.200	0.177	0.160	0.200	0.149	0.150	0.400	0.474	0.400
	I_3+I_4	0.600	0.570	0.600	0.600	0.553	0.600	0.800	0.842	0.800
1	$I_3 \cup I_4$	0.300	0.358	0.300	0.300	0.414	0.300	0.500	0.690	0.600
	PD difference	*0.300*	*0.212*	*0.300*	*0.300*	*0.139*	*0.300*	*0.300*	*0.152*	*0.200*

1.7. ARBITRAGE OPPORTUNITIES IN STUDY 1

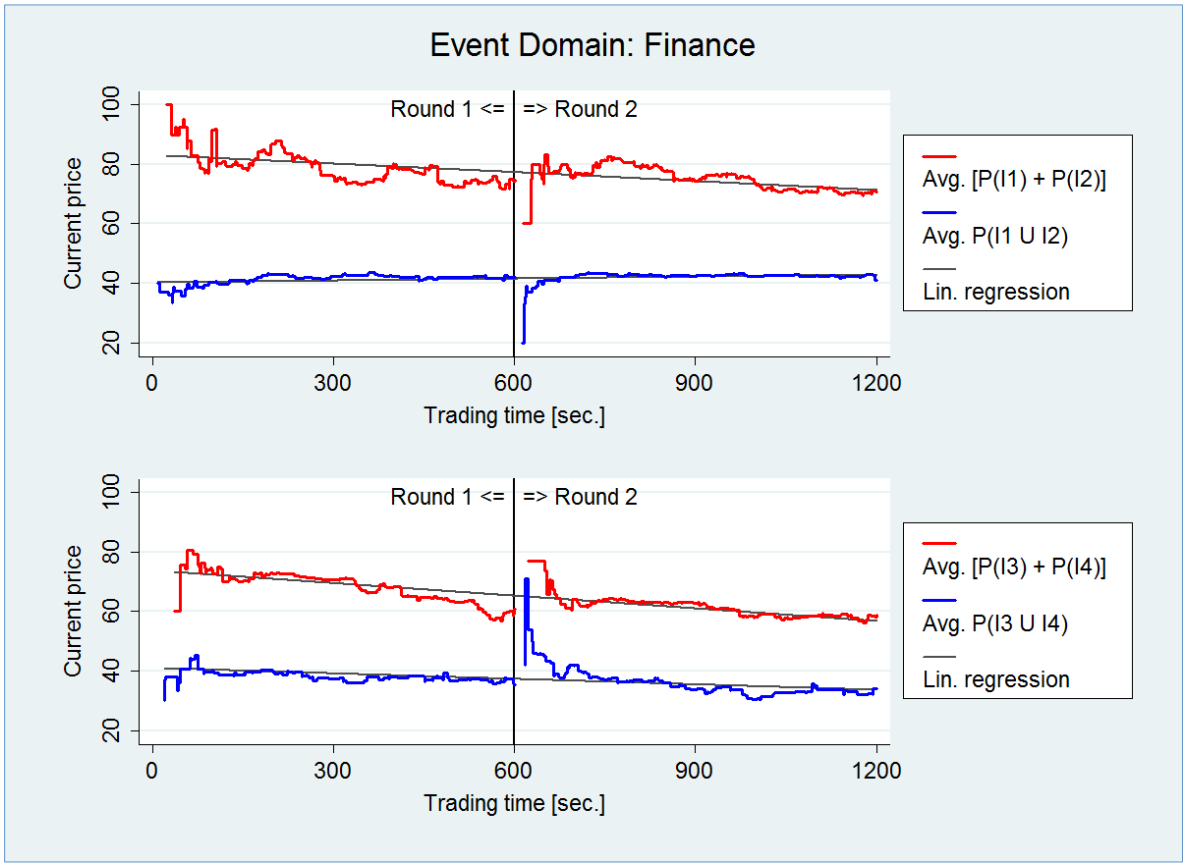
Summary statistics on bid arbitrage opportunities:

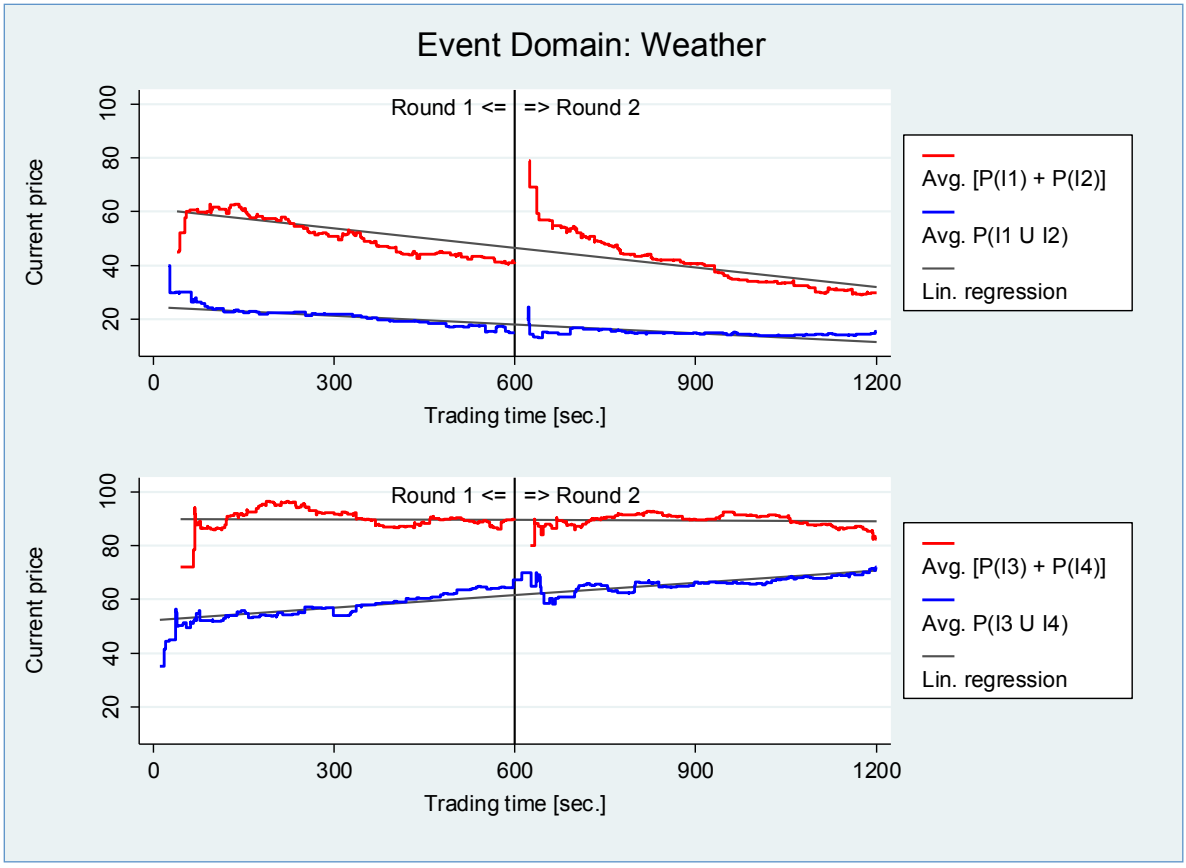
	Bid Arbitrage											
	Trading Round 1				Trading Round 2				Total			
Panel A: No. of markets (10-min. trading round) with no arbitrage opportunities (N=144 trading rounds)												
Finance	3				3				6			
Sports	3				2				5			
Weather	2				7				9			
Total	8				12				20			
Panel B: Total arbitrage period [seconds] per market (10-min. trading round), (N=144 trading rounds)												
	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.
Finance	0.00	47.30	84.01	296.11	0.00	37.36	70.46	305.72	0.00	37.36	77.24	305.72
Sports	0.00	72.87	85.25	210.18	0.00	59.68	75.20	230.82	0.00	62.63	80.22	230.82
Weather	0.00	50.90	82.71	436.26	0.00	46.02	75.24	375.25	0.00	48.93	78.98	436.26
Total	0.00	55.40	83.99	436.26	0.00	46.87	73.64	375.25	0.00	50.71	78.81	436.26
Panel C: Time period [seconds] until exploitation												
	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.
Finance	1.16	15.46	26.88	141.87	1.07	8.43	21.14	208.87	1.07	12.13	23.92	208.87
Sports	1.22	16.18	29.65	133.64	1.05	12.42	19.00	126.36	1.05	12.75	23.48	133.64
Weather	1.23	9.95	28.77	369.73	1.00	12.59	24.74	188.38	1.00	11.45	26.70	369.73
Total	1.16	12.84	28.39	369.73	1.00	11.45	21.38	208.87	1.00	12.24	24.62	369.73
Panel D: Time-weighted amount [cents] per arbitrage occurrence (N=461 occurences)												
	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.
Finance	0.49	5.60	11.85	119.00	0.25	3.03	6.77	50.00	0.25	5.00	9.22	119.00
Sports	0.62	8.38	10.54	44.99	0.01	2.55	5.21	51.00	0.01	4.44	7.45	51.00
Weather	0.05	5.00	6.94	33.00	0.62	3.00	3.77	15.40	0.05	3.91	5.31	33.00
Total	0.05	5.60	9.84	119.00	0.01	3.00	5.29	51.00	0.01	4.10	7.39	119.00

Summary statistics on ask arbitrage opportunities:

	Ask Arbitrage											
	Trading Round 1				Trading Round 2				Total			
Panel A: No. of markets (10-min. trading round) with no arbitrage opportunities (N=144 trading rounds)												
Finance	13				10				23			
Sports	15				17				32			
Weather	15				17				32			
Total	43				44				87			
Panel B: Total arbitrage period [seconds] per market (10-min. trading round), (N=144 trading rounds)												
	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.
Finance	0.00	0.00	22.95	106.84	0.00	6.19	28.15	188.90	0.00	2.89	25.55	188.90
Sports	0.00	0.00	20.75	268.31	0.00	0.00	31.47	395.86	0.00	0.00	26.11	395.86
Weather	0.00	0.00	16.46	225.88	0.00	0.00	37.85	484.85	0.00	0.00	27.16	484.85
Total	0.00	0.00	20.05	268.31	0.00	0.00	32.49	484.85	0.00	0.00	26.27	484.85
Panel C: Time period [seconds] until exploitation												
	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.
Finance	1.85	10.05	20.40	101.43	1.24	9.68	21.80	185.09	1.24	9.86	21.15	185.09
Sports	1.85	10.08	33.20	151.67	1.40	15.61	29.05	334.24	1.40	13.08	30.57	334.24
Weather	1.05	6.69	21.95	180.26	1.08	20.77	47.81	455.34	1.05	9.58	35.23	455.34
Total	1.05	9.52	24.06	180.26	1.08	12.42	30.78	455.34	1.05	10.83	27.82	455.34
Panel D: Time-weighted amount [cents] per arbitrage occurrence (N=136 occurences)												
	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.	Min.	Median	Mean	Max.
Finance	0.20	3.50	4.19	17.00	0.38	2.00	3.24	13.77	0.20	3.00	3.68	17.00
Sports	0.50	1.94	2.49	6.36	0.50	2.65	4.42	15.63	0.50	2.00	3.71	15.63
Weather	0.01	1.55	2.57	7.94	0.81	3.56	8.72	37.00	0.01	3.20	5.73	37.00
Total	0.01	2.13	3.28	17.00	0.38	3.00	5.01	37.00	0.01	3.00	4.25	37.00

1.8. Time Series of Mean Differences between Prices for Packed and Unpacked Intervals for Finance and Weather Events in Study 1




Event Domain: Weather
Round 1 <=
=> Round 2
Current price
100
80
60
40
20
0
300
600
900
1200
Trading time [sec.]
Avg. [P(I1) + P(I2)]
Avg. P(I1 U I2)
Lin. regression
Round 1 <=
=> Round 2
Current price
100
80
60
40
20
0
300
600
900
1200
Trading time [sec.]
Avg. [P(I3) + P(I4)]
Avg. P(I3 U I4)
Lin. regression

S2: Study 2: A Multi-week Field Experiment

2.1. Instructions for the Experiment

NBA Playoffs/FIFA World Cup Study – Study Instructions

Prof. Craig R. Fox (UCLA), Prof. Colin Camerer (Caltech),
Prof. Thomas Langer, Ulrich Sonnemann
(University of Muenster, Germany)

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1. Introduction

Thank you very much for registering for our NBA Playoffs/FIFA World Cup Study!

In the next weeks you will have the opportunity to trade online contracts whose payoffs depend on the outcomes of this year's **NBA Basketball Playoffs** as well as the **FIFA Soccer World Cup '06** in Germany. In the course of this experiment you will be assigned to both one NBA market **AND** one FIFA market. Thus, in the first market you will trade on the NBA Playoffs and in the second market you will trade on the FIFA World Cup. But don't worry, you need not be both a basketball and soccer expert in order to successfully participate in this experiment!

Because the study is based on real sports events, the trading period for the NBA Playoffs will be from April 20 through June 22, 2006 (at the latest) and for the FIFA World Cup from the middle of May through July 9, 2006. Thus, the **overall trading period** lasts **from April 20 through July 9, 2006** and we kindly request that all participants actively trade throughout this period.

You can expect to earn cash payments of €20 (about $24) per person on average, depending on your decisions, the outcomes of the games, and your individual trading performance. It is therefore possible to earn more or less than €20/$24 (including earning nothing), but there is NO way for you to lose any money!

In order to make sure that all participants have the same information about the procedure of this study and on the trading software, we **strongly recommend that you go through this instruction file very carefully**. However, if you feel familiar with some of the information provided in this document, e.g. the NBA Playoffs mode or the trading system, you can skip those sections.

We set up an NBA/FIFA Study homepage where you can access the trading software, and get news and additional study-related information. There will also be a **FAQs section**, where you can get more detailed information on the trading system etc. You can reach this webpage at:

http://www.internetexperiment.de/NBA-FIFA-Study/

There will also be a support helpdesk which can be contacted via:

tradingstudy@hss.caltech.edu or
trading.study@anderson.ucla.edu

We hope that you will enjoy participating in this study--thank you very much for supporting our research!

Prof. Thomas Langer (University of Muenster, Germany)
Prof. Craig R. Fox (UCLA, USA)
Prof. Colin Camerer (Caltech, USA)
Ulrich Sonnemann (University of Muenster, Germany)

2. Timetable

In the following table you can find a summary of all key data related to this study:

Date/Period	Study	NBA Basketball Playoffs	FIFA Soccer World Cup
Wed, April 19		▪ regular season ends, ▪ set of qualified teams will be set (Playoff Matchups)	
Thu, April 20	▪ link to NBA questionnaire sent to participants via email, ▪ practice market opened ▪ all NBA markets opened, start of NBA trading period		
Sat, April 22		▪ Playoffs begin	
Sat, May 20	▪ link to FIFA questionnaire sent to participants via email		
Mon, May 22	▪ all FIFA markets opened, start of FIFA trading period		
Thu, June 8		▪ NBA Finals start date (winner Eastern vs. winner Western Conference)	
Fry, June 9			▪ opening game, ▪ start of group phase
Fry, June 9 through Fry, June 23			▪ group phase
Thu, June 22	▪ last NBA markets closed	▪ latest possible end date of NBA Finals	
Sat, June 24 through Tue, June 27			▪ round of last 16 (1/8-finals)
Fry, June 30 through Sat, July 1			▪ 1/4-finals
Tue, July 4 through Wed, July 5			▪ 1/2-finals
Sat, July 8			▪ game for 3rd place
Sun, July 9	▪ last FIFA markets closed		▪ World Cup Final
Mon, July 10	▪ link for final questionnaire sent to participants via email, ▪ start paying participants		

Tab. 1: Timetable.

3. Assets and Markets

Note: This section explains the most important and crucial aspects of the experimental design and should be read carefully by ALL participants!

3.1 Contingent Claims

The basic activity in this experiment is to trade claims which pay money depending on the outcomes of this year's NBA Playoffs and FIFA Soccer World Cup 2006. Since the first market you will be trading in is based on the NBA Playoffs, we will concentrate on these markets right now and tell you the details for the FIFA World Cup markets later on.

A typical market will consist of four intervals/ranges for the **total number of wins** for a particular team. **For example**, one market might trade four claims on the San Antonio Spurs, spanning the total number of games the Spurs will win in the 2006 Playoffs. One claim will pay a fixed sum of money, 100 Eurocents (= €1 which is about $1.20) if, after the Playoffs are over, the Spurs have won 0-3 games. If you think the Spurs are likely to win very few games, you should buy this claim. If you think they are likely to win more than 3 games, you should sell this claim. Another claim will pay 100 Eurocents if their win total is 4-7; a third will pay 100 Eurocents if the total is 8-11; and a fourth will pay 100 Eurocents if the total is 12-16.

General Question:
"How many games does a particular team win in the 2006 NBA Playoffs?"

The basic idea of these markets is that after the Playoffs (and the World Cup) are over, exactly one asset/claim in each market will pay 100 Eurocents per claim, while the three remaining claims will become worthless. This is due to the fact that the claim intervals represent all possible outcomes, but do not overlap. However, since the outcome of the event is uncertain during most of the trading period, the price for a claim usually varies between 0 and 100 Eurocents. Before you start trading you should carefully think about how much you are willing to pay for these claims and how much you are willing to sell them for in the market!

You will be randomly placed into one market for NBA Playoff games and (later on) another for FIFA World Cup results. **Important**: Each market consists of four separate "team markets", so you can trade in four different teams in each market. In each "team market" you will be endowed with a set of cash and assets representing an initial wealth of 1,000 Eurocents (= €10 or appr. $12). You do not have to trade if you do not wish to.

Please note that there will be different partitions, i.e. asset intervals in the markets. The partitions in the NBA markets are as follows:

Partition 1: [0-3], [4-11], [12-15], [16] games won.
Partition 2: [0-3], [4-7], [8-11], [12-16] games won.

You will be randomly assigned to a market of twenty participants with one of the partitions above. There are no external and/or computer-controlled participants in the market. There are no explicit transaction costs for your trading.

3.2 Unit Portfolio

For each team there is an "extra asset" in the market which is called the unit portfolio (Unit PF). The Unit PF is based on the idea that a full set of all four assets will always guarantee a certain payment of 100 Eurocents. This payoff is independent of how many games a particular team has won, since exactly one (and only one) of the claims will pay 100 Eurocents, while the other three assets will expire worthless.

Therefore you will be able to exchange 100 Eurocents for a complete set of assets at any time in the experiment. Practically, this trade with the experimenter takes place via the unit portfolio, which can be purchased or sold like the other assets via the trading system. However, the trade partner for this deal will always be the experimenter and the price for the unit portfolio is fixed at 100 Eurocents, i.e. it does not depend on bids and asks in the market. In particular it should be clear that this trade does not allow any assessment of the value of a single asset, but the fact that all four assets combined represent a certain payment of 100 Eurocents. To clarify this, we return to our example of the San Antonio Spurs. If you buy one unit portfolio, there will be one asset of each claim in the market added to your portfolio. Thus, exactly one asset of type 0-3, one asset of 4-7, one asset of 8-11 as well as one asset of 12-16 will be added, while your cash will be reduced by 100 Eurocents.

The Unit PF allows you to buy or sell a complete set of all four assets for a particular team at a fixed price of 100 Eurocents. You might want to do this in order to increase your cash on hand or stock in assets, without taking any risks.

After buying a unit portfolio, you can trade and sell the purchased assets in the market independently! By selling a unit portfolio, 100 Eurocents will be added to your cash account, while simultaneously your portfolio stock will be reduced by one of each asset (please note that this sale is only permitted if you own at least one unit of each asset). Hence, by using the unit portfolio you can either enhance liquidity in assets (as long as you have enough cash), or enhance liquidity in cash (as long as you have at least one of all the four assets in the market).

By using the unit portfolio you can exploit arbitrage opportunities in the market more directly. Arbitrage means performing a transaction which results in a sure profit.

Arbitrage opportunity 1. If the market prices enable you to purchase a full set of assets for less than 100 Eurocents, you can realize a sure profit by buying these four assets for less than 100 Eurocents and selling them via the unit portfolio for 100 Eurocents to the experimenter.

Arbitrage opportunity 2. If it is possible to sell the four assets separately in the market for more than 100 Eurocents, you can buy a full set of assets via the unit portfolio for 100 Eurocents and sell them in the market for a higher price afterwards.

Such arbitrage opportunities are not excluded by the trading system automatically. Therefore, you should carefully watch for arbitrage possibilities!

4. Payment/Incentives

In order to motivate you to thoroughly think about your trading activities in this experiment, you will be paid based on your decisions, the outcomes of the games and thus, your individual trading performance. Keep in mind that there is NO WAY FOR YOU TO LOSE MONEY.

At the end of this experiment we will randomly draw **one** out of the four teams from your NBA market and **one** out of the four teams from your FIFA market. These "team markets" then serve as the basis for your payment. Please note, that you will not know which of the teams in your markets will be relevant for your payment until the end of this study, so you should think carefully about your decisions in all "team markets"!

We will then add your cash account to your final portfolio value (with the assets worth either 100 Eurocents or nothing) for both of the drawn NBA and FIFA "team markets", and will pay you the resulting overall value in Eurocents (or US$ at the current exchange rate; today's exchange rate is about 1.20 $/€).

Example: If at the end of the experiment you have 500 Eurocents and three assets worth 100 Eurocents each in the selected NBA "team market" plus 1,000 Eurocents and five assets worth 100 Eurocents each in the selected FIFA country's "team market", you will receive a payment of (500 + 3* 100) + (1,000 + 5* 100) = 2,300 Eurocents (€23 ~ $27.60).

As you will initially be endowed with cash and unit portfolios totaling 1,000 Eurocents (€10 ~ $12) in each market you would earn 2* €10 = €20 ~ $24 if you do not trade at all.

Further details on the means of payment (check, PayPal etc.) will be provided later via email.

5. Trading System

5.1 Installation and Login

The trading system is based on Java technology, so you should have a recent Java version installed to run the trading software on your computer (Java 1.5, recently named Java5). If your Java version is outdated, you can get the latest version at:

http://www.java.com/en/

You can access your NBA resp. FIFA market via the study homepage at:

http://www.internetexperiment.de/NBA-FIFA-Study/

by following the link of your particular NBA or FIFA market number (we informed you of your personal market affiliation by email). Please note that on the first login the trading software (5.5 MB) has to be downloaded to your computer. This will take a while but is not necessary on later logins. You should accept the security certificate issued by the "Chair of Finance, University of Muenster". You will then see the "ECMS | Login" screen and will be asked for your "User:" ID (which we told you by email) and your personal "Password:" (which you chose after completing the first questionnaire). After clicking the "Login" button, the trading screen ("ECMS | internetexperiment.de (Uni Münster)") will appear.

Note: The following sections can be skipped if you have well-founded trading experience and feel comfortable with the continuous double auction trading mechanism!

5.2 Trading Screen

The trading screen is divided into five areas (see figure 1):

Information. In this area you can find information on your current cash balance, portfolio value, and credit line. At the top of this box are tabs which allow you to switch between the four different "team markets". (The screenshots presented in this document refer to the practice market which can be accessed via the study homepage!)

Market. This area gives you an overview of the assets (and intervals) that are traded in this "team market", your own portfolio, the current market price as well as the best (i.e. highest) buy and the best (i.e. lowest) sell offers (which is called the order book). The best buy offer (sell offer) indicates the volume and the price limit of the highest buy offer (lowest sell offer) at the current time, separated by an "@" symbol. To give you an example: "2 @ 30.00" means that one or more trader(s) are ready to buy a quantity of two assets "RUS.[0-5]"at a price of 30.00 Eurocents each.

Order Form. In this area you can enter your own orders.

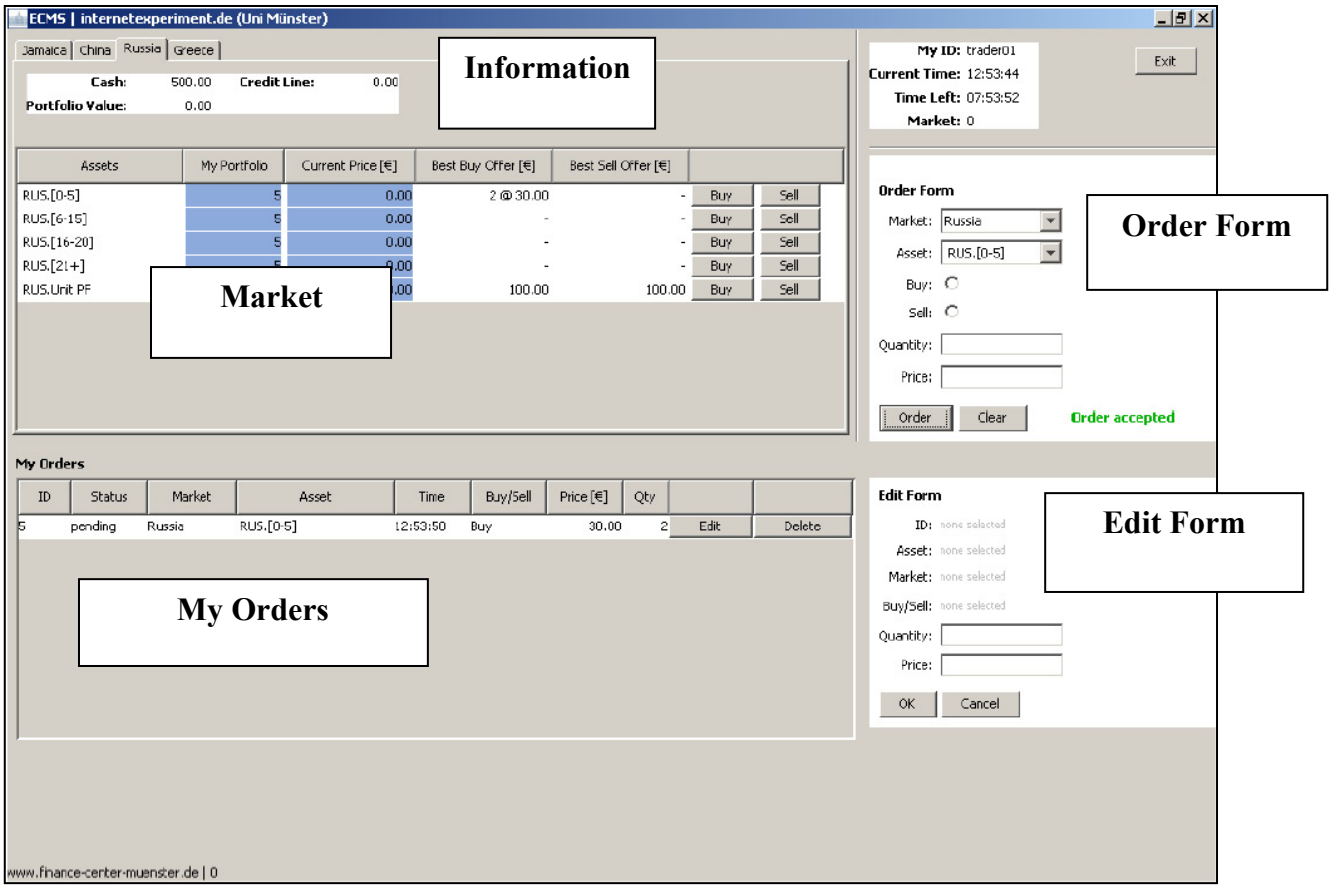


Fig. 1: Trading Screen.

My Orders. This area shows all of your orders which are pending or which were executed (currently there is one pending order in the system) in chronological order. In this area pending orders can be transmitted to the "Edit Form" on the right hand side or they can be deleted and thus, removed from the trading system.

Edit Form. Here, you can modify your pending orders by altering the price limit or the quantity.

5.3 Order Submission

In principle, there are two different ways to submit an order:

1. You can enter all the values (market, asset, buy/sell, quantity and price) in the "Order Form" on your own and click the "Order" button afterwards to submit the order.

2. You can push one of the buttons "Buy"/"Sell" in the "Market" section. The respective asset will be transmitted to the "Order Form" automatically; if available, the best sell offer (if you clicked on the "Buy" button) or the best buy offer (if you clicked on the "Sell" button) will be set as default price. To complete your order, just indicate the quantity you want and click the "Order" button. Of course, all default values can be modified manually.

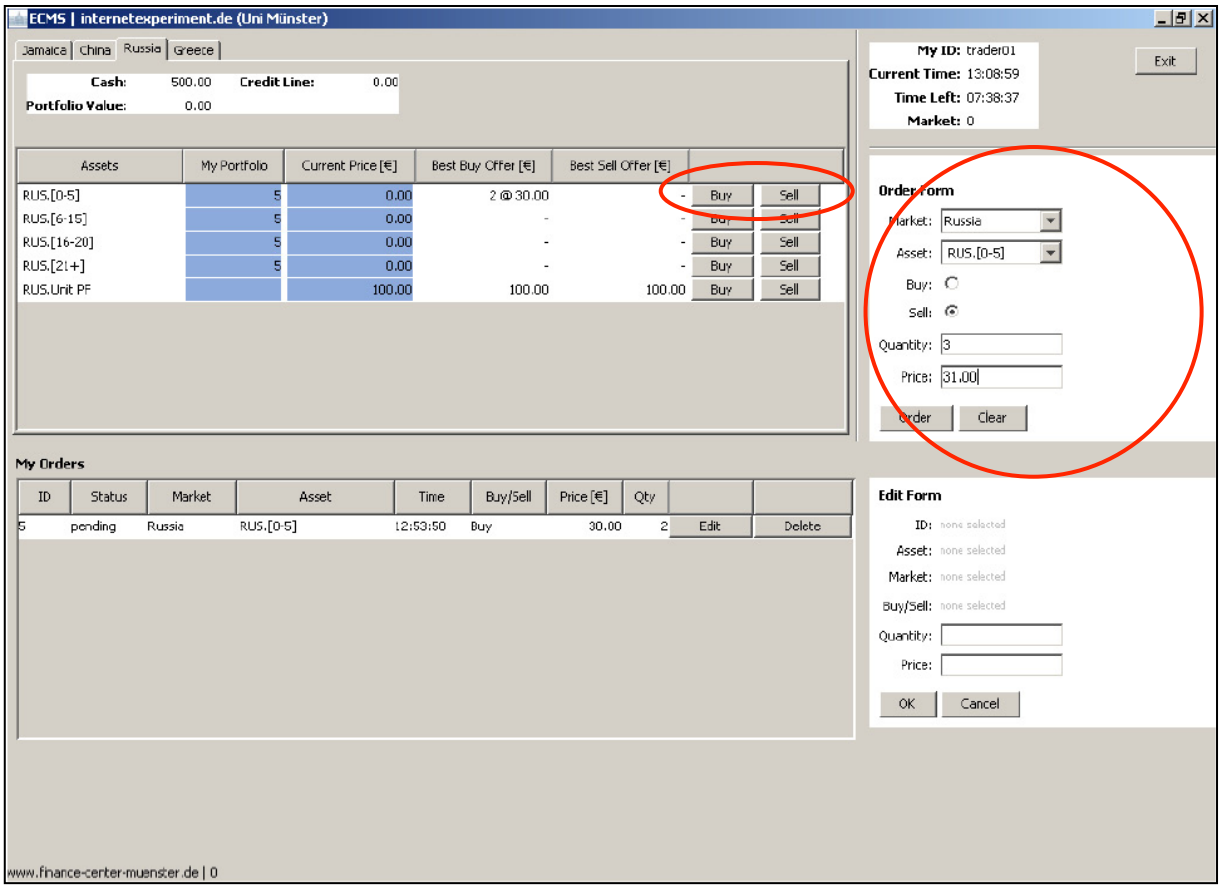


Fig. 2: Order Submission.

After submitting your order, it will be processed by the system. If your order is going to result in a trade, this can last for 1-2 seconds. Your trading screen will be blocked during this time.

In this context you should pay attention to the following two error messages:

Error "not enough cash" and error "short selling restriction"

These error messages will occur, if

3. either you do not have enough cash and/or if you already have too many pending buy orders ("not enough cash"), or if

4. you do not have enough assets and/or if you already have too many pending sell orders ("short selling restriction").

Please note that any pending order will tie-up your cash (buy order) or assets (sell order) until these orders are executed or deleted. This prevents you from placing orders which might not be possible due to a lack of cash/assets. Pending orders can be deleted or edited at any time in order to make the tied-up cash/assets available again.

From figure 2 above you can see that an amount of 2* 30.00 = 60.00 Eurocents is tied-up for the pending buy order at the moment. The disposable cash amount reduced to 500 - 60 = 440 Eurocents.

5.4 Order Execution

The trading system is based on a so-called "continuous double auction". This means that a buy and a sell offer will be executed if the respective buy order has at least the same price limit as the corresponding sell order. Please look at the following order book, which contains a list of all active buy and sell offers in the market:

Buy Offers	Sell Offers
	1 @ 60.00
	1 @ 56.00
	1 @ 50.00
- none -	

Fig. 3: Order book.

Assume you would like to buy assets and enter a buy order for "6 @ 80.00" into the trading system, i.e. you are willing to buy a quantity of six assets at a price limit of 80.00 Eurocents each. In general, only the best offers will appear in the order book of your "Market" section.

In this case, you know for sure that you will buy one asset at a price of 50.00 Eurocents in the market (best sell offer), as you can see from the trading screen.

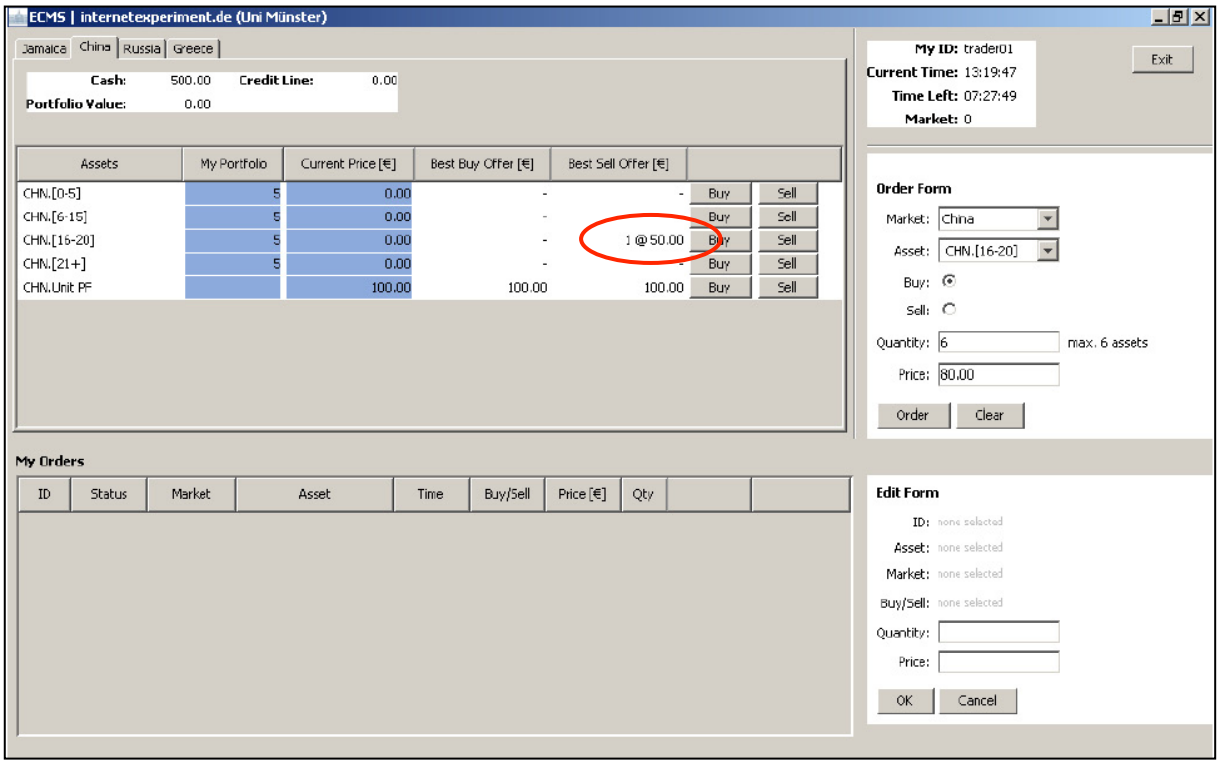


Fig. 4: Order book example.

The remaining part of the order book is hidden to you. However, since you are willing to pay up to 80.00 Eurocents per asset, you will buy a quantity of three assets in total (see Fig. 3).

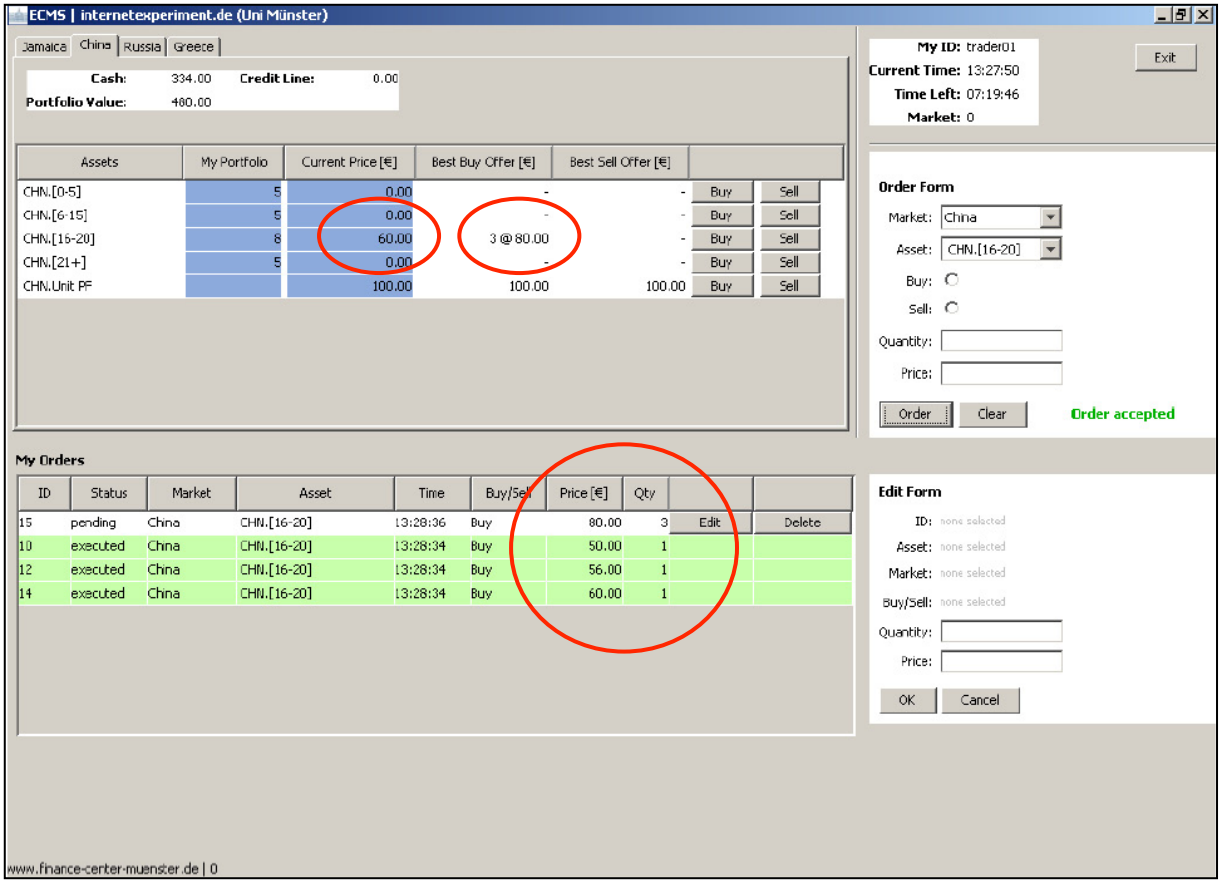


Fig. 5: Splitted Order.

As you can see from the "My Orders" section in Fig. 5, your original order of six assets was split, so that three orders, each consisting of one asset, were executed (highlighted in green colour), while an order of three assets remains in the trading system. The price which is shown in the column "Price" equals the trading price (for the executed orders) and equals your limit price (for the pending order).

The "Current Price" in the "Market" area indicates that the last trade was executed at a price of 60 Eurocents. The remaining part of your order ("3 @ 80.00") appears in the order book as the best buy offer.

Please note: Whenever two orders can be matched, they will always be executed for the price limit of the buy or sell order which was submitted the earliest (time priority).

Note: For more detailed information on the trading system see the FAQs section on our study homepage!

6. NBA Basketball Playoffs Mode

Note: This section can be skipped if you are an NBA Playoffs expert and already know all the details!

Overall, in the National Basketball Association (NBA) there are 30 teams which are divided into Eastern and Western conference (15 teams each). Each conference consists of three divisions with five teams in every division. Within a so-called regular season, each team plays in total of 82 games (which are divided evenly between home and road games). During the regular season, each team faces opponents in its own division four times a season (4x4 = 16 games), teams from the other two divisions within the same conference three or four times a year (in total 36 games) and all 15 teams of the other conference twice (15x2 = 30 games).

Afterwards, the NBA uses a particular seeding system in order to set the Playoffs match-ups: The top three seeds (1-3) for each conference are determined by taking the winners of the conferences' three divisions and ranking them by their regular season record (i.e., their relation between wins and losses). The remaining five seeds (4-8) for each conference are determined by taking the five best teams from the remaining pool of 12 teams.

The Playoffs themselves follow a tournament format: Each team plays a rival in a best-of-seven series, with the first team to win four games advancing to the next round. This means that two teams play against each other, until one of the teams wins four times. While the losing team is eliminated from the Playoffs and does not play any more games, the winning team advances to the next round and has the next match-up according to the following preset bracket:

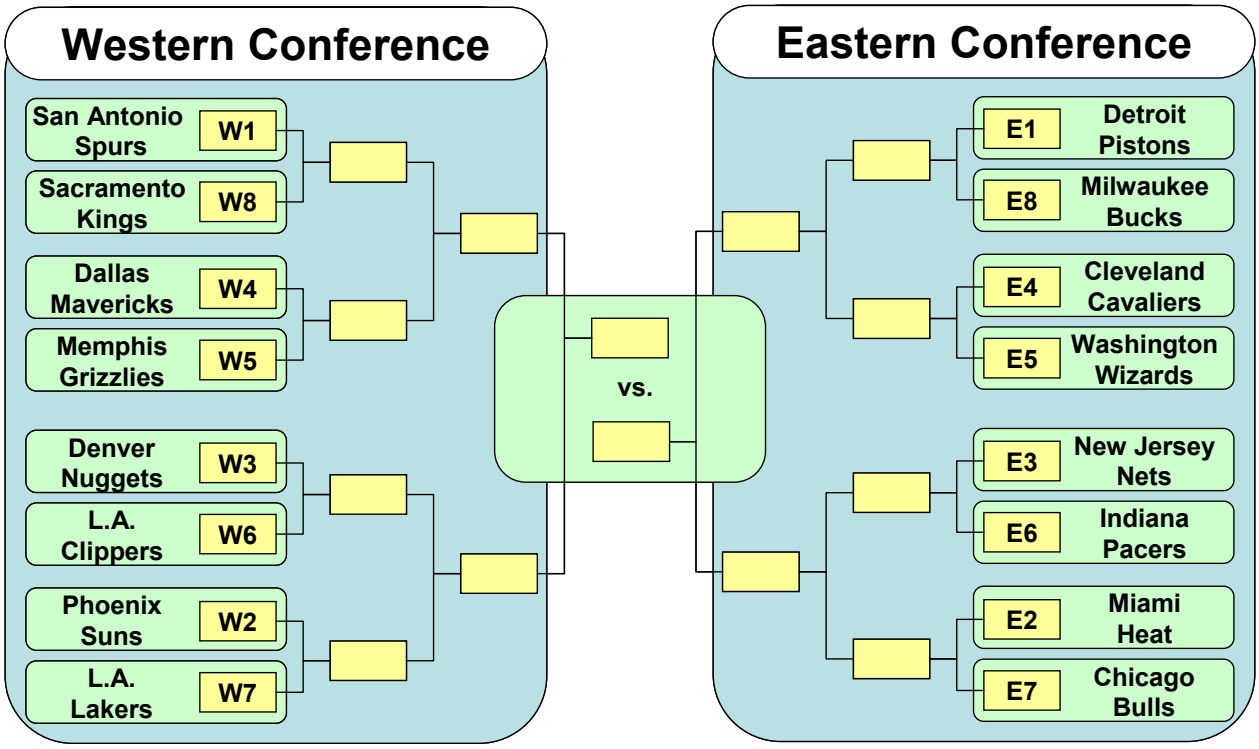


Fig. 6: Traditional NBA Playoffs Bracket with this year's teams.

In the final round (the NBA Finals), the winner of the Western conference faces the winner of the Eastern conference.

Home-court advantage in the NBA Playoffs follows a particular pattern and is based strictly on a team's regular-season record, without regard to whether a team won its division or not. In each round except the NBA Finals, the best-of-seven series follows a 2-2-1-1-1 pattern, meaning that the team with the better won-lost record has home court in games 1, 2, 5, and (the decisive game) 7, while the opponent plays at home in games 3, 4, and 6. In the NBA Finals, home-court advantage follows a 2-3-2 pattern, meaning that one team has home court in games 1, 2, 6, and 7, while the other team plays at home in games 3, 4, and 5.

Please note that the winning team in the NBA Finals always wins exactly 16 games in total; the team that makes it to the NBA Finals but loses, always wins 12 to 15 games etc., while the first-round losers win from 0 to 3 games.

7. FIFA Soccer World Cup Mode

Note: This section can be skipped if you are a FIFA World Cup expert and already know all the details!

After a two-year period of qualification, 32 national teams have qualified for the final tournament (FIFA Soccer World Cup 2006).

In December 2005, the qualified teams were drawn and assigned to eight groups of four nations each. Eight teams (Germany, England, Argentina, Mexico, Italy, Brazil, France and Spain) were seeded as group heads, based on their so-called FIFA ranking and their success in previous FIFA World Cups. The remaining teams were drawn randomly from the different continental zones (and by geographical criteria). They will now compete for the World Cup in two phases, a group phase and a knockout phase.

Group phase. From June 9 on, in all of the eight groups, each team plays every other team in the group once (pure round-robin schedule), guaranteeing that every team will play (at least) three matches. Every match consists of two periods of 45 minutes each and can end in a decision (three points for the winner) or a draw (one point for both teams). At the end of this phase, the two top teams from each group advance to the knockout phase.

Knockout phase. In this phase, teams play each other in single-elimination matches. If there is a draw at the end of the regular playing time (i.e. after the second period of 45 minutes has finished), there are two overtime periods, 15 minutes each. If there is still a draw after the 30 minutes of overtime, a penalty shootout is used to decide the winner. Please note that goals scored in a penalty shootout do not count for the (official FIFA) result of the game (unlike penalty-kicks during the game, which do count for the final score of the game).

In the round of 16 (1/8-finals), the winner of each group plays against the runner-up from another group. This is followed by the quarterfinals, the semifinals and the World Cup final, as can be seen from the following figure:

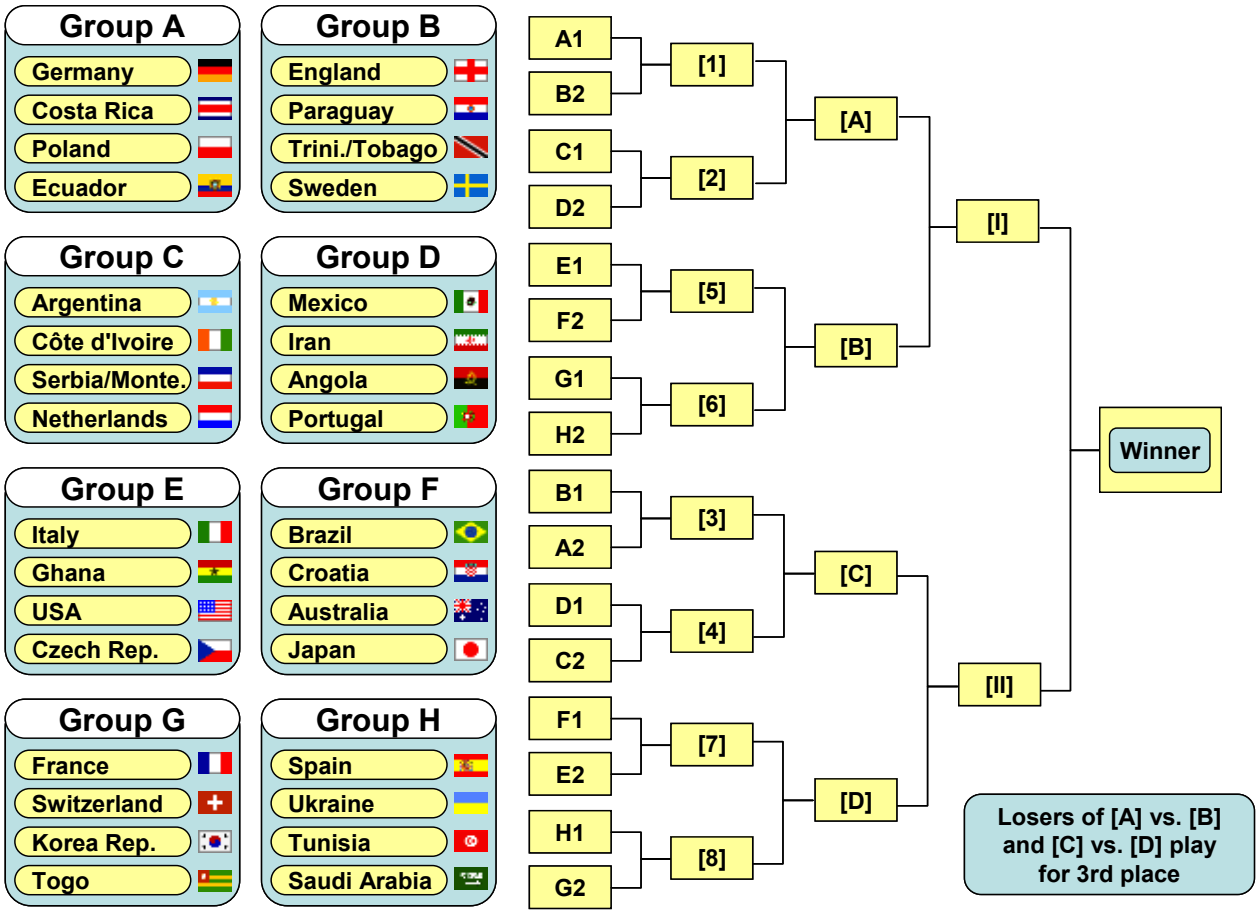


Fig. 7: FIFA Soccer World Cup Bracket.

The losers from the semifinals play each other in a third place match.

2.2. DETAILS OF THE DESIGN OF STUDY 2

From April to July 2006 we conducted internet-based prediction markets for outcomes in the NBA basketball playoffs 2005/06 and the FIFA soccer World Cup 2006. Trading markets were open continuously for nine weeks for the NBA markets (April 20 through June 21, 2006) and seven weeks for the FIFA markets (May 24 through July 9, 2006), except for markets that closed when teams were eliminated. We recruited *N*=317 undergraduate finance students from the University of Muenster (in Germany) and *N*=139 students from an experimental economics laboratory e-mail list at UCLA (United States).

Contracts were all-or-nothing contingent claims on intervals defined by the total number of victories for a particular NBA team during the playoffs, and the total number of goals scored by a particular national team during the entire World Cup tournament (excluding shoot-out goals). For each event domain there were two partitions that combine sub-events differently. For example, in the NBA markets the first partition packed the victory intervals [4, 7] and [8, 11] into a single interval [4, 11], and unpacked the interval [12, 16] into two components of [12, 15] and [16]. However, unlike Study 1, we also included an interval common to both partitions ([0, 3] in the NBA markets). Also as in Study 1, to control for information provided by partitions we explicitly informed all participants of both partitions and that they would be randomly assigned to trade only one. Every participant could trade assets based on four teams— called "team markets"—using the same partition for each of the four teams.

The NBA intervals correspond to the number of victories needed by a team to advance across the four playoffs rounds, so bets on the various win-total events are equivalent to betting that teams will lose in the first round, the second round, and so forth. The intervals for the number of goals in the FIFA soccer World Cup were not structured to correspond to advancement across rounds, but were chosen such that they all appeared plausible based on the results from the three previous World Cups.

Participants were instructed by e-mail about the composition of assets and markets (including the partitions of assets they could trade, and the alternative partition), how to use the trading system, and some details concerning the NBA playoffs and the FIFA World Cup. They also had Internet access to a homepage with study details, FAQs, and a practice market. The market was open continuously. As in Study 1, the trading mechanism was a multi-unit continuous double auction (CDA) with a hidden order book, so that participants could see only the best bid and ask quotes and the most recent trade price for each asset. Traders could submit bid and ask quotes for each asset simultaneously, acting as market makers. Trading took place only among the twenty participants eligible to trade in each market. There was no credit line or short selling opportunity, except for purchases of the unit portfolio from the experimenter.

Participants were initially endowed with different combinations of cash and unit portfolios totaling €10 in each "team market" of the NBA playoffs and were endowed again in the World Cup markets. At the end of the experiment we randomly drew one out of the four teams for each experimental group to compensate participants based on the sum of the actual asset values in their final portfolio and their cash balance, for an expected payment of €20 (€10 for playoffs and €10 for World Cup markets) per person. We also collected questionnaire data from all participants before and after trading, including individual judgments of the probabilities that outcomes would fall into intervals corresponding to the assets they traded.

It is important to stress that participants only had direct access to their own four-team NBA and World Cup markets. They could not directly observe market data (e.g., prices or quotes) from other groups trading different partitions. For each part of the study—NBA playoffs and soccer World Cup—assets on 16 teams were traded. We can thus compare trading prices from two different partitions for each of 16 teams in each of the two event domains. Due to the large number of participants that were recruited, we could fill two identical experimental settings ("clones") with German students and one identical setting with

U.S. students.

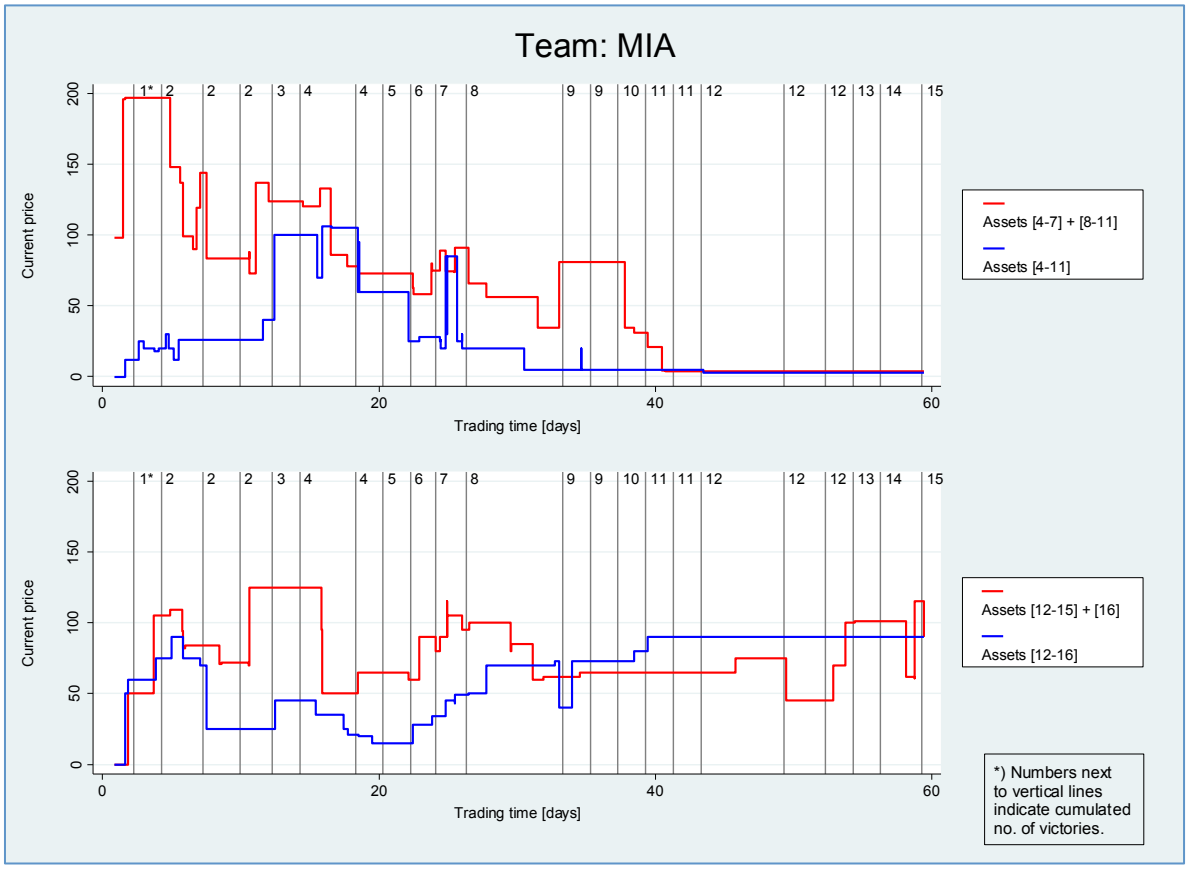
2.3. PARTITION-DEPENDENCE IN PRE-TRADING JUDGMENTS

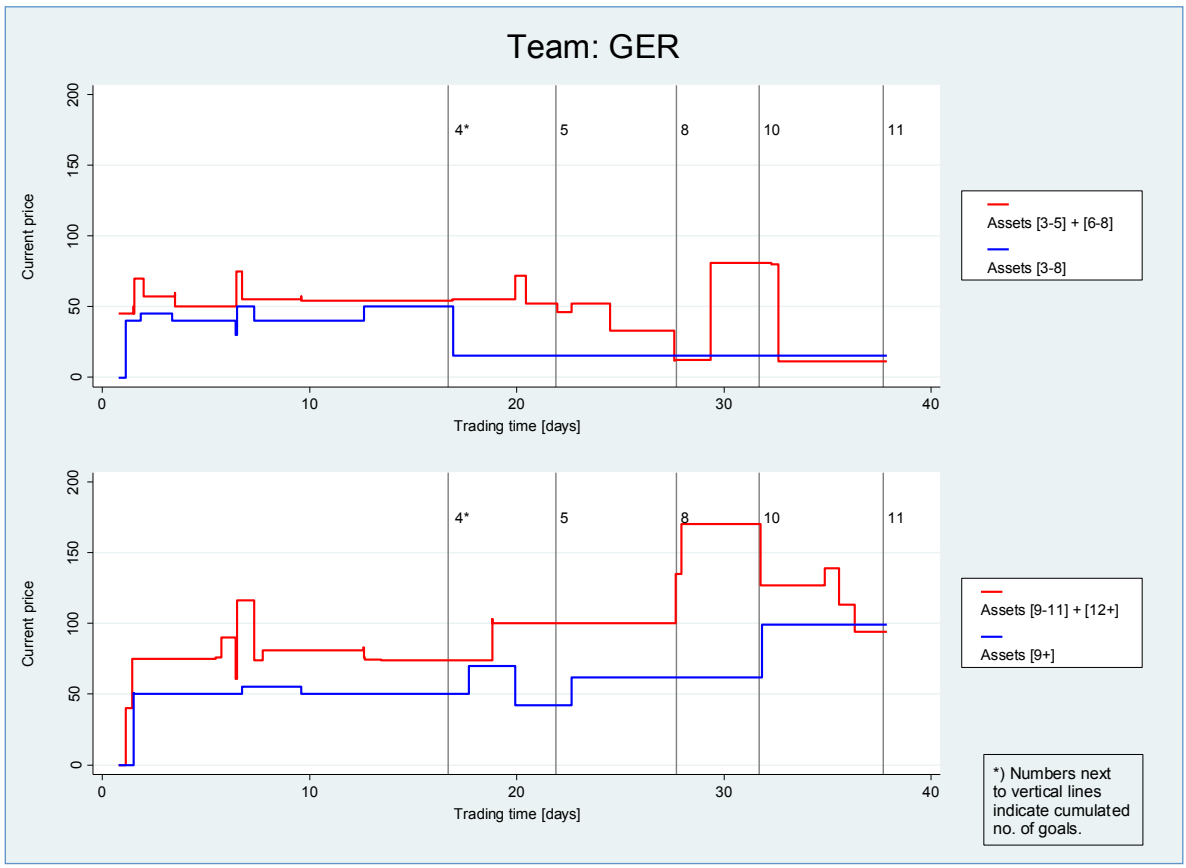
The Table presents differences in medians for interval I_0 and differences in medians for the sum of unpacked events and the packed event per NBA and FIFA team. Number of subjects giving judgments is 30-49 for (1,2) and 30-51 for (3,4). Each subject (N=302 and N=263 resp.) provided judgments for four different teams resulting in 1,208 (1,052) judgments in total. *, **, *** indicate significance at the 10%, 5%, and 1% level (two-tailed) based on a Kruskal-Wallis test for each team.

Team	Δ_{Median}, Whole Population (N=302x4), German and U.S. Subjects (Pooled)			
	Event I_0 Equality	$p(I_1) + p(I_2) - p(I_1 \cup I_2)$	$p(I_3) + p(I_4) - p(I_3 \cup I_4)$	N_1/N_2
CHI	15.0	19.0 **	22.5 ***	37/36
CLE	2.0	20.0 ***	15.0 ***	37/36
DAL	0.0	24.5 ***	20.0 ***	40/37
DEN	-2.0	17.5 ***	18.0 ***	41/34
DET	2.5	25.0 ***	36.5 ***	41/34
IND	-10.0	25.0 ***	12.0 ***	41/34
LAC	5.0	5.0	10.0 ***	40/37
LAL	-5.0	22.5 ***	10.0 **	40/37
MEM	15.0	25.0 ***	23.0 ***	37/36
MIA	-10.0	20.0 ***	15.0 ***	40/37
MIL	-5.0	20.0 ***	10.0 **	40/37
NJN	-10.0 *	30.0 ***	20.0 ***	40/37
PHX	0.0	30.0 ***	27.5 ***	37/36
SAC	-12.5	25.0 ***	2.0 *	41/34
SAS	0.0	30.0 ***	40.0 ***	40/37
WAS	-10.0	10.0 ***	10.0	40/37

Team	Δ_{Median}, Whole Population (N=263x4), German Subjects			
	Event I_0 Equality	$p(I_1) + p(I_2) - p(I_1 \cup I_2)$	$p(I_3) + p(I_4) - p(I_3 \cup I_4)$	N_1/N_2
ARG	-1.5	37.5 ***	40.0 ***	30/34
AUS	-5.0	0.0	5.0	33/34
BRA	0.0	22.0 ***	20.0 ***	33/34
CIV	6.5	10.0 *	8.5 ***	30/34
CRC	0.0	15.0 *	9.0 ***	35/32
CRO	10.0 **	10.0 **	20.0 ***	33/34
CZE	8.0 *	35.0 ***	37.5 ***	35/30
ECU	10.0	10.0	9.0 ***	35/32
GER	0.0	35.0 ***	37.5 ***	35/32
GHA	-2.5	12.5 **	5.0 *	35/30
ITA	4.0	25.0 ***	27.5 ***	35/30
JPN	5.0 **	0.0	6.0 ***	33/34
NED	0.0	32.5 ***	30.0 ***	30/34
POL	5.0	30.0 ***	30.0 ***	35/32
SCG	10.0	0.5	14.0 ***	30/34
USA	0.0	15.0 ***	7.0 ***	35/30

2.4. Further Price Charts (Miami Heat, MIA and Germany, GER)





2.5. General Remarks on Measuring Partition Dependence in Market Prices

Because prices are constantly changing in Study 2 in response to new information over the several weeks of the tournaments, the "equilibrium market prices" for a static event toward the end of trading cannot easily be used to determine the degree of partition-dependence revealed by prices (as we did in Study 1). Therefore, we measured partition-dependence in two more nuanced ways. Both methods measure the hypothetical "pseudo-arbitrage" available by comparing the summed prices for the two unpacked-interval assets (traded in one market) with the price for the equivalent packed-interval asset (traded in a different market). Note that these calculations are not true arbitrage opportunities because traders cannot actually trade in the markets with different partitions; they simply provide an economically interesting measure of the partition-dependent gap in prices between the two independent markets.

2.6. INTERPOLATED-PRICE HYPOTHETICAL ARBITRAGE (MEASURE REPORTED IN THE MAIN TEXT)

In our first method, "interpolated-price hypothetical arbitrage," the most recent and subsequent prices are used to *interpolate* a continuous trade price. The arbitrage is *hypothetical* because it summarizes price differences in separate markets and assumes that trades can take place when there are no standing bids or asks. Because participants cannot trade across markets, they cannot directly act on these pseudo-arbitrage opportunities. This method is conservative because it assumes that hypothetical trades would only be executed at the worst of the observable prices. That is, even when there are no asks available, a trader seeking to buy is presumed to be able to always execute a trade, but only at the higher of the last previous trade price and the next future price. (Similarly, we assume that sell orders are executable at the lower of the last price and the next future price.) This method assumes, counterfactually, that there is a continuous flow of prices at which trades could occur (because there is latent willingness to trade that is not revealed by posted bid and asks). Note that basketball games and soccer matches are occurring during the continuous flow of trading, so using the worst of the last and next prices often means that traders are (hypothetically) betting against unfavorable public information, which adds to the conservatism of this measure.

In formal notation, the interpolated-price hypothetical arbitrage profit at time t is:

(1.1) $\min[P_{t-r}(I_1), P_{t+n}(I_1)] + \min[P_{t-r}(I_2), P_{t+n}(I_2)] - \max[P_{t-r}(I_1 \cup I_2), P_{t+n}(I_1 \cup I_2)]$

(1.2) $\min[P_{t-r}(I_3), P_{t+n}(I_3)] + \min[P_{t-r}(I_4), P_{t+n}(I_4)] - \max[P_{t-r}(I_3 \cup I_4), P_{t+n}(I_3 \cup I_4)]$

for the intervals I_1 and I_2 (intervals I_3 and I_4), where $P_s(I_j)$ is the trade price at time s for interval j, and $t–r$ and $t+n$ are the times of the most recent and next trades.

To illustrate further, suppose the trade prices of a thinly-traded asset are 42 at day 20 and 48 at day 25, and there are no trades between those dates. If a trader is *buying* the asset, we assume he could buy it at the *higher* price of 48 during days 20 to 25 even though there is no

trading during those days (and even if there are no posted bids or asks). If he is *selling* the asset, we assume he could sell it for the *lower* price of 42 during days 20 to 25.

Figure 2.6.1. shows the interpolated-price hypothetical arbitrage profit over time for Dallas (DAL) in the NBA event domain. The blue line in the first panel shows the hypothetical arbitrage profits from selling at the minimum interpolated prices for unpacked intervals I_1 and I_2, and buying at the maximum interpolated price for interval $I_1 \cup I_2$ (as defined in (1.1)). The red line, by contrast, shows the hypothetical profits from the reverse arbitrage strategy, i.e., selling at the minimum interpolated price for the packed interval $I_1 \cup I_2$, and buying at the maximum interpolated prices for unpacked intervals I_1 and I_2. Because this "profit" can be positive or negative, the second panel shows the value of this hypothetical profit when it is above zero (i.e., the profit conditional on it being positive). Panels three and four show the same calculations for the assets based on unpacked intervals I_3 and I_4 and the packed interval $I_3 \cup I_4$ (as defined in (1.2)). The hypothetical profits from selling the unpacked-interval assets and buying the packed-interval asset (blue lines), depicted in panels two and four, are often positive and large.

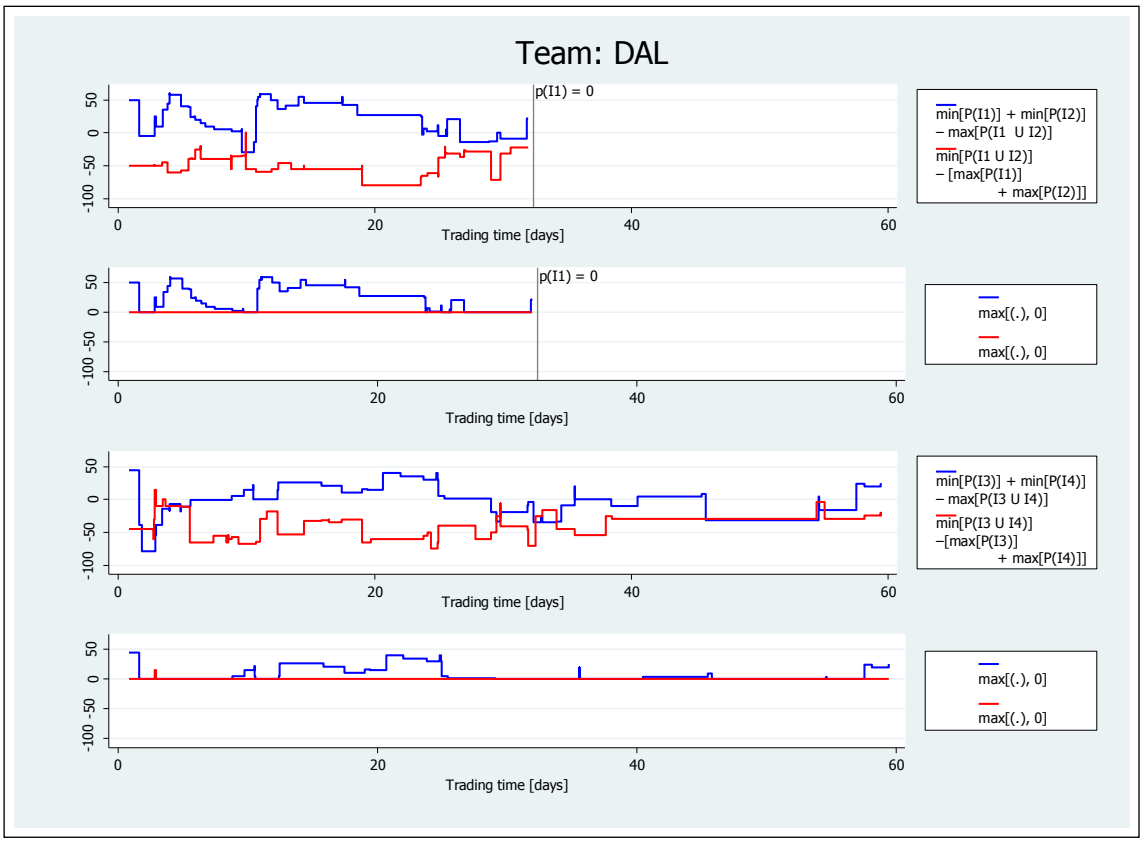


Figure 2.6.1. Interpolated-price hypothetical arbitrage (Dallas Mavericks, DAL).

Figure 2.6.2. shows the corresponding data from trades on Italy (ITA) in the World Cup. The results are similar. Note that if there were reverse partition-dependence (the packed-interval asset price is higher) the red lines in Figures 2.6.1. and 2.6.2. would be above zero, but this is never the case. The fact that there is virtually no reverse effect shows that partition-dependence in the expected direction (as indicated by the blue curves) is systematically positive and not merely the result of random error.

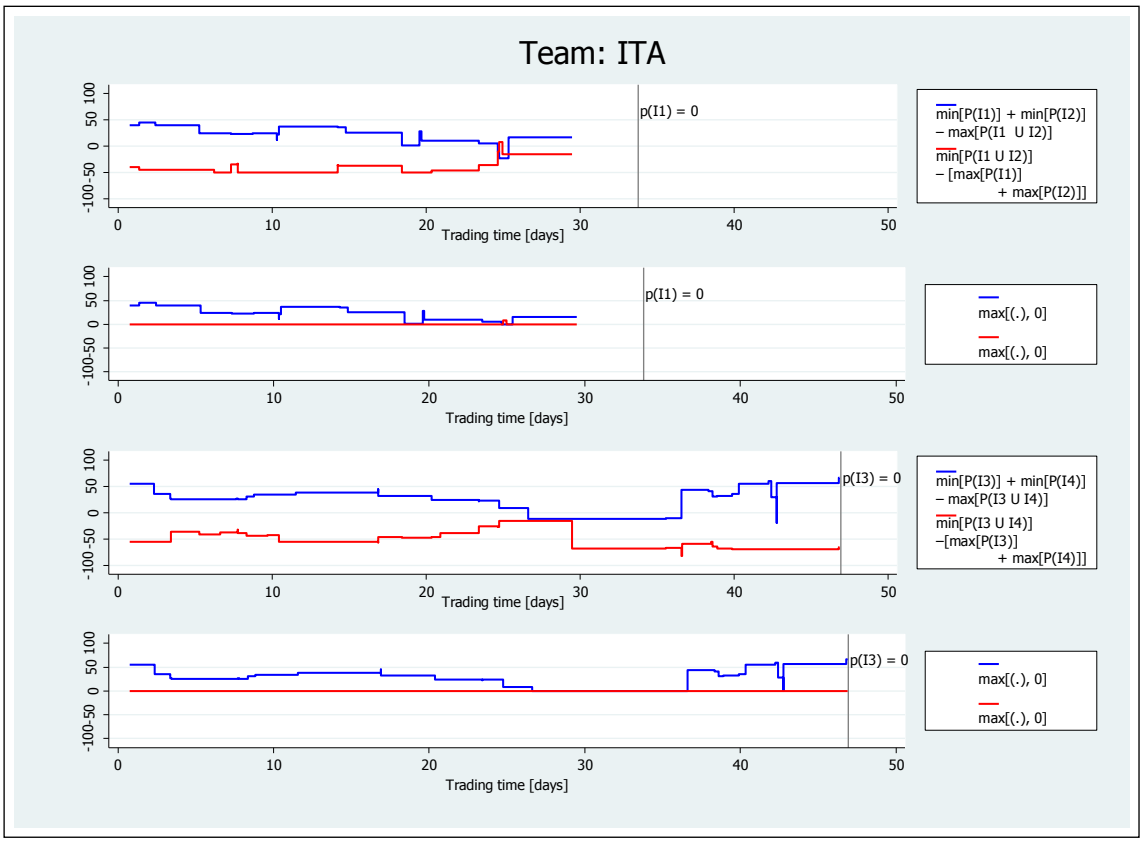


Figure 2.6.2. Interpolated-price hypothetical arbitrage (Italy, ITA).

To measure the daily average interpolated-price hypothetical pseudo-arbitrage profit for each team, we calculated the area under the blue and red curves in the second and fourth panels of Figures 2.6.1. and 2.6.2., and divided by the total trading time (in days). These statistics are provided for each team and interval in Table 2.6.1. and graphically displayed in Figure 2B of the main text. Note the figures are always positive because if the return to pseudo-arbitrage is negative, we assume the trade would not be made (i.e., only positive profits are averaged).

The average per-day hypothetical profit from exploiting bias toward the ignorance prior by selling the unpacked-interval assets and buying the packed-interval asset, is higher than for the reverse strategy (buying unpacked and selling packed) for 21 out of 32 teams for intervals I_1 and I_2, and for 27 out of 32 for intervals I_3 and I_4 (significant by sign test at $p<0.1$ and $p<.001$, respectively). The median per-day pseudo-arbitrage profit exploiting such partition-dependence, across all teams and sports, is 5.61 for intervals I_1 and I_2 and 6.41 for intervals I_3 and I_4; the average of this median across intervals is 6.01.

Table 2.6.1.

Per-day profitability of interpolated-price pseudo-arbitrage strategies

Team	Low Intervals		High Intervals	
	Arbitrage PD (Sell I_1, I_2, Buy $I_1 \cup I_2$)	Arbitrage Reverse PD (Buy I_1, I_2, Sell $I_1 \cup I_2$)	Arbitrage PD (Sell I_3, I_4, Buy $I_3 \cup I_4$)	Arbitrage Reverse (Buy I_3, I_4, Sell $I_3 \cup I_4$)
NBA Playoffs teams				
CHI	1.24	0.85	2.04	0.00
CLE	3.71	0.72	13.48	0.00
DAL	22.39	0.00	7.38	0.02
DEN	3.49	5.48	2.43	1.54
DET	16.10	2.70	0.48	7.50
IND	7.98	0.19	0.00	0.00
LAC	9.41	0.00	7.76	0.00
LAL	8.56	0.00	8.29	0.00
MEM	0.16	2.14	11.51	0.00
MIA	27.51	0.00	13.52	2.03
MIL	0.00	2.97	2.75	0.00
NJN	5.87	1.69	24.03	0.00
PHX	14.53	0.23	8.17	0.00
SAC	0.38	0.90	0.15	0.58
SAS	28.59	0.00	16.07	0.33
WAS	8.27	0.00	5.23	0.00
FIFA World Cup teams				
ARG	0.53	2.55	13.05	0.00
AUS	2.33	1.07	7.24	0.36
BRA	0.00	5.63	0.57	3.50
CIV	0.04	4.53	0.08	0.72
CRC	1.01	6.30	0.01	0.24
CRO	0.66	2.24	1.22	0.00
CZE	21.85	0.00	29.21	0.00
ECU	12.24	0.05	9.74	0.01
GER	11.87	0.04	9.35	0.20
GHA	0.00	23.55	1.98	0.00
ITA	22.84	0.06	27.66	0.00
JPN	8.11	0.51	1.68	0.00
NED	10.73	0.00	6.54	2.14
POL	0.71	0.19	0.81	0.46
SCG	0.60	0.20	0.25	0.00
USA	5.45	8.08	1.35	0.00

2.7. ACROSS-MARKETS PSEUDO-ARBITRAGE BASED ON AVAILABLE BIDS AND ASKS (MEASURE NOT REPORTED IN THE MAIN TEXT)

Our second method (not reported in the main text) calculates the time-weighted pseudo-arbitrage profits from selling the unpacked-interval assets in one market and buying the equivalent packed-interval asset in the other market, at available bid and ask prices. Because trading is often quite thin, there are long stretches of time when bids and asks are not available on all assets and the measured partition-dependence is zero.

Keep in mind that participants could only trade in one market at a time, so they *could not actually execute these arbitrage trades* (which is why we refer to them as "pseudo-arbitrage"). Asking how large the opportunities are is simply a way to characterize the economic size of the partition-dependence, using all the information on bids and asks.

Consider intervals I_1 and I_2 which are traded separately (unpacked) in partition 2 and packed in partition 1. If there is partition-dependence, then the bids for assets I_1 and I_2 will be high (compared to bids for the packed asset $I_1 \cup I_2$). So one kind of pseudo-arbitrage is to take the sum of the current bids for assets I_1 and I_2 (i.e., the prices at which one could sell those assets) and to subtract the current ask for the equivalent asset $I_1 \cup I_2$ (i.e., the price at which one could buy that asset). If this difference is positive, then a trader with access to both markets could sell the two unpacked assets of intervals I_1 and I_2 for more than she could buy the packed interval asset $I_1 \cup I_2$. If there is reverse partition-dependence, then the opposite strategy would be profitable (buying the components and selling the packed asset). The size of these arbitrage strategies is represented in our notation as $B(I_1) + B(I_2) - A(I_1 \cup I_2)$ (i.e., selling unpacked and buying packed, arbitraging partition-dependence) and $B(I_1 \cup I_2) - [A(I_1) + A(I_2)]$ (i.e., selling packed and buying unpacked, arbitraging reverse partition-dependence) where $B(I_k)$ is the best (highest) bid quote for interval I_k and $A(I_k)$ is the best (lowest) ask quote for interval I_k.

Figure 2.7.1. below shows these statistics over the life of the experiment for NBA team DAL. Look at the top panel first. The top panel shows $B(I_1) + B(I_2) - A(I_1 \cup I_2)$ (in blue) and $B(I_1 \cup I_2) - [A(I_1) + A(I_2)]$ (in red). The second panel shows the maxima of each of these spreads and zero (i.e., it only shows their values when they are positive, when pseudo-arbitrage is profitable). The blue spikes in the second panel indicate that there are pseudo-arbitrage opportunities, which are sometimes quite large in magnitude but are sporadic and usually short-lived. The red line at zero indicates that there is never a set of available bids and asks consistent with profitable arbitrage against reverse partition-dependence. The horizontal lines at the bottom of the second panel indicate the spans of time during which *any* bid or ask exists in the market for each of the assets in the arbitrage strategy. When those lines are interrupted there is no liquidity and hence no opportunity for arbitrage.[1]

The third and fourth panels show the same time series for the pseudo-arbitrage of intervals I_3 and I_4. There are frequent interruptions in the bid-ask existence series (at the bottom of the fourth panel), so pseudo-arbitrage opportunities are rare.

[1] Missing ask quotes were set to $+\infty$ and missing bid quotes were set to zero. The values of the positions are therefore calculated as

$\min[B(I_1) + B(I_2), 100] - \min[A(I_1 \cup I_2), 100]$ and $\min[B(I_1 \cup I_2), 100] - \min[A(I_1) + A(I_2), 100]$, and

$\min[B(I_3) + B(I_4), 100] - \min[A(I_3 \cup I_4), 100]$ and $\min[B(I_3 \cup I_4), 100] - \min[A(I_3) + A(I_4), 100]$.

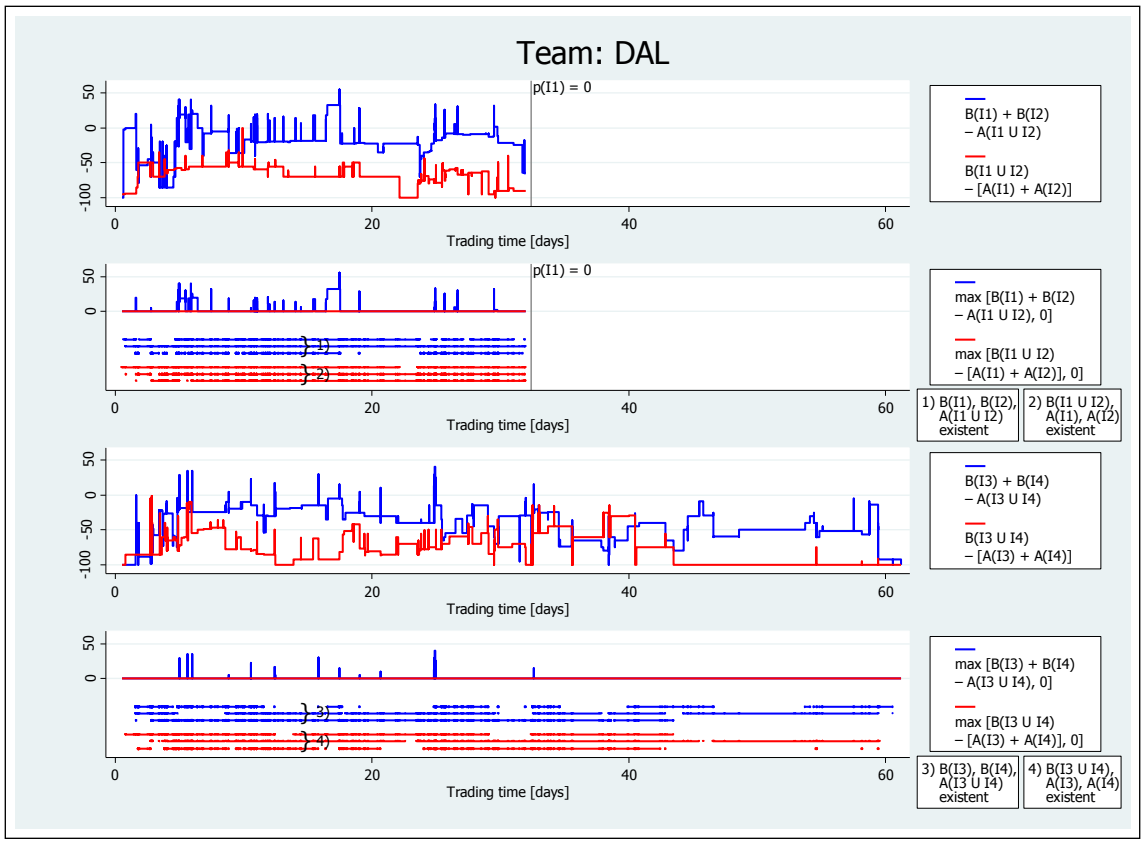


FIGURE 2.7.1. CROSS-MARKET PSEUDO-ARBITRAGE (DALLAS MAVERICKS, DAL).

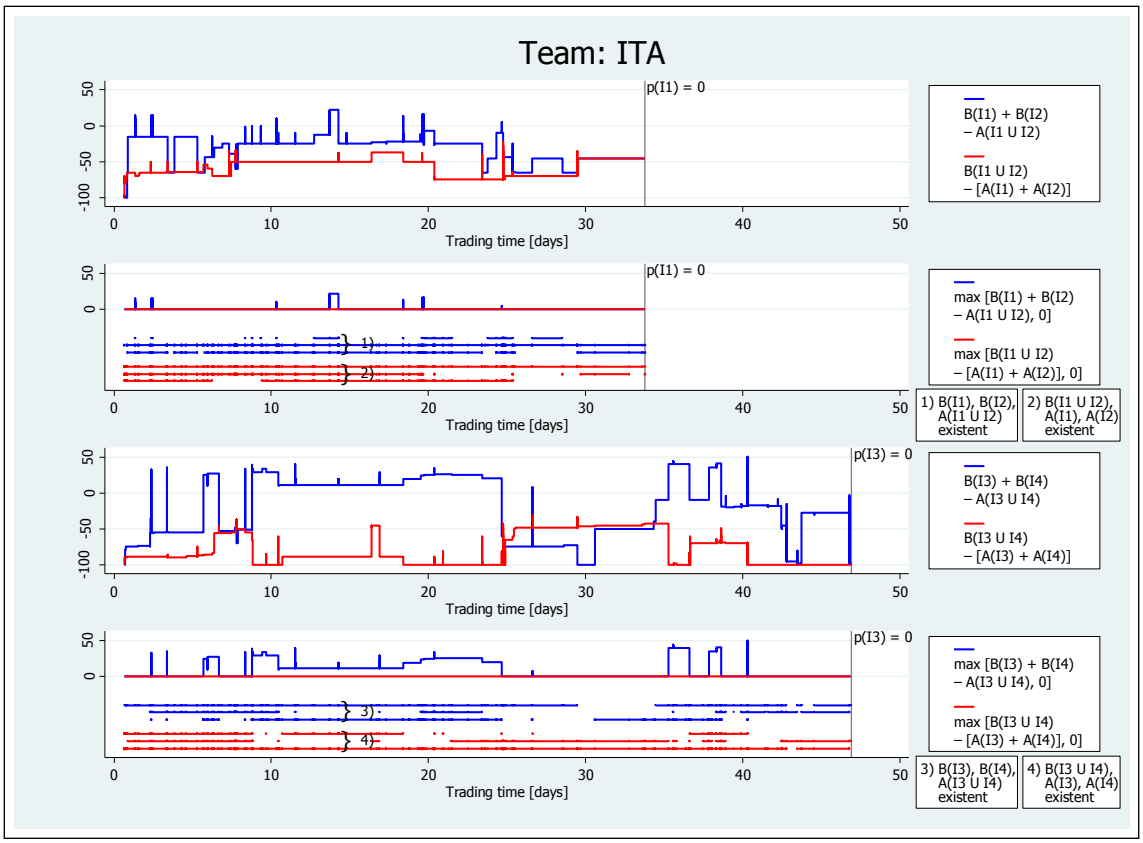


FIGURE 2.7.2. CROSS-MARKET PSEUDO-ARBITRAGE (ITALY, ITA).

Figure 2.7.2. shows the same time series for the World Cup winning team ITA. There are few pseudo-arbitrage opportunities for the low-goal intervals I_1 and I_2, but quite a bit of pseudo-arbitrage for intervals I_3 and I_4. From days 9 through 25, there is a persistent gap in the bids of unpacked events I_3 and I_4 and the ask for event $I_3 \cup I_4$. These examples illustrate the advantage of using the continuous bid and ask information. Trades are rather rare for ITA events (only about one trade per day across all assets) but bids and asks are common enough to show persistent gaps in (potential) prices.

Table 2.7.1. reports the value of the time-weighted pseudo-arbitrage statistics for all teams. These are the area under the blue and red curves in the second and fourth panels of

Figures 2.7.1. and 2.7.2., divided by the total trading time.[2] The profitability of strategies exploiting partition-dependence (in columns (2) and (4)) is often very low, but is above 1.0 for 9 of 32 teams. Furthermore, pseudo-arbitrage against reverse partition-dependence is much less profitable. For 38 of the 46 team-partition comparisons, arbitraging against partition-dependence is more profitable than arbitraging against reverse partition-dependence (excluding 18 team-partition cases in which both figures are zero), a fraction significantly lopsided by a conservative sign test ($z=5.88$, $p<.001$).

[2] Note that the relevant trading time ends either when the last auction for assets I_1, I_2 or $I_1 \cup I_2$ (I_3, I_4 or $I_3 \cup I_4$) occurred or when the corresponding interval asset I_1 (or I_3) expired worthless.

TABLE 2.7.1.

PER-DAY PROFITABILITY OF BID/ASK HYPOTHETICAL PSEUDO-ARBITRAGE STRATEGIES

Team	Low Intervals		High Intervals	
	Arbitrage PD (Sell I_1, I_2, Buy $I_1 \cup I_2$)	Arbitrage Reverse PD (Buy I_1, I_2, Sell $I_1 \cup I_2$)	Arbitrage PD (Sell I_3, I_4, Buy $I_3 \cup I_4$)	Arbitrage Reverse (Buy I_3, I_4, Sell $I_3 \cup I_4$)
NBA Playoffs teams				
CHI	0.00	0.04	0.06	0.00
CLE	0.01	0.00	0.11	0.00
DAL	1.95	0.00	0.03	0.00
DEN	0.00	1.08	0.00	0.00
DET	1.36	0.26	0.00	5.06
IND	0.12	0.00	0.20	0.00
LAC	0.16	0.00	0.71	0.00
LAL	0.00	0.00	5.14	0.00
MEM	0.00	0.00	2.61	0.00
MIA	0.96	0.00	0.75	0.00
MIL	0.00	0.04	0.00	0.00
NJN	0.65	0.00	7.90	0.00
PHX	0.25	0.00	1.46	0.00
SAC	0.00	0.00	0.00	0.00
SAS	0.44	0.00	0.24	0.00
WAS	0.05	0.03	0.00	0.00
FIFA World Cup teams				
ARG	0.05	0.00	0.15	0.00
AUS	0.55	0.01	0.48	0.00
BRA	0.00	0.11	0.07	0.00
CIV	0.00	0.00	0.00	0.00
CRC	0.00	0.06	0.00	0.00
CRO	0.03	0.00	0.00	0.00
CZE	0.64	0.00	9.93	0.00
ECU	0.00	0.00	0.00	0.00
GER	0.22	0.00	0.79	0.00
GHA	0.00	0.04	0.00	0.00
ITA	0.35	0.00	8.36	0.00
JPN	3.05	0.00	0.00	0.00
NED	0.29	0.00	0.00	0.00
POL	0.00	0.02	0.23	0.00
SCG	0.01	0.00	0.11	0.00
USA	0.00	0.00	0.00	0.00

The hypothetical profits from these two measures (described in 2.6. and 2.7.) could be considered lower and upper bounds on the financial magnitude of partition-dependence. Profitability as measured using simultaneously-available bids and asks provides a lower bound because there are so many stretches of time with incomplete bids and asks. Profitability

as measured by the interpolated-price method provides an upper bound because it artificially liquefies the market by assuming there is always a latent trade waiting to occur at the right price (though it is still conservative because it assumes trades would be executed at the worst of the most recent and next future prices).

S3: Study 3: Macroeconomic Indicators

3.1. The Market for Macroeconomic Indicators

In October 2002, Goldman Sachs and Deutsche Bank launched large-scale markets for bets on the outcomes of macroeconomic indicators. The indicators are the change in U.S. non-farm payrolls (NFP), levels of the Institute for Supply Management's (ISM) purchasing manager index (a measure of business confidence), U.S. initial jobless claims (IJC) (adjusted to reflect seasonal hiring patterns), retail sales (RSX) (excluding automobiles, adjusted for normal seasonal variations), and others. These "economic derivatives" (ED) markets were designed to give professionals, such as institutional traders (hedge funds, proprietary traders, pension funds, large banks, etc.) the opportunity to take positions in unexpected fluctuations of macroeconomic risks, and potentially to provide better widespread distributional forecasts of the underlying variables.

For each underlying numerical variable (i.e., the release of a specific numerical macroeconomic indicator) a diverse set of contracts was available for trading, including capped options (capped calls and floored puts), forwards (range forwards), and digital (binary) options (digital calls, digital puts, and digital range options) (see CME [1]).[3] Contrary to plain-vanilla options, digital range options, for example, have two strike prices (a lower and an upper bound) that define a certain interval of the possible outcomes of the indicator. These options pay out a fixed amount ($1) if the released statistic falls within this range and nothing otherwise. Therefore, digital range options in economic derivatives have the same basic structure as the all-or-nothing contracts that are common in standard financial prediction markets.

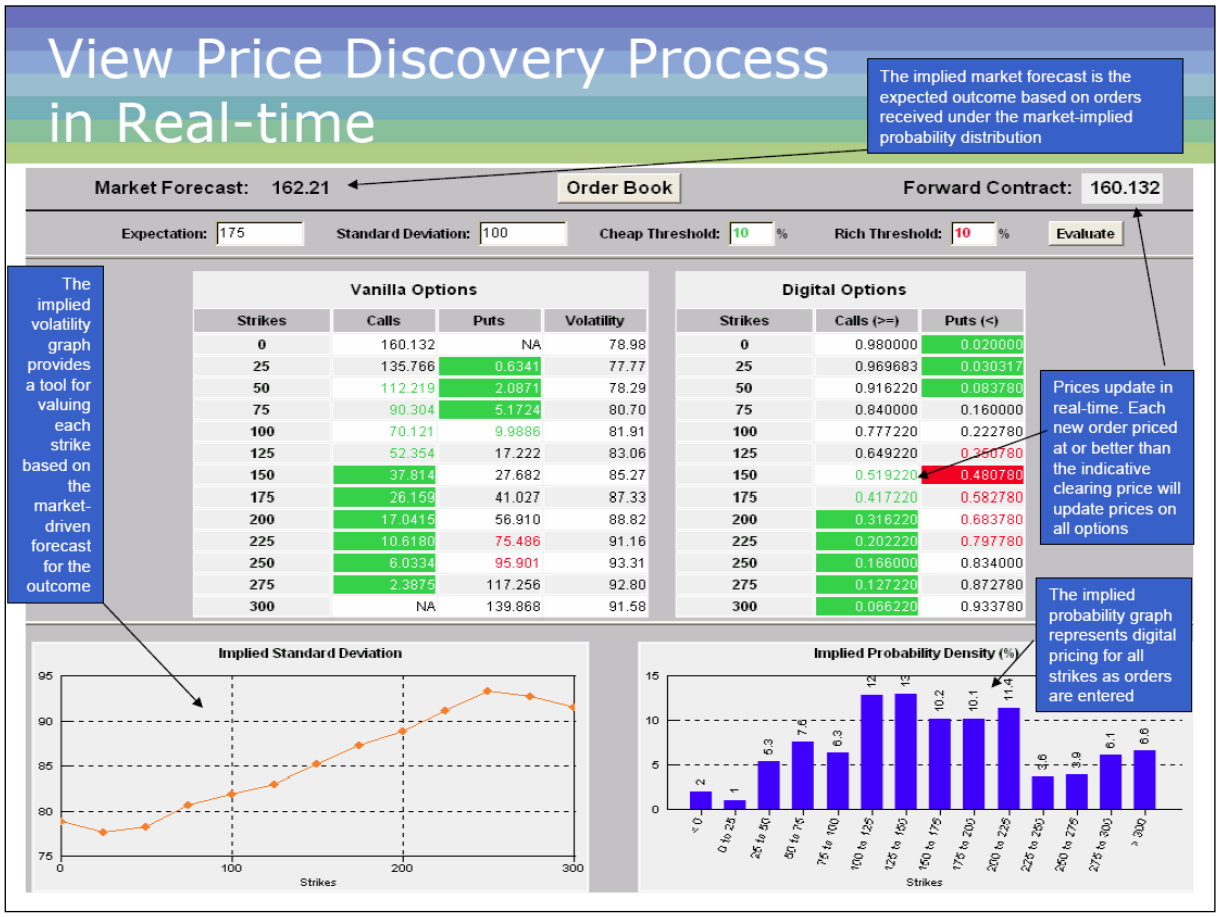
The market mechanism employed is a parimutuel system which is generally used in

[3] Trading in digital options represents about three quarters of trades, but less than half in terms of transaction volume. Hedgers usually prefer plain-vanilla options which account for much larger volumes [2, p.12]

horse race betting and explored a little in the lab [3]. In this mechanism the prices of the instruments are based solely on relative demand for their implied outcomes. Investors who bet on event A and win (i.e., event A occurs) share the winnings from those who bet on all other ("losing") events. As parimutuel clearing applies to all kinds of derivatives offered in the economic derivatives markets (capped options, forwards, and digital (binary) options), these instruments are decomposed into a combination of several "state contingent claims" (SCC) for valuation. The state contingent claims are in fact digital range options based on available exercise prices, which highlights the relevance of the different strike-price intervals of the state space for the pricing of these derivatives. As in horse betting, the trading system periodically discloses interim prices showing what the payouts would be if no further orders were submitted. These auctions typically take place in the morning before the economic statistic is released and are sometimes preceded by other auctions on the same statistic release one or two days before (e.g., non-farm payrolls auctions are held on the morning the data are released and the two days before). Thus, these markets usually have a very short-term forecast horizon and thereby offer hedging opportunities against so-called event risks. Each auction lasts for 1–2 hours.

3.2. Screenshot of Trading Interface for Macroeconomic Indicators Markets

The following screenshot of the trading interface for economic derivatives is taken from "Economic Derivatives. Options on economic statistics", a presentation prepared by trading and sales groups within Deutsche Bank AG and Goldman Sachs.



Vanilla Options

Strikes	Calls	Puts	Volatility
0	160.132	NA	78.98
25	135.766	0.6341	77.77
50	112.219	2.0871	78.29
75	90.304	5.1724	80.70
100	70.121	9.9886	81.91
125	52.354	17.222	83.06
150	37.814	27.682	85.27
175	26.159	41.027	87.33
200	17.0415	56.910	88.82
225	10.6180	75.486	91.16
250	6.0334	95.901	93.31
275	2.3875	117.256	92.80
300	NA	139.868	91.58

Digital Options

Strikes	Calls (>=)	Puts (<)
0	0.980000	0.020000
25	0.969683	0.030317
50	0.916220	0.083780
75	0.840000	0.160000
100	0.777220	0.222780
125	0.649220	0.350780
150	0.519220	0.480780
175	0.417220	0.582780
200	0.316220	0.683780
225	0.202220	0.797780
250	0.166000	0.834000
275	0.127220	0.872780
300	0.066220	0.933780

3.3. PRICES OF DIGITAL OPTIONS AND IMPLIED PROBABILITIES

Market prices can be used to derive a risk neutral density function of the market's aggregated beliefs about the outcome of every single data release. For instance, Figure 3.3.1. shows these probabilities from one set of digital options, for a retail trade statistic announced in April 2005.

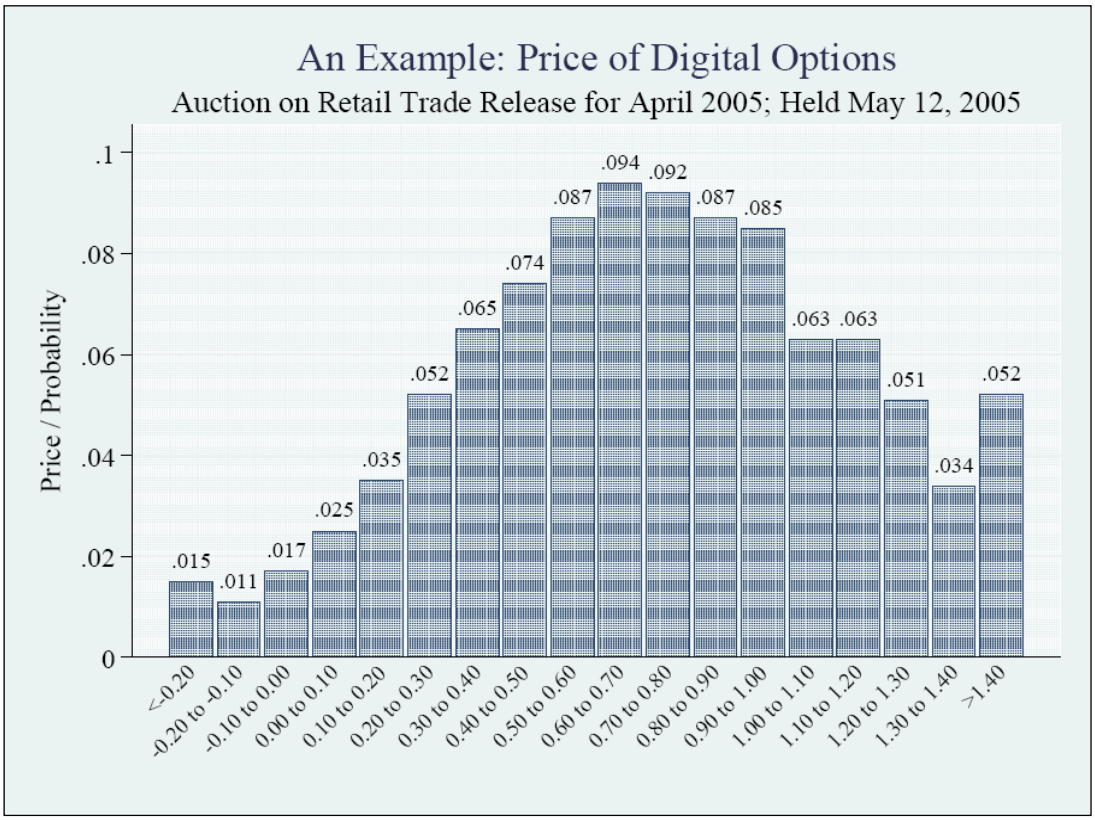


Figure 3.3.1. Prices of various digital options in the market for macroeconomic derivatives. Payouts are determined by the retail trade release for April 2005 (taken from [4]).

As illustrated in the Figure, these markets typically entailed 10 to 20 equidistant strike prices for each upcoming data release, dividing the state space in 11 to 21 mutually exclusive and collectively exhaustive ranges. The ranges are deliberately set to reflect the likely range of the outcomes: strike prices are set to cover at least two to three standard deviations based on

historical volatility of the indicator and the scale midpoint is chosen to reflect mean survey expectations.[4] For example, the strike prices for a U.S. non-farm payrolls auction may range from –250,000 (i.e., a decrease in payrolls from the previous level) to +100,000 in increments of 25,000 jobs. This generates a total of sixteen intervals and a scale midpoint of –75,000 jobs (]–∞; –250,000], [–249,999; –225,000], …, [75,001; 100,000], [100,001; +∞[).

[4] See [5, pg. 47] and [1, pg.5]

3.4. A MIXTURE MODEL FOR INCORPORATING PARTITION DEPENDENCE

Each economic derivatives (ED) market presents a single partition of possible event outcomes to participants (the digital option outcome ranges). We can posit a simple econometric model to estimate the degree of partition-dependence: For each event category x, assume $f_{obs}(x) = (1 - \lambda) \cdot f_{true}(x) + \lambda \cdot f_{1/N}(x)$, where $f_{obs}(x)$ is the probability distribution implied by the observed market prices, $f_{true}(x)$ is the unobserved unbiased probability distribution, $f_{1/N}$ is a distribution assigning equal probability mass to each interval, and λ is the weight on the $1/N$ ignorance prior.

If each event were traded repeatedly, the empirical distribution of realized outcomes could be compared to the distribution of implied probabilities and the $1/N$ distribution to produce a sharp estimate of the apparent weight on the $1/N$ component. However, there is only one observation of implied probabilities for each point of time and each economic statistic. Therefore, we pool the data for the different points of time and across the different statistics.[5] We compute a mean forecast $M_{obs} = \mu(f_{obs})$ for each event by weighting the interval midpoints by the observed probabilities f_{obs} and determine a respective ignorance prior mean $M_{1/N}$ by assigning equal weight to each interval midpoint (and treating the extreme intervals as [4] do). From the definition of $f_{obs}(x)$ it follows that M_{obs} is a linear function $(1-\lambda) \cdot M_{true} + \lambda \cdot M_{1/N}$. Call the actual realization of the economic statistic X. A little algebra shows that the observed forecast error can be written as

$$M_{obs} - X = [M_{true} - X] - \lambda/(1-\lambda) \cdot [M_{obs} - M_{1/N}]. \qquad (1)$$

That is, the observed forecast error $M_{obs} - X$ has two components. The first component is the error term from a de-biased forecast based on $f_{true}(x)$ (which has an expectation of zero). The second component is a negatively-weighted term which reflects the degree of partition-dependence (through the weight λ). Intuitively, suppose the forecast from market data M_{obs} is

[5] To make the statistics comparable we follow [4] and normalize the data by the historical size of the forecast error.

above the equal-weight forecast $M_{1/N}$. If partition-dependence contaminates $f_{obs}(x)$, then $f_{obs}(x)$ is biased downward (toward $M_{1/N}$) relative to the de-biased ideal forecast $f_{true}(x)$ (which is an unbiased predictor of X). This downward bias means the forecast error $M_{obs} - X$ is likely to be negative. Thus, when $[M_{obs} - M_{1/N}]$ is positive $M_{obs} - X$ is likely to be negative (and vice versa). The negative correlation can be used to estimate $-\lambda/(1-\lambda)$ and infer an implied λ.

Table 3.4.1. summarizes the results of estimating regression (1) for markets for four different statistics.[6] This analysis reveals a negative correlation between forecast errors and the forecast – $1/N$ gap, which is consistent with bias toward a $1/N$ prior. Although one of the event domains (initial unemployment claims) shows no bias, the other three domains show substantial bias. When these results are pooled across all domains the results are highly significant. The coefficient estimated from pooling all the event domains, –.77 implies a value of the weight λ=.44 (because –.77 is an estimate of $-\lambda/(1-\lambda)$). Three of the four event domains imply values of λ from .39 to .56.

	No. of Events	Regression Results			Implied Weight λ on $1/N$	
		Coefficient $-\lambda/(1-\lambda)$	t-Statistic	p-value (one-tailed)	λ Implied by Regression	Error-minimization
Initial jobless claims (IJC)	64	0.13	0.16	0.44	-0.15	0.06
Business confidence (ISM)	30	-0.64	-1.88	0.04	0.39	0.08
Non-farm payrolls (NFP)	33	-1.29	-1.53	0.07	0.56	0.56
Retail sales (excl. autos) (RSX)	26	-1.01	-1.32	0.10	0.50	0.50
All statistics pooled	153	-0.77	-2.60	0.01	0.44	0.39

Table 3.4.1. Results of Regressions of Forecast Errors.

[6] These are all the data available from Gürkaynak and Wolfers.

A second analysis computes the mean absolute error between the actual realization of the economic statistic, and the λ-weighted combination of the forecast from the observed probability, M_{obs}, and the forecast $M_{1/N}$, for various weights λ. The values of λ that minimize the error from an λ-weighted combination are provided in the rightmost column of Table 3.4.1. For two of the statistics (unemployment claims and business confidence) the weights are low, but positive. For the other two statistics the weights are close to .50. For all statistics pooled, the error-minimizing λ weight is .39.

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S4: Study 4: Horse Races

4.1. A DETAILED DISCUSSION OF STUDY 4 AND ALTERNATIVE THEORIES FOR 1/N-DRIVEN OVERWEIGHTING OF LONGSHOTS

Study 4 shows that the market-implied probabilities m of a longshot with a (low) empirical relative frequency p* are higher when there are fewer horses N in a race; i.e.,

(1) m(p*|N) is ***decreasing*** in N for low p*

This property (1) will emerge a model in which some fraction of bettors preferences are equally distributed across all N horses, those bettors are strategically naïve (i.e., they ignore information contained in the betting patterns of others), and others possess private information signals and learn from the betting of others.[7] The former naïve betting force will push prices toward 1/N, while the latter force will push prices toward p*. Since the naïve bettors do not respond to price signals (by definition) the resulting prices will be a function of both p* and 1/N and satisfy property (1). Arbitrage will be limited because track takeout means that overall betting is negative-sum (ignoring risk preferences, for the moment).

Ottaviani and Sorensen (2008) give a concise review of several general explanations for the favorite-longshot bias (FLB). The FLB is that m(p*)>p* for low-p* horses. Note that the empirical relationship (1) which is reported here (from the Snowberg and Wolfers working paper) is more specialized than the FLB, and has ***not been established or discussed*** in the previous FLB literature.

We will first note and dismiss some theories that Ottaviani and Sorensen (2008) review that do not apply to natural US markets.

[7] This model is described intuitively by Camerer (1998), and Thaler and Ziemba (1988). So far as we can tell, it is not in the literature otherwise in a formal way.

One alternative theory (Isaacs 1953) is that informed bettors have market power, and "underbet" the favorite on purpose, to preserve returns on inframarginal bets (leading to residual overbetting of longshots). This is highly unlikely in US betting markets because there is free entry, and no evidence of concentration of betting activity. A closely related alternative theory is that private bookmakers (which exist in the UK and other countries) have market power (Shin 1991, 1992) and create a similar effect on prices, but the US data are all from the track-operated pari-mutuel system, so this explanation cannot apply. Hurley and McDonough (1995) and Terrell and Farmer (1996) showed that the FLB can result because the amount of arbitrage is limited by the fact that the track takes a percentage of the betting pool (15-25%) before paying winners from the post-take losing bets. Note, however, that in lab and field experimental studies 1 and 2 in our paper, arbitrage is **not** limited because traders can always buy a spanning set of contingent claims and there is no equivalent of track take-out.

Two types of explanations that plausibly account for the FLB in the pari-mutuel US data, and **might** also account for property (1): Preferences, and microstructure interactions with heterogeneous beliefs or signals.

Preferences

The earliest explanation for FLB was proposed based on the earliest evidence, by Griffiths (1949). He suggested that low probabilities are generally overweighted. Weitzman (1965) suggested the FLB is due to standard risk preference in the sense of convex utility (which can explain why bettor accept negative expected value bets in the first place). Griffiths's simple explanation held up over time reasonably well. Snowberg and Wolfers (2010) construct a crucial test between overweighting of probability and risk-loving preferences and conclude that the former is a better description.

In a different domain, Barberis and Huang, 2008, argue that an apparent preference for

positive skewness in "lottery stock" returns, and overpricing of out-of-the-money options (relative to Black-Scholes type models), cannot be explained by a preference for a skewness, and are better explained by overweighting of low tail probabilities. Polkovnichenko and Zhao (in press) provide further evidence of probability overweighting from options markets.

Both the overweighting and risk-loving theories treat a single bet on a horse, at an "objective" probability (estimated by empirical frequency p*) as a single risk that is evaluated. In this type of model, it does not matter whether a horse with a .03 objective probability of winning is competing with 5 or 11 other horses. So these theories do not make any prediction about how m(p*|N) depends on N.

Microstructure interactions with heterogeneous beliefs or signals:

Several interesting explanations use the interaction of trading microstructure and heterogeneity to explain the FLB. In an early contribution, Ali (1977) showed that if risk-neutral bettors have heterogeneous prior beliefs and capital constraints, then the market probability of all horses are less extreme than the median bettor's belief. (Note that this theory is ideally tested using data in which individual beliefs and market prices are compared. Our study 1 has such data from the lab, and finds no difference between median beliefs and market prices; so the Ali (1977) explanation cannot explain study 1.)

The most empirically convincing recent theory assumes that traders all get private information signals based on a common prior belief, but trade is simultaneous (Ottaviani, Sorensen, 2009, 2010). As a result, even though traders have rational expectations, they are statistically "surprised" ex post, by *which* favorite emerges when the results of the simultaneous betting are announced. Given that revelation, they would prefer to bet more on the revealed favorite and cancel bets on the revealed longshot, but are assumed to be unable to do so. The result is an FLB. (The outcome satisfies ex ante rational expectations in the sense

that betters cannot guess ex ante *which* ex post favorite will be underbet, even though they would like to recontract ex post on whichever horse emerges as the surprise favorite.)

This theory does reasonably well with some empirical stylized facts. Here are the weaknesses: (a) It does not always predict a favorite-longshot bias (depends on the number of horses being small relative to bettors, and on information being sufficiently precise); (b) the main proof only holds for an equal common prior for all horses [their Figure 4 illustrates a slight dampening of the FLB for an asymmetric prior]; and (c) the effect is completely eliminated if trading is not simultaneous. Furthermore, they consider the case in which the number of bettors is held fixed but the number of outcomes (e.g. horses) changes (Ottaviani and Sorensen, 2010, section 5.3). In extreme cases a reverse FLB can result. However, they do not present a proof that increasing N (the number of horses) reduces the longshot bias, as the 1/N PD heuristic predicts. It is *conceivable* that one might derive such a result from their framework, but it is not shown in their paper.

Their paper rests heavily on the assumption (c), which they report as a stylized fact that "a large proportion of bets are laid in the very last seconds before post time." (p 2 of their working paper). However, this late-trading claim is just not correct empirically.[8] Bettors in this market *are* able to observe interim prices in the last couple of minutes and trade, to some extent, accordingly.

Conclusion: There is extant no theoretically robust alternative explanation that can explain the 1/N effect we observe in the horse racing field markets . The Ali-type explanation

[8] OS's (2010) source is a consulting report in 2004. (http://www.hbpa.org/resources/Ntrataskreportsep04.pdf). Actually, the report does not contain any data at all on how much "very last second" betting there is. Instead, it is an analysis of how rapid program trading **can** generate last-minute betting precisely (in a way that is designed, actually, to overturn the OS result by enabling program traders to exploit information revealed in the very last time periods). Camerer (1998) reports a small sample of data suggesting that about half the betting occurs in the last three minutes before the race is set to begin ("post time").

can be ruled out by direct experimental comparison of beliefs and prices (as in our study 1). This lab data is a different source of data than Ali et al. have in mind but is precisely lab-field complementarity. The Ottaviani/Sorensen explanation depends on several assumptions that are difficult to test, and particularly on no late betting, which is empirically not tenable. As a result, we cannot be sure that the 1/N explanation is the correct one, but we can be confident that there is no better alternative explanation that is both theoretically and empirically well-grounded.

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