Testosterone and Trading: A Biological Driver of Asset Mispricing

By

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Abstract: Traditional finance theories state that asset prices are determined by firm fundamentals, such as per-share earnings and relative risk. However, a growing body of literature shows prices often do not reflect underlying value and are largely formed by expectations of future cash flows that are discordant with financial fundamentalsand are vulnerable tocross-sectional sentiment influences. This paper demonstrates asset mispricing by a biological driver of competitive bidding—testosterone—in experimental asset markets. We show that testosterone drives competitive bidding leading prices to dissociate from fundamental value, producinglarger andlonger-lasting bubbles. Further, testosterone reduces trading performance and increasestraderoverconfidence.

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Introduction

Traditional financestates thatasset prices aredetermined by firm fundamentals, such as per-share earnings and relativerisk, and financial markets efficiently allocate resources.Yet what trading behaviors cause asset mispricing? And what drives those behaviors? A growing body of literature shows systematic deviations from efficiency and identifies factors unrelated to asset fundamentals[1], such as sunshine, hours of daylight, mood, and professional sports outcomes that affect asset prices.Behavioral asset pricing models show that noise traders move markets away from efficiency, increase volatility, and create abnormal returns despite the presence of information traders (Shefrin and Statman 1994). Further, prices often do not reflect underlying value and are largely formed by expectations of future cash flows discordant with financial fundamentals (De Long et al. 1990), with cross-sectional sentiment influences (Bakerand Wurgler 2006).People, after all, determine prices.

Economic history provides evidence of prices exceeding fundamental values for extended periods of time, most recently in housing prices (Bernanke 2010) and most colorfully in the tulip bubble of the 1630's (Garber 1989). Price bubbles driven by credit booms can damage the economy by degrading the stability of the financial system (Allen and Gale 2000). In addition to procyclical expansions of credit and unknown future cash flows of firms (which cause wildly divergent valuations), biology could also be a driver of overpricing. Microstructure studies suggest bidding and selling give rise to prices and trading volume; increases in buying volume reduce bid-ask spreads and assert upward pressure on prices, while aggressive selling depresses them (McInish and Wood 1992). Understanding pricing mechanics can improve our understanding and prediction of equilibrium prices yet despite an extensive asset pricing

[1] Sunshine: Hirshleifer and Shumway 2003; hours of daylight: Kamstra, Kramer, and Levi 2003; mood: Bassi 2013; sports: Edmans, García, and Norli 2007.

literature little is known about what drives individual asset trading decisions. This paper demonstrates asset mispricing by a causal biological driver of competitive bidding—specifically, testosterone—in experimental asset markets.

Studies such as Lo and Repin (2002) showing significant physiologic responses to market events in active professional securities traders and Kandasamy et al. (2013) testing the effects of stress hormones on risk aversiondemonstrate that biological factors can have substantial impact on financial decision making.Empirical, field, and experimental studies comprise a broad literature spanning psychology, neuroscience, and economicsshowinghormonal influences on how people buy, sell, and take risk.

Hormonesare chemical messengers regularly released in the body that affect the likelihood of behaviors, and testosterone is one of the most potent. Testosterone is an androgen (sex hormone) thatdirectsphysical development and influences behaviors such aggression,competitiveness, dominance, risk-taking, career choice, and economic decision making[2].A buddingliteratureshows how testosterone affectsfinancial behavior, yet none have tested for causal effects onasset tradingin men.Coates et al.(2008)show correlation between testosterone levels and earnings for a small sample of traders, introducing questions about testosterone's role on trader behavior. Our study investigates the mechanics of asset pricing and how testosteroneaffects competition, changes buying and selling,impacts volatility and trading volume, drivespricebubbles andimpacts earnings for individual traders.

This paper connects finance literature with biologyto understand asset pricing by usingan experimental asset marketparadigm where a single variable—testosterone—is manipulated

[2]Winning and losing: Booth et al. 1989; Dominance: Mazur & Booth, 1998; Trust: Zak, P.J., Kurzban, R., Ahmadi, S. Swerdloff, R.S., Park, J., et al. 2009; Trust and reciprocity: Boksem et al. 2013; Gender Differences: Sapienza, Zingales, Maetripieri, 2009; Optimizing: van Honk et al. 2004, Stanton, Liening, & Schultheiss 2011; Competition: Apicella, Dreber, & Mollerstrom 2014

within normal physiologic range, meaning that traders in the experiment are in hormonal states men experience naturally. Our methodologyallows us to draw clear conclusions about causation between testosterone levels and trading behaviorand attendant impact on equilibrium prices. We accomplish this by simulating changes that normally occur within the body via exogenous manipulation, that is, by administeringsynthetic testosterone to traders. The advantage of administering a hormone exogenously is that it allows clear identification stemming from different levels normally found in people's bodies.

We use the same drug that is prescribed to nearly 2 million men each year and used extensively by financial professionals (Wallace, 2012). With the proliferation of advertising aiming to remedy "low testosterone syndrome" and ease of receiving medical prescription, a large and growing proportion of men are currently using Androgel (and similar generics), and some inject anabolic steroids at (remarkably) higher doses (Baillargeon et al. 2013).In fact, the meteoric rise and high penetration rates of this drug among financial professionals allows our experiment to mimic the "testosterone shock" in real-world asset markets such as the NYSE.

We use an experimental asset trading framework known as a "continuous double-auction" market to simulate a typical, dynamic market environment. First introduced in Smith, Suchaneck, and Williams (1988), this trading platform allows traders to post offers to buy and sell shares, view all offers posted by others (i.e., limit orders), and tradesimultaneously in real time. One of the key features of this market is that all traders know the fundamental value of the asset while they trade, which allows for clear identification and measurement of price deviations and bubble formation. Another feature is that individual buying and selling prices and volume endogenously determine market prices, making drivers of mispricing more readily

identifiable.Thisdesigndistills essential components of financial markets,offersreal money trading earnings, and, ultimately, allows clearhypothesis testing in a controlled setting.

We measurebid and ask prices posted, profitability,and testosterone levels for every participant, as well as average prices, bid-ask spread,measures of price deviations, and volume. Also, we collect survey data to assess participants' opinions of market prices, theirown and others' relative trading performance, as well as the reasons for their performance.We find that bubble size, rate of price increase, and price volatility are higher in high testosterone markets relative to marketswith non-manipulatedlevels of testosterone. Competitive bidding drives up prices, which motivate upward price movements above (publically known) fundamental values and sustains high prices until a burst occurs and dramatic subsequent decrease in prices follows. Further, market prices increase as buying offers increase in quantity and at higher bidding prices among traders with elevated testosterone but not inmarkets with non-manipulated traders. We corroborate our findings by showingthataverage testosterone traders accurately and systematically incorporate(declining) fundamental value into their trading prices, while testosterone-treated traders do not.A deterministic factor perpetuating bubbles among traders with elevated testosterone istheir systematically higherbids as prices serially increase. Normal-testosterone trading groups do not do this. The rate at which bubbles formed is greater among high-testosterone trading groups, which leads to rapid sell-offs after the burst of the bubble. This is reflected in a greater volatility in high-testosterone markets. We find a negative correlation between testosterone levels and earnings from trading, and a positive correlationwith share accumulation through competitive purchasing with testosterone levels.These results are related because aggressive over-buying of overpriced assets lead to poor performance. Testosterone-treatedtradersare more likely to attribute their success to their own talent, quality of their

calculations, and individual strategies relative to placebo participants, who rate themselves as more lucky. Testosterone-treated tradersperceive prices as “too low” despite remarkable upward departure from fundamental value.

The paper is organized as follows. The next section describes the experimental asset markets, andthe rationale for testing the influence of hormones on financial behavior. Section 3 details the associated hypotheses. Section 4 presents the results, and section 5 summarizes and proposes future work that can triangulate these results with congruence to broader financial markets.

2. Experimental Asset Markets and Biological Influences on Trader Behavior

2.1 Experimental Financial Markets

Laboratory experiments bridge the gapsbetween empirical studies thatface exogenous shocks and measurement difficultiesand theoretical modelsthat areoften difficult to test to obtain a better understanding of complex financial systems. Controlled experiments identify underlying data-generating processes, mechanisms, and causalfactors influencing equilibrium prices. This is the approach we takehere. We use the Smith, Suchanek, and Williams' (1988) (SSW henceforth) experimental market paradigm—a lab-based asset trading market characterized by public and transparent asset fundamental value structure, balanced overall endowments between traders, a simple stochastic dividend, and clear trading rules.The controlled trading environmentallows for identification of pricing dynamics because the number of variables is drastically reduced.The spartan framework of thesemarkets is a feature, not a shortcoming, and allow for manipulation of market structures to determine their impact on trading behavior and equilibrium prices.Many studies have used the SSWparadigm, including testing the influence of short-selling on bubbles, whether experience reduces the size of bubbles, if infusing the market with money can re-ignite overpricing, and if confusion drives price bubbles[3]. The perennial result is that bubbles form with inexperienced traders (although seasonedbusinesspeople, too, create bubbles), and that experience reduces mispricing over time.Our motive for employing theSSW-type double-auction continuous call framework is not to study bubble formation*per se* but to causally test a possible biological driver ofbehaviorsthat lead to asset mispricing, itseffect on the market, and impact on individual trading performance.

[3] Short selling: Haruvy & Noussair 2006; experience Dufwenberg, Lindqvist, & Moore 2005; rekindling: Hussam, Porter, & Smith 2008; confusion: Kirchler, Huber, Stöckl 2012.

2.2 Biological Influences on Financial Decision Making

A growing literature in finance, economics, and psychology has identified channels influencingfinancial decisionmaking independent of the intrinsic value of the asset in question.Weather, sports outcomes, time of year,journalist reporting (independent of market conditions), and more recently, biological factors are shown to systematically influenceinvestor behavior and asset prices[4].Psychological biases are pervasive among financial professional's decision makingand can be seen in empirical research such as the disposition effect (Odean 1998) and herding (Welch 2000),myopic loss aversion in experimental settings (Haight and List 2008), and for general investors (Thaler, Tversky, Kahneman, and Schwartz1997).

Kuhnen and Knutson (2011) show that excitement and anxiety have opposite effects on investment decisions, with positive affect increasing confidence and risk taking and negative affect attenuating both. Lo and Repin (2002) show significant physiologic responses to market events in professional foreign exchange and derivatives traders in their working environment, demonstrating arobust market-mind-body connection. Kandasamy et al. (2013)show specific hormones released during stress causally increase risk aversion when stress is chronically high. Similarly, Coatesand Herbert (2008) show that market volatility is reflected in biological responses of individual traders, whereby they release stress hormones in sync with the variance of the assets they trade(supporting the standard Markowitz 'like expected returns, dislike variance'duality of financial securities).

[4] Edmans, Garćia, and Norli (2007) show how international sporting outcomes, such as soccer affect returns as a consequence of mood changes[4]. Thaler (1987) presents convergent evidence of systematic excess returns in January despite arbitrage opportunities. Dougal et al. (2012) show a causal influence of *Wall Street Journal* columnists on stock prices by dampening or amplification of salient sentiment. Bassi *et al.* (2013) corroborate previous work on weather by demonstrating that mood is the channel by which weather modulates risk aversion and, by extension, financial decision making. Risk preferences can be affected by simple market information. Cohn et al. (2013) show counter-cyclical risk aversion changed after presenting a depiction of downward secular trend[4] to financial professionals. Andrade, Odean, Lin (2012) manipulate mood through videos prior to trading and show larger price bubbles form in experimental markets after traders watched exciting videos relative to neutral and fearful.

Biological mechanisms evolved in humans to increase the probability of survival, procreation, and species perpetuation in uncertain environments (McDermott, Folwer, Smirnov 2008). Those biological systems likely drive market behaviors because the same brain regions that process risk and reward in financial choicesexisted long before the first IPO(Kuhnen and Knutson 2005; Preuschoff, Bossaerts, and Quartz 2006).Risk aversion kept humans alive in the face of meaningful uncertainty that today can manifest as avoidance of risky assets and over-reactions to earnings news (McDermott, Fowler, Smirnov 2008; Veronesi 1999; Kandasamy 2013).Financial decision making is an integrated process where risk and reward are valued by interconnected neural systems. In an fMRI experiment where multiple participants were scanned simultaneously while trading assets, Smith et al. (2014) show differential neural responses to price changes, and find different activation patterns between high and low earners. Hormones influence neural activity that can encourage or discourage behaviorsin changing environments and are therefore a testable channel of asset mispricing.

The human body produceshormones systematically, cyclically, and responsively. Testosteroneis produced in a multi-step process starting with the brain signaling the testes (in men) and concludes with its release into the bloodstream. Testosterone has daily, seasonal, and lifetime patterns:it is highest in the morning and declines throughout the day; peaks during summer and spring; declines throughout the lifetime after spiking in the late teens. Testosterone has been shown to vary naturallyin the body, decreasing as low as 60% (Kreuz et al., 1972) to increasingas much 72% (Escasa, Casey, Grey, 2011). Changes in testosterone activate physical, emotional, and perceptual factors in the short term, as well as long-term developmental pathways.Dihydrotestosterone (DHT) is the ‘high octane version’ (“metabolite”) of testosterone known to assert strong behavioral influences in men (Grino, Griffin, and Wilson 1990). Previous

work shows that testosterone is associated with aggressive behavior, reduced cognitive ability, increased appetite for competition, and relative earnings, and DHT is associated with emotional reactivity.

Testosterone production is affected bycompetition, status, dominance, and aggression[5]. Changes in hormone levels influence behaviors that can stimulate additional production of the hormone—hormones affect behavior, and behavior influences hormones (Makino, Hashimoto, and Gold 2002). For example, menwho were shown distrust produced a spike ofDHT,which is likely to induce aggression and further release of testosterone (Zaket al. 2005). This positive feedback cycle is likely relevant in financial markets, where decisions and market behavior affect and are likely affected by hormones.

Despite popular culture's characterization, testosterone is not simply the 'male aggression' hormone—women also produce it, and testosterone has anxiolytic and analgesic properties (Aikey et al. 2002; Hermans et al. 2008). Aggression is not always a direct outcome of high baseline levels of testosterone, but can result fromchanges in testosterone(Choi, Parrott, Cowan, 1990; Zak et al. 2005; Mehta and Josephs 2006).

Although correlations have been foundbetween testosterone and financial trading, this is the first study demonstrating clear causality.

Experimental work shows that engaging in competition is correlated with increases in testosterone and that increases in testosterone correlate with increased willingness to compete (Booth et al. 1989; Apicella, Dreber, and Mollerstrom 2014). Coates and Herbert's (2008) paper on hormones and financial trading at a London trading firm suggests that there is correlation between asset trading performance and testosterone. van Honk et al. (2004) show that

[5] Competition: Booth et al. 1989; status: Mazur & Lamb 1980; dominance: Mazur & Booth 1998; aggression: Choi, Parrott, & Cowan 1990.

testosterone administration caused greater proportion of choices from the "bad" card decks in the Iowa Gambling Task. Similarly, Stanton, Liening, and Schultheiss (2011) show a correlation between baseline testosterone levels and choosing negative payoff decks of the Iowa Gambling Task, though it is unclear whether it is due to impaired learning or *bona fide* risk-taking. Sapienza, Zingales, and Maestripieri (2009) suggest that basal testosterone levels predict risk taking among females, and that high prenatal exposure predisposes both genders to choose high risk careers. However, no study to date had testedwhether testosterone causally affects financial trading. Given that the majority of traders are male (Stock 2010; Coates and Herbert 2008) and that their decisions are highly meaningful economically, understanding factors affecting their financial trading is paramount.

Testing testosterone's causal effects on financial trading requires changing testosterone in the body to in order tocompare active financial trading to men withnon-manipulated levels—the keytoascertaining testosterone'sinfluence isto inducechanges to determine causality and widen the range of the explanatory variable itself[6].

2.3Experimental Design

Our experiment consists of seventeen groups of male participants (referred to as traders) recruited from the Claremont Colleges (total n=144). Ten groups were given testosterone and seven were given a placebo. The testosterone dose increased traders' testosteronelevels to "high normal" levels comparable to the normal range of variation for men in their respective age group (Salameh et al. 2010), variation that has been shown to occur naturally (Escasa, Casey, and Grey 2011). The experiment wasa double-blind design and each sessiontook place over two daysto

[6]There is an extensive clinical literature on testosterone and its manipulation as well as a commercial, widely prescribed synthetic drug (Androgel®) used to increase testosterone in men. The process by which the body absorbs, processes, and eliminates the drug is clearly documented as well as the time-course of levels in the body after administration.

allow testosterone levels toincrease and stabilize following exogenous application. The first session consisted of a medical screening, blood draw, and demographic survey; trading took place the following day after a second blood draw (See Appendix for exhaustive experimental design).

Only males were included because the United States Food and Drug Administration only approved the synthetic testosterone drug used in the experiment (Androgel®) for men, and our primary question is about the effects of testosterone on asset trading in men.Our sample includes MBA, financial engineering, finance, economics, business students as well as every other discipline from the Claremont Colleges. All traders in a session were given either testosterone or a placebo so all traders in the sessionhad elevated or average levels, respectively.

Trading was done in z-Tree (Fischbacher 1999) usinga continuous double-auction market with an asset yielding a stochastic dividend following Smith, Suchanek, and Williams(1988). The asset paid a dividend of 0 or 18 cents at the conclusion of each period with equal probability, giving it an expected value of 9 cents for each of 12 periods. The fundamental value of the asset began at$12 \times 9 = 108$ cents at the start of each round, decreasing by 9 cents each period and reaching zero at the end of each round (periods 12, 24, and 36) (see Figure I). Participants were provided with a chart of the expected value of a share of stock over the duration of periods (See Appendix for complete instructions and the table of fundamental values).

The double-auction format allows participants to place bids to buy assets as well as offers to sell them simultaneously with full information about market-clearing prices and currently posted offers, mimicking advanced trading environments.Each group of participants constituted a *session* consisting of three distinct *rounds* of 12 *periods*. Participants were endowed with either 6 stocks and 216 cents, or 2 stocks and 648 cents at the start of every round by random assignment

(both endowments are monetarily equivalent to 864 cents).The resultingdata include market level data, such as prices,volume, and rate of price change. Individual data include bids and asks, individual trader's profitability, and survey responses.

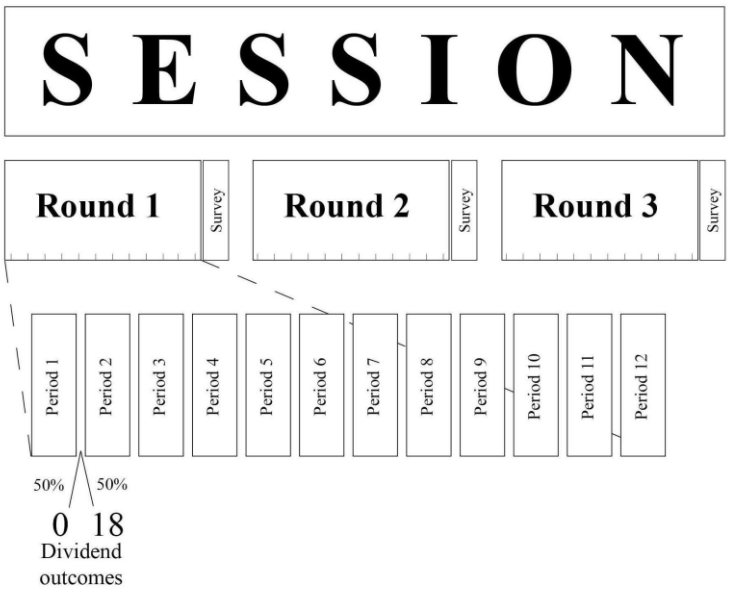


Figure I. Trading took place in three rounds of twelve periods each in each session. After each period a dividend of either 0 or 18 is issued to every share of the asset(i.e., every share in the entire market receives the same dividend). After each round a survey was given to assess participant market perceptions and attribution of performance. It includes questions such as, "What do you think determined your performance?" where traders rate on a 1-7 scale how specific factors such as luck, talent, and their calculations. In addition, traders were asked about whether prices were higher or lower than expected and whether price fluctuation was higher/lower than expected.

3. Hypotheses

In the following section we outline the motivation for testing the influence of testosterone on financial trading in an experimental setting, and set forthtest specific testable hypotheses regarding whether testosterone causes asset mispricingand identify behavioral drivers from which mispricing arises.

3.1 Motivation for measuring effects of testosterone on financial trading

A mature literature in biology showshormones affect humans and animalsin subtle and dramatic ways (e.g., signaling satiation to stop eating, to sparking violence, respectively), and convergent evidence suggests testosterone may play a role in economic behavior.

Thus, pairing the SSW-type asset trading paradigm with testosterone is a natural fit to test hormonal causality in financial decisions making while simultaneously identifying microstructural drivers that give rise to market outcomes. If testosterone affects financial trading then it would be captured both in equilibrium prices as well as microstructural drivers in those markets.

3.2 Primary Questions

The chief questionsare,*does* testosterone affect trading of financial assets in a dynamic market—a process involving learning, timing, and dynamic adjustment in a rapidly changing environment—and, if so,*how*?The first question is answerable by comparing market-level data such as average prices, price volatility, and volume of trades (called *turnover*) between trading groups with elevatedtestosterone relative to those with average levels (placebo groups). The second is addressed by testing individual-level data such as prices and quantities of bids to

purchase and offers to sell. Together, a complete picture of markets and their microstructural underpinningemerges.

Price Bubbles

The primary step of the analysis is to compare transaction prices in testosterone trading sessionscompared to placebo.If prices are indeed different between treatments in a market trading an asset with a universally known fundamental value it would support the hypothesis that testosterone affects prices. Also, having a clear fundamental valuestructure allows for unambiguous identification of price bubbles by using standard measures in the experimental literature. We test for differences in market prices and their persistence between conditions using *amplitude* and *market value amplitude* (MVA). Both measures capture the differences between average price per period and the corresponding fundamental value (explained in more detail in results section below). We expectedprices to be higher in testosterone sessions relative to placeboin early trading rounds and thatthese differences woulddampen over time. This prediction is consistent with experimental asset trading of this type and it is likely due to the design of the experiment, markets with higher testosterone should display the same pattern. Further, it is likely that a uniform or increasing fundamental value would elicit more dramatic price differences.

Bid and Asks

Consistent with literature showing higher levels of testosterone predicting willingness to compete, we expect that the high-testosterone traders will bidmore aggressively (i.e., higher quantity and higher prices) for the asset.Complementarily, asking pricesare expected to be higher among high-testosterone traders in response to elevated bidding. If these predictions bear out we will have a channel by which prices differentially increase and form bubbles.

Persistence of Price Deviations

We expect that higher levels of testosterone will lead to market prices that persist above their associatedfundamental values over consecutive periods of trading. In other words, we do not expect spontaneous or short-lived blips, but relatively protracted deviations in initial trading rounds. The standard measure in the experimental literature is *duration* and captures the number of consecutive rounds pricesexceedfundamental value.

Trading Volume

Due to the likely increase in competitiveness among high-testosterone males we expect that more shares will transfer ownership over the course of the experiment. This will be evidenced by comparing the normalized number of shares (called *turnover*) transacted over the course of the experimental session. However, it is possible if there is a strong asymmetry between bids and asks that the number of transactions will not necessarily be larger in high testosterone trading groups.

Prices in sync with fundamental value

Smith, Suchanek, and Williams'(1988) analysis of period-by-period price adjustments measure how accurately traders incorporate assetfundamental value in their trading decisions. We expect that the period-to-period linear decline in fundamental value will not be clearly reflected in incremental price changes in the testosterone and systematically adjusted for in placebo sessions. Put differently, prices inhigh testosterone sessions are expected to trade out of fundamental value patternover time, meaning that prices period-to-period will not adjust to asset declining fundamental value.

Testosterone's effect on earnings

Based on Stanton, Liening, and Schultheiss (2011) and van Honk et al. (2004) we expect earnings will have a negative relationship with testosterone levels. Given literature showing impaired updating and reduced anxiety, we expect testosterone to decrease earnings for individual traders and show a significant negative relationship between blood levels of the hormone and earnings.

Testosterone and confidence, market sentiment

Albeit scant research has been done on testosterone and self evaluation of performance, we expect high testosterone traders to attribute their success to their skill, talent, and calculations and less to luck. Studies in have shown testosterone improves mood (Pope, Kouri, and Hudson2000; Anderson, Bancroft, and Wu 1992) and moods effects on confidence (Bassi, Colacito, and Fulghieri 2013) we expect minor difference in mood relative to normal testosterone peers and a subsequent increase in trader confidence caused by elevated testosterone. Given that prices are likely to be higher in the high testosterone sessions, it is unclear*a priori* whether traders in those sessions will consider prices too low or too high relative to average testosterone traders with probably lower prices.

4. Results

Exogenous treatment increased testosterone levels in the treatment groups while traders given placebo had no significant changes, allowing for clear identification. Our hypotheses about market prices, volume, and mispricing persistence were mostly confirmed and explained through high-frequencyindividual trading data. We use established measures(and developed new ones) to quantify the effects of testosterone on asset trading and address our specific hypotheses. All

measures of bubble size were greater and longer lasting inhigh testosteronemarkets compared to placebo,with the most significant effects in round 1. Individual trading data show that high testosteronetradersbid prices higher as prices rose and continued to do so, thus creating durable mispricing patterns. Average testosteronetradersincorporatedecreases in fundamental valueinto their trading strategies while high testosterone sessions show a stuntedability to do so. Testosterone levels negatively correlate with earnings, and high testosterone traders view themselves as more talented and skillful, and perceived prices as being "too low" despite patent overpricing.

Changes in Testosterone in Treatment Group

Baselinetestosterone and DHT levels were similar between treatment groups. The testosterone group's average testosterone level was473 ng/dl (nanograms per deciliter, a standard measure of hormones in blood) and the placebo group averaged 439 ng/dl with standard deviations of 158 and 170, respectively (t-test between treatments: p=0.37). DHT levels were similar as well at baseline (p=0.37). After administration testosteroneand DHT levels were measured and found significantly higher in the testosterone groups compared to placebo. The testosterone group average increased 63%to 771 ng/Dl (p=0.000), while the placebo group was statistically similar to their initial levels with 485 (p=0.16)[7]. DHT levels increased 180% from 47 to 132 ng/dl in the testosterone-enhanced group (p=0.000), while placebo group levels remainsimilar (41 ng/dl on day 1, 51 on day 2, p=0.06) (see Figures II.a. and II.b.).Traders in the testosterone group had levels within the normal reference range (Salameh et al., 2010), with only 5 traders who exceeded this range, and only slightly so.

[7]Given that measurements were taken at different times of the day variation is expected and in the direction observed. Levels are highest in the morning and decline throughout the day (first measurement was in the evening and the second was taken at noon). Intraday variability for young men is approximately 20% (Brambilla et a. 2009).

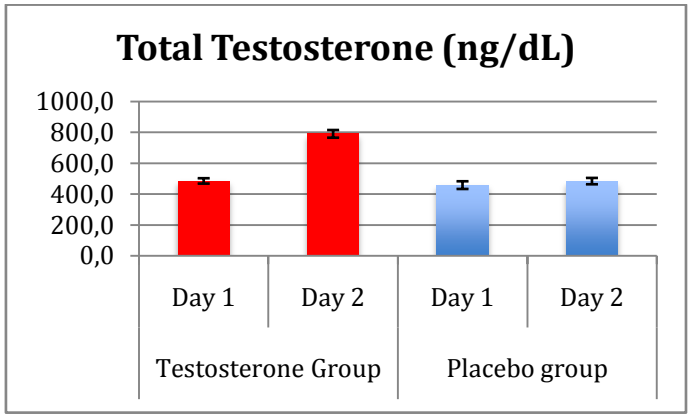


FIGURE II.A. TOTAL TESTOSTERONE LEVELS AT BASELINE ARE COMPARABLE BETWEEN CONDITIONS (DAY 1).POST-ADMINISTRATION LEVELS SHOW THE TREATMENT GROUP'S AVERAGE 63% INCREASE IN TOTAL TESTOSTERONE WHILE THE PLACEBO GROUP AVERAGE DID NOT SIGNIFICANTLY INCREASE (DAY 2).THE INCREASE IN THE PLACEBO GROUP'S TESTOSTERONE ACCORDS WITH THE NATURAL DAILY CYCLE.

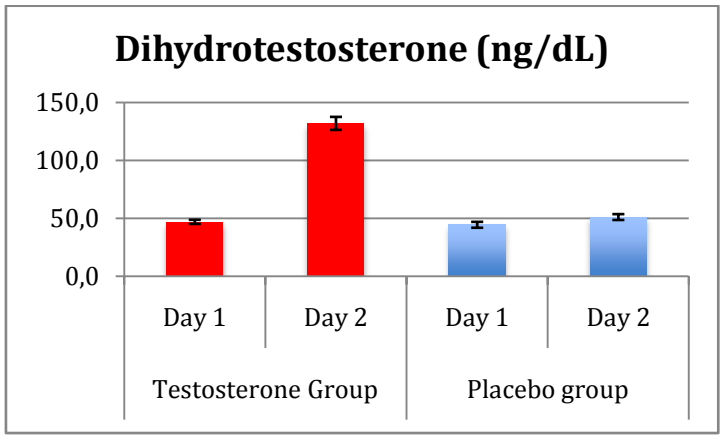


FIGURE II.B. DIHYDROTESTOSTERONE LEVELS ARE COMPARABLE BETWEEN CONDITIONS AT BASELINE, MEANINGS TRADERS ARE SIMILAR. AVERAGE POST-ADMINISTRATION LEVELS SHOW TREATMENT GROUP'S DIHYDROTESTOSTERONE INCREASED BY 180%. SIMILAR TO TESTOSTERONE, DHT HAS A DIURNAL CYCLE AND IS EXPECTED TO BE HIGHER AT THE TIME OF THE SECOND BLOOD DRAW BECAUSE IT IS EARLIER IN THE DAY THAN THE INITIAL SAMPLE POINT.

Market Analyses

We find clear evidence of higher prices and greater price deviations from fundamental value in the testosterone trading groups relative to placebo, affirming our primary hypothesis. Figure III shows the mean per-period price deviation from fundamental value is markedly higher in high-testosterone trading groups.

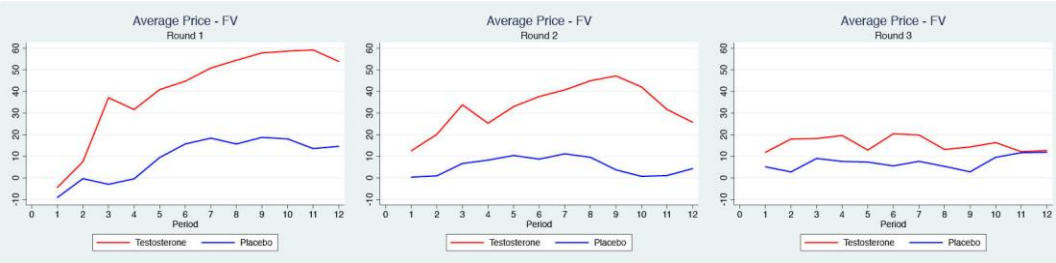


FIGURE III. AVERAGE PRICES MINUS FUNDAMENTAL VALUE ARE SHOWN FOR EACH ROUND BY TREATMENT CONDITION.IT IS EVIDENT THAT AVERAGE PRICES IN HIGH TESTOSTERONE SESSIONS ALWAYS EXCEED CORRESPONDING PERIOD'S PRICES IN BASELINE TESTOSTERONE SESSIONS. CONSISTENT WITH OTHER ASSET TRADING EXPERIMENTS, BUBBLES DECREASE IN SIZE WITH EACH PROGRESSIVE ROUND YET WITH SIGNIFICANT DIFFERENCES BETWEEN CONDITIONS.

The primary measures of bubble size are *amplitude*, the trough-to-peak change in market asset value relative to fundamental value, and *market value amplitude*(MVA), which is amplitude multiplied by associated volume of trade in that period (see Table I in Appendix for definitions of all measures). We find that testosterone groups formed statistically larger bubbles than placebo groups in the first round of trading[8] (See Table I).

TABLE I—SUMMARY OF FINDINGS FOR DIFFERENCES BETWEEN MARKETS WITH HIGH TESTOSTERONE AND AVERAGE LEVELS OF TESTOSTERONE(PLACEBO).

[8]We test differences using every published measure of bubble size and obtain the same pattern in results, yet only report the two most commonly used measures, amplitude and market value amplitude.

		Round 1			Round 2			Round 3		
Type of Measure	Variable	Testost.	Placebo	p-value	Testost.	Placebo	p-value	Testost.	Placebo	p-value
Bubble size	Amplitude	0.85	0.39	*0.03*	0.59	0.30	0.21	0.47	0.21	0.14
		(0.4)	(0.23)		(0.43)	(0.23)		(0.41)	(0.11)	
	Market value amplitude	8.76	2.57	0.04	4.64	1.43	0.14	2.02	0.91	0.17
		(5.89)	(2.65)		(4.4)	(1.34)		(1.8)	(0.92)	
Bubble lifespan	Duration	5.00	4.00	0.43	4.80	2.86	0.19	4.00	2.29	0.14
		(2.24)	(1.51)		(2.71)	(0.99)		(2.49)	(0.7)	
Volume of trades	Turnover	2.94	2.88	0.77	2.52	2.61	0.49	2.01	2.48	0.14
		(1.03)	(0.86)		(0.85)	(0.56)		(0.62)	(0.58)	
Rate of change	Lead-up	17.39	5.59	0.04	10.24	3.87	0.17	3.75	1.73	0.17
		(16.17)	(3.87)		(15.7)	(4.73)		(2.62)	(1.27)	
Price variability	Price-fundamental value Variance	784.9	147.5	0.03	416.7	97.17	0.28	307.7	42.19	0.38
		(603.1)	(184.1)		(355.9)	(115.2)		(522.4)	(49.85)	

NOTES: DIFFERENCES IN MEANS BETWEEN AVERAGE MEASUREMENTS DURING EACH PERIOD BETWEEN T AND PLACEBO GROUPS. DATA ANALYZED USING AVERAGE PRICES, MEDIAN PRICES, AND AVERAGE VOLUME PER PERIOD (2-TAILED MANN-WHITNEY TEST).STANDARD ERRORS SHOWN BELOW RESPECTIVE MEANS IN PARENTHESES.

Amplitude is the maximum normalized difference between average prices and fundamental value during a trading period (Porter and Smith 1995). We tested whether the treatment sessions produced price bubbles of larger amplitude than placebo sessions (using a two-tailed Mann-Whitney U-test for this, as well as all other market variables). We found that amplitude in round 1 of the treatment sessions was 0.85 (SD=0.39) compared to 0.39 (SD=0.23) for round 1 in the placebo sessions, a significant 75% difference (p=0.03). Amplitude remained higher across the second and third rounds for the treatment sessions compared to the placebo sessions but did not reach statistical significance.

Market value amplitude is the volume-weighted average price above fundamental value (Hussam, Porter, and Smith 2008). The MVA in round 1 was 109% greater for treatment sessions compared to placebo sessions (testosterone=8.76, SD=5.89, placebo=2.57, SD=2.65; p=0.04), and statistically similar between rounds 2 and 3. As traders gained experience the bubble diminished.MVA decreased during rounds of trading for both conditions, showing significant changes for the testosterone sessions between round 1 and 2 (p=0.01), 2 and 3 (p=0.03), and 1 and 3 (p=0.01), and a significant reduction between round 1 and 3 for the placebo sessions (p=0.02).

Duration measures the number of consecutive periods the difference between average price and fundamental value grew (Porter and Smith 1995). Duration was not statistically different between high and average testosterone sessions using non-parametric Mann-Whitney test, yet highly significant in panel data analysis controlling for group size across distinct rounds: the binary coefficientfor testosterone treatment is 0.375, p=0.002(controlling for group size) (See Table V.b.). This indicates the impact of the testosterone treatment on sessions' bubble duration.

Turnover captures relative trading activity and is measured by the number of trades divided by the number of shares in the market (normalization adjusts for non-constant trading group size)(Porter and Smith 1995). We find no evidence that testosterone affected turnover in any of the three rounds (p=0.77, p=0.50, p=0.14, respectively). We did find that the turnover significantly decreased for high testosterone sessions as rounds advanced between 1 and 2 (p=0.04) and 1 and 3 (p=0.02; round 1=1.66, round 2=0.21, round 3=0.17).

In addition to quantifying bubble size, we measured the rate at which bubbles formed and collapsed and introduce *lead-up* as a measure of the rate of change of bubbles—the maximum difference between price and fundamental valuestarting from the difference in the first period,

divided by the number of intervening periods (i.e., "rise over run"). We find that the high testosterone session bubbles had lead-up 106% larger than placebo in round 1 (treatment=13.4, SD=8.2; placebo=3.8, SD=3.4; p=0.04). Differences between treatment groups were not statistically different in rounds 2 and 3.

The difference in price variability between groups is evident in the first round, where average variance for prices minus fundamental value is 138% greater for testosteronethan placebo sessions (testosterone=784.8, SD=603.1; placebo=147.5, SD=184.1; p=0.03). Table I summarizes the differences between the testosterone and placebo sessions (See Table A1 in appendix for market variable definitions).

Parametric Relationships—We found participants' testosterone levels positively correlate with market behavior at the session level (average of all three rounds) and measures of mispricing: amplitude (r=0.27, p=0.05), market value amplitude (r=0.33, p=0.02), duration (r=0.26, p=0.06), and price minusfundamental value volatility (r=0.40, p=0.01). Figure V shows representative scatterplots in two panels.

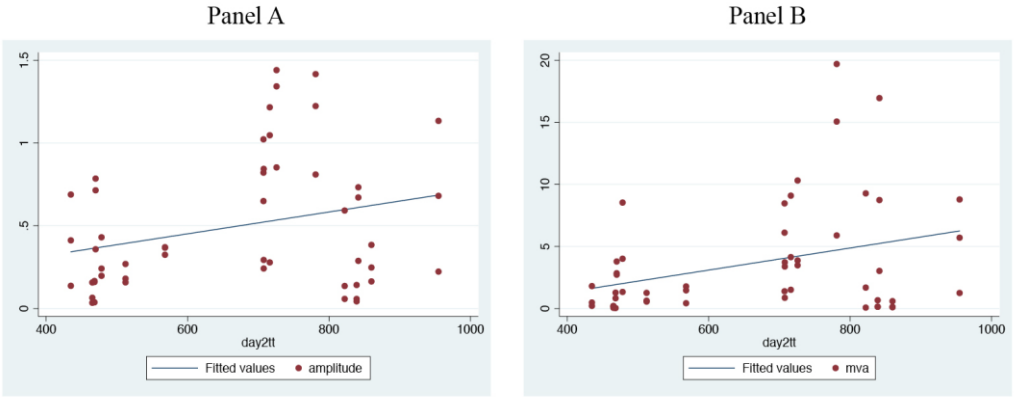


FIGURE V. THE RELATIONSHIP BETWEEN TOTAL TESTOSTERONE AND BUBBLE AMPLITUDE (PANEL A) AND BUBBLE MARKET VALUE AMPLITUDE(PANEL B).

We found similar positive correlations betweenDHT levels and amplitude (r=0.27, p=0.05), market value amplitude (r=0.38, p=0.01), price minusfundamental value volatility (r=0.34, p=0.02), and lead-up (r=0.24, *p*=0.09). Figure IV depicts the correlations between amplitude and market value amplitudeand day 2 DHT for all participants. OLS regression shows that DHT levels at the time of trading significantly increase amplitude, controlling for group size, age, academic major, and trading experience (See table II). We extend this analysis using panel data to test for effects across rounds, controlling for group size (Tables III.a. and III.b.)

TABLE II—OLS REGRESSION SHOWING THE EFFECT OF DHT LEVELS (DAY2DHT) DURING TRADING ON AMPLITUDE (SIZE OF THE BUBBLE) FOR ALL ROUNDS (N=51). *DAY2DHT* REPRESENTS BLOOD LEVELS OF DHT DURING THE EXPERIMENT, *TRADERS* IS THE NUMBER OF PARTICIPANTS IN A SESSION, *ECONBIZ* IS A BINARY FOR ECONOMICS AND BUSINESS MAJORS, *XTRADE* CAPTURES THE NUMBER OF YEARS OF TRADING EXPERIENCE.

Explanatory variables	Coefficients
Day2dht	0.011**
	(0.011)
traders	0.000
	(0.032)
age	0.009
	(0.024)
econbiz	-0.796
	(0.378)
xtrade	1.15
	(0.465)
Constant	-0.338
Adjusted R-squared	0.072

Notes: Standard errors reported in parentheses

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

Table III.a.— Panel regression of **amplitude** as the dependent variable and a binary variable for testosterone (1) and placebo (0), round, and number of traders as IVs. Regression results show that the testosterone-treated groups had larger amplitude than placebo groups, that bubble size decreased significantly in the third round of trading, and that the size of the trading group did not significantly impact market prices (Small group is 7-9 traders; medium 10-12; large 13-14).

	Coefficients
Binary	0.38***
	(0.11)
Round 2	-0.19
	(0.13)
Round 3	-0.30**
	(0.13)
Small Group	-0.13
	(0.13)
Medium Group	1.15
	(0.465)
Large Group	0.75
	(0.23)
Constant	0.53***
	(0.13)
Adjusted R-squared	0.29

Notes: Standard errors reported in parentheses

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

Table III.b.— Panel regression tests whether **duration** is affected by testosterone across rounds, controlling for trading group sizes. IVs are binary for testosterone (1) and placebo (0), rounds dummies, and number of traders. Results show testosterone-treated groups had longer lasting bubbles than placebo groups regardless of size of trading group (Small group is 7-9 traders; medium 10-12; large 13-14).

	Coefficients
Binary	1.73**
	(0.68)
Round 2	-0.59
	(0.74)
Round 3	-1.29*
	(0.13)
Small Group	-0.58
	(0.76)
Medium Group	0.18
	(0.87)
Large Group	0.56
	(1.40)
Constant	3.74***
	(0.76)
Adjusted R-squared	0.20

Notes: Standard errors reported in parentheses

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

Individual-Level Analyses

In this section we use individual traders' quantity and specific bid and ask prices, number of assets purchased, earnings, and survey responses to explain what causes higher prices and greater volatility observed at the market level.

We begin by addressing why prices are significantly and consistently higher among high testosterone relative to placebo sessions. Bids and asks for an asset influence its price in financial markets and auctions,and prices in turn affect the bidding and asking behavior of traders. We tested differences in buying and selling patterns between treatment groups in relation to price

changes over time. We identify periods of rising average prices with a binary variable called *momentum,* which equals 1 when the price in a period is greater than the preceding period, and 0 otherwise.

We computed average buying and selling offer prices for each period (*average buy* and *average sell*, respectively) to quantify average willingness to buy and sell. Using a panel regression assigning each round as an entity and each period within the round as the time dimension we use entity fixed effects to account for differences across sessions. This method analyzes each round separately rather than entire sessions of three rounds because there is a break in the time series between rounds. Because dividend payouts are likely to affect trading behavior we control for them in the regression as follows: *pay* indicates the effect of the number of consecutive dividend payouts in trading periods, and *no pay* indicates number of consecutive periods of zero dividend payouts. Regression results show traders who received placebo do not increase buying prices as prices increased. Oppositely, testosterone-treated traders offered higher buying prices as market prices increased in round 1 by an average of $0.20 ($p$=0.001) and round 2 by an average of $0.23 ($p$=0.001). Traders with elevated testosteronebid higher as market prices increasedwhile participants given placebo did not, thereby explaining the differences in average prices and bubble size between groups.We ran a similar regression for average selling price and found no significant differences across treatments. Both trading group treatments decrease buying offer prices as streaks of zero dividends persists (see Table IV).

TABLE IV—DEPENDENT VARIABLE: AVERAGE BUYING OFFER PRICE (2-TAILED P VALUES). THIS PANEL REGRESSION SHOWS THE EFFECT OF RISING PRICES ON BUYING PRICES WHILE CONTROLLING FOR DIVIDEND DISTRIBUTION STREAKS OCCURING CONCURRENTLY. THIS RESULT SHOWS THAT BIDDING PRICES CONTINUES TO RISE DESPITE BUBBLE FORMATION IN PREVIOUS PERIODS IN ROUND 1 IN TESTOSTERONE-TREATED TRADERS.

	Placebo			Testosterone		
	Round 1	Round2	Round3	Round1	Round2	Round3
Momentum	0.09	0.15*	0.06	0.20***	0.23*	0.13
	(7.60)	(9.87)	(40.41)	(3.57)	(8.33)	(9.18)
Pay	0.01	-0.56	-0.08*	-0.00	-0.07	-0.09
	(3.12)	(4.72)	(3.50)	(0.50)	(5.07)	(4.12)
NoPay	-0.03	-0.01***	-0.09***	0.07	-0.04*	-0.02***
	(2.32)	(5.06)	(3.05)	(0.74)	(2.35)	(5.35)
Adjusted R2	0.15	0.41	0.11	0.49	0.53	0.43
Constant	0.05	0.07	0.07	0.07	0.08	0.08

Notes: Standard errors reported in parentheses

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

In addition to the prices buyers want to pay and sellers want to accept for an asset, the quantity of buying and selling offers are informative. *Buying offer turnover* and *selling offer turnover* measure the number of buying and selling offers divided by the total number of shares in that period, respectively(i.e., normalized bids and asks). The difference between buying offer turnover and selling offer turnover reflects supply and demand differentials and is called *turnover difference*(Positive turnover differenceindicates excess selling and negative represents excess buying).We find that high testosteronetraderspostsignificantly more buying offers as prices serially increased in round 1($\beta = -0.17$, p=0.01) (see Table V).

TABLE V—DEPENDENT VARIABLE: TURNOVER DIFFERENCE (2-TAILED P VALUES). THIS PANEL REGRESSION SHOWS THE EFFECT OF RISING PRICES ON BIDDING OFFERS WHILE CONTROLLING FOR DIVIDEND DISTRIBUTIONS OCCURING CONCURRENTLY. THIS RESULT SHOWS THAT EXCESS DEMAND DROVE PRICES HIGHER AS PRICES SERIALLY INCREASED IN ROUND 1.

	Placebo			Testosterone		
	Round1	Round2	Round3	Round1	Round2	Round3
Momentum	0.01	0.14	-0.10	-0.17***	-0.20*	-0.10
	(0.80)	(0.11)	(0.12)	(0.07)	(0.12)	(0.13)
Pay	-0.07	0.00	-0.03	-0.02	-0.04	0.07
	(0.03)**	(0.00)	(0.04)	(0.03)	(0.07)	(0.06)
NoPay	0.01	-0.02	-0.01	-0.02	-0.02	0.01
	(0.20)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)
adj-R2	0.17	0.35	0.42	0.36	0.17	0.22
Constant	0.11	-0.02	0.08	0.35	0.32	0.24

Notes: Standard errors reported in parentheses

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

As discussed earlier, market-level data show *turnover*does not significantly differ between treatments. This null result, however, does not rule out differences in bids and asks. We analyze differences between treatment conditions in bids and asks before and after peak price in each round and find that placebo-treatedtraders posted more buying offers prior to (treatment mean=0.36, placebo mean=0.46, p=0.001) as well as after the peak price was reached (treatment mean=0.36, placebo mean=0.47, p=0.003). However, their offers werebelow fundamental value on average, meaning they consistently tried to "buy low" to "sell high". Conversely, we see high-testosterone traders "buying highto sell higher".Among high testosterone traders we find increased selling offers relative to placebo after prices peaked (treatment mean=0.71, placebo mean=0.45, p=0.001). Also, high testosteronetraders' average buy offer minus fundamental value was 139% higher than placebo participants prior to the peak price (treatment: \$0.29; placebo: \$0.05 p=0.001). After the price peak, high testosterone traders offered on average 28.6

cents and placebo participants offered an average of 12.2 cents in excess of fundamental value, an 80% difference (p=0.001). Finally, the acceleration of selling offers coupled with lower demand prices among the high testosterone groups precipitated 'bursting' of bubbles (See Table VI).Overall, the differential prices between treatment conditions can be explained by the differences in bids and asks, a serial bilayer with high testosterone traders consistently bidding and buying above average testosterone traders.

TABLE VI—DIFFERENCES IN BUYING AND SELLING OFFERS BEFORE AND AFTER PEAK PRICES USING TWO-SAMPLE T-TEST BETWEEN CONDITIONS.

	Pre-peak			Post-peak		
	Placebo	Treatment	*p*-value	Placebo	Treatment	*p*-value
Buying turnover	0.47 (0.26)	0.36 (0.25)	0.00	0.47 (0.31)	0.36 (0.29)	0.00
Selling turnover	0.51 (0.26)	0.53 (0.28)	0.28	0.45 (0.23)	0.71 (0.35)	0.00
Average Buying price	66.31 (27.99)	88.82 (33.18)	0.00	32.99 (22.41)	50.01 (37.66)	0.00
Average selling price	102.28 (85.74)	176.19 (263.13)	0.00	81.95 (149.36)	174.19 (297.77)	0.00

Note: Standard deviation reported in parentheses

One of the strengths of this experimental design is that the fundamental value and itstrajectory are known. The fact that fundamental value decreases in a linear step-functionsuggests "rational" traderswilladjust downward accordingly similarly to dividend issuancesand earnings announcements (Campbell and Beranek 1955). To test this we employ SSW's "rational expectations" approach that tests whether prices reflect the constantly declining fundamental value of the asset by analyzing period-by-period price movements vis-à-vis excess bids.

We use the equation:

(1) $\overline{P}_t - \overline{P}_{t-1} = a + b(B_{t-1} - O_{t-1}) + e_t$

where $\overline{P}_t - \overline{P}_{t-1}$ is the change in mean price from period *t-1* to period *t* and $B_{t-1} - O_{t-1}$ is the difference between the number of buying and selling offers—or excess bids—in period *t-1*. Assuming that excess bids reflect excess demand in the market, a positive β coefficient reflects participants' expectations of forthcoming upward price movements. The intercept, a, is driven by two components: the expected value of the declining fundamental value, and an adjustment for risk.

We ran separate panel regressions for testosterone and placebo traders with a similar design as before: rounds are the fixed entity, and periods within the round are the time component. As described above, the dependent variable is price change from period *t-1* to period *t* and explanatory variables are *lagged excess bids,* and dummy variables for each round. Under this specification the coefficient of lagged excess bids is expected to be positive, showing that excess demand drives prices up. We found that the constant term was significantly negative for placebo in all three rounds (round 1=-6.52 cents, round 2=-8.39 cents and round 3=-8.37 cents, all $p<0.001$), which are notably close to the decline infundamental value of 9 cents per period especially in the second and third rounds. We did not find this result for testosterone-treated trading groups, indicating that placebo traders systematically incorporated declining fundamental value into their trading decisions while their high testosterone counterparts did not (Table VII).

TABLE VII— RATIONAL EXPECTATIONS IN ASSET MARKETS: AVERAGE PRICE ADJUSTMENTS; DEPENDENT VARIABLE: AVERAGE P_T-P_{T-1}; STANDARD ERRORS IN PARENTHESES

	Placebo			Testosterone		
	Round1	Round2	Round3	Round1	Round 2	Round 3
Constant	-6.52***	-8.39***	-8.37***	-0.73	-5.86	-7.22
	(1.30)	(3.08)	(1.00)	(2.93)	(1.99)	(1.82)
Lagged Excess Bids	-1.39	-3.97	-0.65	-12.60	-9.28**	-3.55
	(5.81)	(10.70)	(3.41)	(7.91)	(4.64)	(3.95)
R^2	0.036	0.007	0.014	0.049	0.062	0.050

Notes: Standard errors reported in parentheses

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

We analyzed the effects of testosterone on change in shares measured by start of round compared to end of round shares owned during a trading round and found a significant positive correlation between DHT and changes in the number of shares in round 1 (r=0.22, *p*=0.01) among all traders, pooling the treatment and controls together. That is, there is a positive relationship between a participant's DHT levels and share ownership regardless of whether the trader received testosterone or placebo. Congruously, we find DHT negatively correlated with participants' cash holdings at the end of the trading session, meaning that higher testosterone traders, both in their natural and elevated levels earned less money in trading (r=-0.26; *p*=0.02).

Post-trading surveys showed high testosterone participants attributed their trading performance more to their own talent (testosterone=4.4, SE=0.10; placebo=4.1, SE=0.01; *p*=0.01) and less to luckrelative to their placebo counterparts (testosterone=4.0, SE=0.10; placebo=4.4, SE=0.14; *p*=0.01). High testosterone participants also attributed their success to their own calculations (testosterone=4.6, SD=0.10; placebo=4.3, SD=0.10; *p*=0.07) and their own individual strategies more than those in the placebo group (testosterone=5.1, SD=0.08; placebo=4.8, SD=0.09;

p=0.01). Tellingly, high testosterone participants perceived prices on average as lower than expected, a surprising result given that prices were higher in their sessions relative to placebo (treatment=4.2, SD=0.18, placebo=3.5, SD=0.14; *p*=0.01) (Tables IIIa-c in Appendix).

Our results demonstrate significant differences in asset prices, persistence of mispricing, and their attendant behavioral drivers caused by changes in levels of testosterone in traders in an experimental financial market. The resultsshowing testosterone causes a systematic shiftare robust to academic major, age, asset trading experience and size of trading portfolio.

5. Conclusion

Using a vetted experimental asset trading paradigm with a hormonal treatment we find that testosterone drives competitive bidding and transactions at higher pricesdespite clearly identifiable departure from fundamental value.

Much like sentiment, which causes entire asset classes to move in the same direction, endogenous changes in hormones affect people similarly and can cause synergistic movements in financial markets:Bull markets simulate winning for traders and increase endogenous production of testosterone, placing them at high testosterone states. This initial "kick", where testosterone production increases in response to wins, can fuel further mispricing and bubble formation as shown in this experiment. Again, this is likely to occur in situations of rising prices where there many traders are "winners", and consequently bid competitively for the appreciating assets further driving up prices.Exacerbating such scenariosare the biased self-attribution that accompany high-testosterone states we find in our survey results: traders in high testosterone states would attribute their superb earnings to their own talent, when in fact they are enjoying a bubble, and likely perpetuate a bubble with aggressive overbidding.

The dampened differentials between treatment groups and null results in later trading roundsare not surprising given that the market is closed and the fundamental valueis both known and declining—after all, learning occurs with experience. We expect that differences between conditions would be more pronounced and persistent if fundamental value was uncertain or increasing instead of decreasing to zero at the end of each round—prices would likelydiverge without bound. Further, given the autocatalytic cycle of rising prices fueling additional price increases and likely concomitant influence on testosterone levels, the influence of the androgen is likely to persist beyond the duration of effects observed here. In other words, in an environment with uncertain fundamental value and no clear trading deadlines (except perhaps portfolio balancing and tax-motivated selling)mispricingwould be more pronounced and persistlonger. It is a consequence of the design that causes early crashes, yet it is highly likely that more pronounced differences would result if these tempering forces were absent. A larger field study examining differential testosterone levels over medium-term time scale would enrich our understanding of androgen's role in financial decision making and subsequent impact on asset prices.

We show that higher levels of testosterone drive competitive bidding at higher prices that cause meaningful upward deviations from fundamental value. Individual traders with high testosteronebid prices higher as prices increasedthereby widening the gap between prices and fundamental values. Testosterone traders bought stocks at high prices and later sought to re-sell in high volume, putting downward pressure on prices. It is this sequence: buy above-fundamental value as prices increase, hold, then sell as prices fall, that characterize asset market bubbles and subsequent rapid price deflations. This pattern also explains the lower relative earning among higher testosterone participants. Similar to Biais et al. (2005) who found that

trader traits strongly influence trading behavior and earnings, we find that androgenically average traders were calibrated to fundamental values, while high-testosterone traders misperceived market prices, posses inflated perception of skill, and earn less money.

The objective of this paperwas not solely to isolate afactor affecting asset prices, but also to understandhow testosteroneaffects volume, bidding, buying and its collective impact on markets. Understanding how hormones affect immediate human decision making within financial contexts allows for a greater understanding of a mechanism which nests other, more distal and aggregate outcomes, such as bubbles and crashes. These results show us something new and germane about how a specific hormone affects how men trade financial assets and suggests attendant macroeconomic implications. Keep in mind that the level to which traders in the experiment were elevated lie within normal physiologic range, meaning that the experiment not only simulated a financial market, but also hormonal states men can experience over the course of their day.

Implications of this research include the need to incorporate intelligent policy and safeguards that integrate behavioral changes resulting from hormones, such as more responsive risk management systems and trading rules. Also,it is presently unknown if these results can be generalized to women; closer examination of gender differences in financial trading—an area difficult to study empirically due to paucity of female traders in the field—would improve our understanding of what drives financial markets and how to improve them.

Alfred Marshall once said, “The Mecca of the economist lies in economic biology rather than in economic dynamics”, and here we show how biology affects economic dynamics. Our results harmonize previous findings and provide clear evidence of hormones affecting financial decision making and consequentinfluence on asset prices. These results corroborate finance literature on

sentiment, overconfidence, and gender differences and complement work on asset pricing, decision making such M&A, IPOs, capital structure decisions, and time-varying risk aversion.It is therefore likely that testosteronesignificantlyaffects decisions that meaningfullyaffect the economy.

References

Aikey, J.L., J.G. Nyby, D.M. Anmuth, and P.J. James. 2002. Testosterone rapidly reduces anxiety in male house mice (*Mus musculus*). *Hormones and Behavior* 42:448-60.

Allen, F. and D. Gale. 2007. Financial contagion. *Journal of Political Economy* 108:1-33.

Anderson, R.A., J. Bancroft, and F.C.W. Wu. 1992. The effets of exogenous testosterone on sexuality and mood of normal men. *Journal of Clinical Endocrinology and Metabolism* 74:1503-07.

Andrade, E.B. T. Odean, and S. Lin. 2012. Bubbling with excitement: an experiment. Working paper, SSRN.

Apicella, C.L., A. Dreber, and J. Mollerstrom. 2014. Salivary testosterone change following monetary wins and losses predicts future financial risk-taking. *Psychoneuroendocrinology* 39:58-64.

Baillargeon, J. et al. 2013. Trends in androgen prescribing in the United States 2001 to 2011. *JAMA Internal Medicine* 173:1465-66.

Baker, M. and J. Wurgler. 2006. Investor sentiment and the cross-section of stock returns. *Journal of Finance* 61:1645-80.

Bassi, A. R. Colacito, and P. Fulghieri. 'O sole mio: an experimental analysis of weather and risk attitudes in financial decisions. *Review of Financial Studies* 26:1824-52.

Bernanke, B. 2010. Monetary policy and the housing bubble. *Board of Governors of the Federal Reserve System at the Annual Meeting of the American Economic Association, Atlanta Georgia*.

Boksem, M. et al. 2013. Testosterone inhibits trust but promotes reciprocity. *Psychological Science* 24:2306-14.

Biais, B. et al. 2005. Judgemental overconfidence, self-monitoring, and trading performance in an experimental market. *The Review of Economic Studies* 72:287-312.

Booth, A. et al. 1989. Testosterone, and winning and losing in human competition. *Hormones and Behavior* 23:556-71.

Brambilla, D.J., A.M. Matsumoto, A.B. Araujo, and J.B. McKinlay. 2009. The effect of diurnal variation on clinical measurement of serum testosterone and other sex hormone levesl in men. *J Clin Endocrinol Metab* 94:907-13.

Campbell, J.A. and W. Beranek. 1955. Stock price behavior on ex-dividend dates. *The Journal of Finance* 10:425-29.

Choi, P.Y.L., A.C. Parrott, and C. Cowan. 1990. High-dose anabolic steroids in strength athletes: effects upon hostility and aggression. *Human Psychopharmacology* 5:349-56.

Coates, J. and J. Herbert. 2007. Endogenous steroids and financial risk taking on a London trading floor. *Proceedings of the National Academy of Sciences* 105:6167-72.

Cohn, A. J. Engelmann, E. Fehr, and M. Maréchal. 2013. Evidence for countercyclical risk aversion: an experiment with financial professionals. *UBS Center Working Paper Series No. 4*.

De Long, J. B., A. Shleifer, L.H. Summers, and R.J. Waldmann. 1990. Noise trader risk in financial markets. *Journal of Political Economy* 98:703-38.

Dougal, C. J. Engelberg, Diego García, and C. Parsons. 2012. Journalist and the stock market. *Review of Financial Studies* 25:639-79.

Dufwenberg, M. T. Linqvist, and E. Moore. Bubbles and experience: an experiment. *American Economic Review* 95:1731-37.

Edmans, A., D. García, and Ø. Norli. 2007. Sports sentiment and stock returns. *The Journal of Finance* 62:1967-98.

Escasa, M.J., J.F. Casey, and P.B. Gray. 2011. Salivary testosterone levels in men at a U.S. sex club. *Archives Sexual Behavior* 40:921-26.

Eisenegger, C., A. von Eckardstein, E. Fehr, S. von Eckardstein. Pharmacokinetics of testosterone and etradiol gel preparations in healthy young me. *Psychoneuroendocrinology* 38:171-78.

Fischbacher, Urs. 1999. z-Tree – Zurich Toolbox for Readymade Economic Experiments - Experimenter's Manual.*Working Paper Series ISSN 1424-0459*.

Garber, P. 2000. Famous first bubbles: The fundamentals of early manias. Cambridge: MIT Press.

Grino, P.B., J.E. Griffin, and J.D. Wilson. 1990. Testosterone at high concentrations interacts with the human androgen receptor similarly to dihydrotestosterone. *Endocrinology* 126:1165-72.

Haigh, M.S. and J.A. List. 2005. Do professional traders exhibit myopic loss aversion? An experimental analysis. *The Journal of Finance* 60:523-34.

Haruvy, E. and C.N. Noussair. The effect of short selling on bubbles and crashes in experimental spot asset markets. *The Journal of Finance* 61:1119-57.

Hermans, E.J., N.F. Ramsey, and J. van Honk. 2008. Exogenous testosterone enhances responsiveness to social threat in the neural circuitry of social aggression in humans. *Biological Psychiatry* 63:263-70.

Hirshleifer, D. and T. Shumway. 2003. Good day sunshine: stock returns and the weather. *The Journal of Finance* 58:1009-32.
Hussam, R.N., D. Porter, and V.L. Smith. 2008. Thar she blows: can bubbles be rekindled with experienced subjects? *American Economic Review* 98:924-37.

Kamstra, M.J. L.A. Kramer, and M.D. Levi. 2003. Winter blues: a SAD stock market cycle. *American Economic Review* 93:324-343.

Kandasamy, N. et al. 2013. Cortisol shifts financial risk preferences. *Proceedings of the National Academy of Sciences* 111:3608-13.

Kirchler, M. J. Huber, and T. Stöckl. 2012. Thar she bursts: reducing confusion reduces bubbles. *American Economic Review* 102:865-83.

Kreuz, L.E., R.M. Rose, J.R. Jennings. 1972. Suppression of plasma testosterone levels and psychological stress. *Archives of General Psychiatry* 26:479-82.

Kuhnen, C.M. and B. Knutson. 2011. The influence of affect on beliefs, preferences, and financial decisions. *Journal of Financial and Quantitative Analysis* 46:605-26.

Kuhnen, M.C. and B. Knutson. 2005. The neural basis of financial risk taking. *Neuron* 47:763-70.

Lo, A. and D.V. Repin. 2002. The psychophysiology of real-time financial risk processing. *Journal of Cognitive Neuroscience* 14: 323-339.

Makino, S., K. Hashimoto, and P.W. Gold. 2002. Multiple feedback mechanisms activating corticotropin-releasing hormone system in the brain during stress. *Pharmacology, Biochemistry and Behavior* 73:147-58.

Mazur, A. and A. Booth. 1998. Testosterone and dominance in men. *Behavioral and Brain Sciences* 21:353-97.

Mazur, A., and T.A. Lamb. 1980. Testosterone, status, and mood in human males. *Hormones and Behavior* 14:236-46.

McDermott, R., J.H. Fowler, and O. Smirnov. 2008. On the evolutionary origin of prospect theory preferences. *The Journal of Politics* 70:335-50.

McInish, T. and R. Wood. 1992. An analysis of intraday patterns in bid/ask spreads for NYSE stocks. *The Journal of Finance* 47:753-64.

Mehta, P. and R.A. Josephs. 2006. Testosterone change after losing predicts the decision to compete again. *Hormones and Behavior* 50:684-92.

Odean, T. 1998. Are investors reluctant to realize their losses? *The Journal of Finance* 53:1775-98.

Pope, H.G. Jr., E. Kouri, and J.I. Hudson. 2000. Effets of supraphysiologic doses of testosterone on mood and aggression in normal men. *Archives General Psychiatry* 57:133-40.

Porter, D.P, and V.L. Smith. 2003. Stock market bubbles in the laboratory. *The Journal of Behavioral Finance* 4:7-20.

Preuschoff, K., P. Bossaerts, and S.R. Quartz. 2006. Neural differentiation of expected reward and risk in human subcortical structures. *Neuron* 51:381-90.

Salameh, W.A. et al. 2010. Validation of a total testosterone assay using high-turbulnce liquid chromatography tandem mass spectrometry: total and free testosterone reference ranges. *Steroids* 75:169-75.

Sapienza, P., L. Zingales, and D. Maestripieri. Gender differences in financial risk aversion and career choice are affected by testosterone. *Proceedings of the National Academy of Sciences* 106:15268-73.

Shefrin, H. and M. Statman. 1994. Behavioral Asset Pricing Theory. *Journal of Financial and Quantitative Analysis* 29:323-49.

Smith, A. et al. 2014. Irrational exuberance and neural crash warning signals during endogenous experimental market bubbles. *Proceedings of the National Academy of Sciences* 111:10503-08.

Smith, V.L., G.L. Suchanek, and A.W. Williams. 1988. Bubbles, crashes, and endogenous expectations in experimental spot asset markets. *Econometrica* 56:1119-51.

Stanton, S.J., S.H. Liening, and O.C. Schultheiss. 2011. Testosterone is positively associated with risk taking in the Iowa Gambling Task. *Hormones and Behavior* 59:252-56.

Stock, K. 2010. Women Fight for Equality on the Trading Floor." Fins Finance, September 2. *http://www.fins.com/Finance/Articles/SB127446219607394935/Women-Fight-for-Equality-on-the-Trading-Floor.*

Thaler, R., A. Tversky, D. Kahneman, and A. Schwartz. 1997. The effect of myopia and loss aversion on risk taking: an experimental test. 1997. *Quarterly Journal of Economics*112:647-61.

Thaler, R. 1987. The January effect. *The Journal of Economic Perspectives* 1:197-201.

van Honk, J. et al. 2004. Testosterone shifts the balance between sensitivity for punishment and reward in healthy young women. *Psychoneuroendocrinology* 29:937-43.

Veronesi, P. 1999. Stock market overreaction to bad news in good times: a rational expectations equilibrium model. *Review of Financial Studies* 12:975-1007.

Wallace, Charles. 2012. Keep taking the testosterone. February 9. http://www.ft.com/cms/s/0/68015bb2-51b8-11e1-a99d-00144feabdc0.html#axzz3U7GpqVHc

Welch, Ivo. 2000. Herding among security analysts. *Journal of Financial Economics* 58:369-96.

Zak, P. et al. 2009. Testosterone administration decreases generosity in the ultimatum game. *PLoS ONE* 4(12): e8330. doi:10.1371/journal.pone.0008330.

Zak, P. J., Borja, K., Matzner, W. T. & Kurzban, R. 2005. The neuroeconomics of distrust: sex differences in behavior and physiology. *American Economic Review Papers and Proceedings* 95: 360-363.

Appendix

Unabridged Methods and Experimental Design

One-hundred-forty male participants were recruited from the Claremont Colleges for this double-blind experiment. Only males were included because the United States Food and Drug Administration has only approved the synthetic testosterone drug used in the experiment (Androgel®) for men. Average age of participants was 23 years (SD=7.0), and the ethnic distribution was 67% White, 13% Asian, 7% Hispanic, 6% Black, 3% Indian, and 4% Other. All participants were paid for the experiment and gave written informed consent prior to inclusion. The Institutional Review Board of Claremont Graduate University approved this experiment. No adverse reactions were reported.

Each session required two days to complete due to the pharmacokinetics of Androgel®, which peaks in blood in approximately 2 hours and stabilizes approximately 16 hours after application (Eisenegger et al., (2013); Swerdloff et al. (2000)).

A. Asset Trading

We used a continuous double-auction market with an asset yielding a stochastic dividend following Smith et al.(1988). The double-auction format allows participants to place bids to buy assets as well as offers to sell them simultaneously, mimicking typical trading environments.

Each group of participants constituted a *session* consisting of three distinct *rounds* of 12 *periods*. There were 17 total sessions for this study. The asset paid a dividend of 18 or 0 cents at the conclusion of each period with equal probability, giving it an expected value of 9 cents per period. The fundamental value of the asset began at 12*9=108 cents at the start of each round, decreasing by 9 cents each period and reaching zero at the end of each round (periods 12, 24, and

36) (see Fig. 1). Participants were provided with a chart of the expected value of a share of stock over the duration of twelve periods (See Appendix for complete instructions and the table of fundamental values).

Trading was done on z-Tree (Fischbacher 1999). Participants were endowed with either 6 stocks and 216 cents, or 2 stocks and 648 cents at the start of every round by random assignment (both endowments are monetarily equivalent to 864 cents).

Figure I:

B. Procedure

Day 1—Participants were briefed upon arrival at the Center for Neuroeconomics Studies at 6pm on all aspects of the experiment and signed a consent form. They were then assigned an alphanumeric identifying code to maintain anonymity throughout the experiment. Next, they had a private medical screening by a licensed physician to rule out contraindications for use of topical androgen gel in accordance with clinical instructions.

A licensed phlebotomist then obtained a 20ml blood sample from an antecubital vein using a Vacutainer® maintaining a sterile field. Next, in a private room, participants removed their shirts and were given a clear gel to apply to their shoulders and upper arms. T was raised using 10g of Androgel® 1%, a clear alcohol-based gel containing 1% synthetic T. An alcohol hand sanitizer of similar consistency was used as the placebo as in our previous protocol (Zak et al., 2009). Finally, participants completed a background survey and were asked to return the next day to complete the experiment (see Appendix).

Day 2—Participants signed in upon arrival at noon. Next, they were seated and given printed instructions, briefed on the structure of the experiment, completed a survey, and a second 20ml

blood draw was obtained prior to the start of trading. Participants were given an opportunity to ask questions about the trading task prior to starting the trading session

A series of questions was presented between rounds of trading. This survey assessed participants' evaluations of their performance, market prices, behavior of other participants, and their emotional states. For example, participants were asked "What do you think determined your performance?" and were given a list of eight criteria including luck, talent, character, and calculations. Participants were also asked, "What do you think just happened in the last trading session? (1=strongly agree; 7=strongly disagree)" regarding whether prices were higher than expected, lower than expected, fluctuated more than expected, and prices were "about right" (See Appendix for complete survey). Participants were privately paid the accumulated amounts of final cash holdings from each round upon dismissal.

Survey—A demographic survey was conducted on day 1 to document participant age, ethnicity, field(s) of study, experience trading financial assets, relationship status, and personality traits.

Blood Handling Procedure—Each blood draw consisted of two 8-ml EDTA whole blood tubes and one serum-separator tube. Blood tubes were immediately placed on ice following blood draw. The tubes were then placed in a centrifuge and spun at 1500 rpm for 12 min at 4° C. Plasma and serum were pipetted from tubes and placed into 2-ml microtubes with screw caps. These tubes were immediately placed on dry ice and transferred to a −80◦ C freezer until assayed.

Unit of Analysis—The primary analyses compare sessions in which all participants received T to sessions in which everyone received the placebo. This permits us to assess market behavior for elevated versus basal T. We also analyze individual behavior for those receiving T compared to those given the placebo.

TABLE AI—MEASURES OF BUBBLE SIZE AND ATTRIBUTESFOR MARKET LEVEL ANALYSIS

Measure name	*Description*	*Equation*
Amplitude	Trough-to-peak change in market asset value relative to fundamental value	$\frac{\max\{(P_t - f_t)}{E} - \frac{\min\{(P_t - f_t)}{E}$
Average Bias	By how much do prices deviate from fundamental value, either positive or negative over a 12-period Round	$\frac{1}{N}\sum_{p=1}^{N}(MedianP_p - FV_p)$
Duration	How long do prices persist above fundamental value	$\max\{m: P_t - f_t < P_{t+1} - f_{t+1} < \ldots < P_{t+m} - f_{t+m}\}$
Lead-up	How quickly price levels rise from first period price to trough; rate of change	$\frac{\max(\bar{P}_p - FV_p) - initial(\bar{P}_1 - FV_1)}{T_{P_{Max}}}$
Market Value Amplitude	Normalized market value of trade; period amplitude weighted by volume of trade	$\max\{[P_t - f_t / E]V_t : t = 1,\ldots,12\}$
Normalized absolute price deviation	Sum of all absolute deviations of transacted prices from fundamental value divided by shares outstanding	$\sum \left\lvert \frac{P_{i,t} - FV_t}{shares} \right\rvert$
Relative Deviation	Average deviation from fundamental value normalized by fundamental value	$\frac{1}{N}\sum_{p=1}^{N}(\bar{P}_p - FV_p)/\lvert\overline{FV}\rvert$
Relative Absolute Deviation	Average level of mispricing, insensitive to direction of mispricing	$\frac{1}{N}\sum_{p=1}^{N}\lvert\bar{P}_p - FV_p\rvert/\lvert\overline{FV}\rvert$
Total Dispersion	Sum of deviation of median prices from fundamental value	$\sum_{p=1}^{N}\lvert MedianP_p - FV_p\rvert$
Turnover	Trading activity in a market; number of assets traded divided by number of assets in the market	$\frac{\sum AssetsTraded}{\sum Assets}$
Price Volatility	Variability of average prices	$\frac{1}{N-1}\sum_{t=1}^{12}(P_t - \bar{P})^2$
Price-fundamental value Volatility	Variability of average prices minus their respective fundamental values	$\frac{1}{N-1}\sum_{t=1}^{12}[(P_t - FV_t) - \overline{(P - FV)}]^2$

TABLE II—VARIABLE DEFINITIONS OF INDIVIDUAL-LEVEL ANALYSIS

Measure name	*Description*
Average Buy	Average price of buying offers posted
Average Sell	Average price of selling offers posted
Momentum	A binary variable of change of prices between consecutive periods: 1 for increase, 0 for no increase
Buying Offer Turnover	Number of buying offers divided by outstanding shares
Selling Offer Turnover	Number of selling offers divided by outstanding shares
Turnover Difference	Difference between number of Buying Offer Turnover and Selling Offer Turnover within a period, which is a measure of excess bids in the market
Pay	A variable that counts the number of consecutive periods during which a dividend of $0.18 was paid.
No Pay	A variable that counts the number of consecutive periods during which a dividend of $0.00 was paid.

TABLE IIIA—COMPARISON OF RESPONSES FROM INTER-PERIOD QUESTIONNAIRE FOR SELF-EVALUATION QUESTIONS BETWEEN TESTOSTERONE (T) AND PLACEBO (P)

	Overall			Period 1			Period 2			Period 3		
	T	P	p-value	T	P	p-value	T	P	p-value	T	P	p-value
Luck	4.0	4.4	0.00	3.7	4.1	-0.16	3.9	4.3	-0.04	4.3	5.0	-0.01
	(0.1)	(0.14)		(0.13)	(0.29)		(0.15)	(0.17)		(0.19)	(0.15)	
Talent	4.4	4.1	0.01	4.2	4.1	-0.22	4.5	4.5	-0.16	4.6	4.6	0.02
	(0.1)	(0.09)		(0.15)	(0.14)		(0.13)	(0.19)		(0.22)	(0.17)	
Character	3.6	3.4	-0.2	3.3	3.4	-0.23	3.6	3.5	-0.30	3.8	3.3	0.07
	(0.16)	(0.1)		(0.28)	(0.19)		(0.25)	(0.16)		(0.32)	(0.17)	
Calculations	4.6	4.3	0.07	4.6	4.4	-0.46	4.5	4.4	0.07	4.7	4.3	0.05
	(0.11)	(0.11)		(0.24)	(0.19)		(0.11)	(0.15)		(0.19)	(0.23)	
Self strategies	5.1	4.8	0.01	5.0	5.0	-0.28	5.0	4.8	-0.20	5.3	4.8	0.01
	(0.08)	(0.1)		(0.19)	(0.16)		(0.14)	(0.17)		(0.08)	(0.15)	
Self	4.31	4.07	0.1	4.61	4.37	-0.25	4.38	3.8	0.09	3.95	4.04	-0.48

mistakes	(0.15)	(0.09)		(0.25)	(0.15)		(0.29)	(0.12)		(0.22)	(0.11)	
Other mistakes	4.6	4.6	-0.47	5.1	4.3	-0.28	4.36	4.34	-0.46	4.3	4.3	-0.31
	(0.13)	(0.02)		(0.15)	(0.34)		(0.2)	(0.17)		(0.19)	(0.34)	
Other strategies	4.8	4.4	0.02	5	4.6	0.03	4.6	4.3	-0.20	4.7	4.4	-0.203
	(0.1)	(0.12)		(0.13)	(0.17)		(0.2)	(0.25)		(0.15)	(0.2)	

Note: T-test by Wilcoxon signed rank test, two-tailed p-values.

TABLE IIIB—COMPARISON OF RESPONSES FROM INTER-PERIOD QUESTIONNAIRE FOR MARKET OPINION QUESTIONS BETWEEN TESTOSTERONE (T) AND PLACEBO (P)

	Overall			Period 1			Period 2			Period 3		
	T	P	p-value	T	P	p-value	T	P	p-value	T	P	p-value
Prices went higher than I expected	3.7	3.9	-0.29	4.5	4.1	-0.23	3.6	3.9	-0.15	3	3.8	-0.12
	(0.2)	(0.18)		(0.25)	(0.31)		(0.21)	(0.31)		(0.4)	(0.41)	
Prices went lower than I expected	4.2	3.5	0.003	3.7	3.4	-0.31	4.4	3.6	0.03	4.5	3.5	0.04
	(0.18)	(0.14)		(0.28)	(0.18)		(0.3)	(0.25)		(0.32)	(0.3)	
Prices fluctuated more than I expected	3.8	3.5	-0.18	3.8	3.5	-0.25	3.8	3.6	-0.25	3.8	3.6	-0.37
	(0.14)	(0.17)		(0.2)	(0.24)		(0.27)	(0.3)		(0.28)	(0.37)	
Prices were about right	3.6	3.7	-0.26	3.4	3.5	-0.37	3.6	3.8	-0.20	3.8	3.8	-0.40
	(0.14)	(0.14)		(0.27)	(0.23)		(0.27)	(0.26)		(0.21)	(0.25)	

Note: T-test by Wilcoxon signed rank test, two-tailed p-values.

TABLE IIIC—COMPARISON OF RESPONSES FROM INTER-PERIOD QUESTIONNAIRE FOR TRADING STRATEGY QUESTIONS BETWEEN TESTOSTERONE (T) AND PLACEBO (P)

	Overall			Period 1			Period 2			Period 3		
	T	P	p-value	T	P	p-value	T	P	p-value	T	P	p-value
Follow other	3.1 (0.12)	3 (0.14)	-0.3	2.9 (0.2)	3.2 (0.21)	-0.26	3.2 (0.21)	2.9 (0.29)	-0.18	3.1 (0.23)	2.9 (0.24)	-0.35
No strategy	2.4 (0.1)	2.3 (0.13)	-0.21	2.4 (0.15)	2.2 (0.13)	-0.12	2.5 (0.17)	2.3 (0.3)	-0.15	2.2 (0.17)	2.4 (0.26)	-2.80
Understand rules	2.0 (0.8)	2.1 (0.14)	-0.37	2.4 (0.11)	2.5 (0.29)	-0.28	1.9 (0.13)	2.1 (0.17)	-0.15	1.7 (0.13)	1.7 (0.22)	-0.44
Understand Action	2.1 (0.08)	2.3 (0.13)	-0.11	2.4 (0.12)	2.7 (0.22)	-0.11	2.1 (0.13)	2.2 (0.17)	-0.35	1.8 (0.15)	2 (0.2)	-0.15
Others buying too high	3.9 (0.76)	4.5 (0.18)	0.01	4.2 (0.29)	4.4 (0.41)	-0.35	3.9 (0.19)	4.7 (0.26)	0.02	3.6 (0.31)	4.5 (0.29)	0.03
Others buying too low	4.2 (0.13)	4.4 (0.19)	-2.1	4.5 (0.22)	4.6 (0.36)	-0.35	4.2 (0.18)	4.3 (0.3)	-1.00	4.02 (0.28)	4.3 (0.34)	-0.22
Others selling too high	3.9 (0.16)	4.5 (0.18)	0.01	4.2 (0.29)	4.4 (0.41)	-0.35	3.9 (0.19)	4.7 (0.26)	0.02	3.6 (0.31)	4.5 (0.29)	0.03
Others selling too low	3.9 (0.16)	3.3 (0.11)	0.001	3.9 (0.36)	3.3 (0.18)	0.09	3.9 (0.21)	3.5 (0.25)	-0.18	4.1 (0.23)	3.1 (0.13)	0.01
Don't know	3.2 (0.1)	3.2 (0.17)	-0.38	3.5 (0.15)	3.4 (0.22)	-0.22	3.2 (0.18)	3.2 (0.32)	-0.46	2.9 (0.23)	2.9 (0.35)	-0.28

Note: T-test by Wilcoxon signed rank test, two-tailed p-values.

INSTRUCTIONS

1. General instructions

This is an experiment in financial decision-making where you will earn money based on trades you make. The experiment will have 3 rounds; each Round includes 12 trading periods in which you can buy or sell stocks. All trades will be made in *cents*. Please do not speak with any other participant during this experiment. This part of the experiment will last for approximately one hour, including ten minutes for you to review these instructions.

When the experiment starts, half of the participants will be given 6 shares of stock and 216 cents and the other half

will be given 2 shares of stock and 648 cents. Both of these two portfolios are worth 864 cents. You will be randomly assigned one of these portfolios. Six (6) to sixteen (16) traders will participate in the market.
Each trading session has 12 periods that each last for 90 seconds. In each period you may buy or sell units of stock. You can be a buyer and seller of stocks at the same time. Each unit of stock is identical, except the price to purchase or sell. Stocks have a lifespan of 12 periods, and your inventory of stock carries over from one trading period to the next within each trading session.
At the end of each of the 12 trading periods, a dividend is paid for each unit of stock you own at that time. The dividend has a 50% chance of being either 0 or 18 cents. The trading software determines this randomly. As a result, the average dividend per period is 9 cents.
After each trading session, the dividends you earn will be added to your money holdings.
The way to calculate your earnings is described below in Section 3.
You will be asked a series of questions at the beginning of the first trading period and at the end of each trading period. Please answer all these questions.

2. Calculating your earnings

Your earnings in each period are the dividends you receive based on the number of stocks you hold at the end of the trading period. That is:
YOUR EARNINGS FOR A PERIOD =
DIVIDEND PER UNIT °— NUMBER OF UNITS HELD AT THE END OF THE PERIOD
Example: If you own 10 shares and the payout is 18 cents: 18 x 10 =180
Your total earnings for each session are the total of your dividend earnings for each of the 12 periods plus the amount of cash that you have at the end of period 12.

That is:
EARNINGS FOR PERIOD 1
EARNINGS FOR PERIOD 2
EARNINGS FOR PERIOD 3
EARNINGS FOR PERIOD 4
….
EARNINGS FOR PERIOD 12
CASH ON HAND AT THE END OF PERIOD 12
TOTAL EARNINGS
Your profit is the sum of the profits from the three trading sessions. The computer software will track your progress throughout the experiment and give you the final amount you earned, so no need to calculate this yourself.

3. Finding your way around the trading screen

Period

This shows the number of the period you are in. There are 12 periods in each Round. The second Round starts with period 13 and the third Round starts at period 25.

Remaining time (measured in seconds)

This shows the time remaining in the period in seconds. Each period lasts 60 seconds so the timer counts down from 60 seconds to 0 seconds.

Money

The number of cents that you have available for trading.

Shares

The number of units of stock that you currently own.

To buy and sell stock you use the blue and red boxes, taking note of the 'Standing Sell Offers' and 'Standing Buy Offers' columns

Standing Sell Offers

Shows all of the stocks that are available for purchase in descending order with the lowest price at the bottom.

Standing Buy Offers

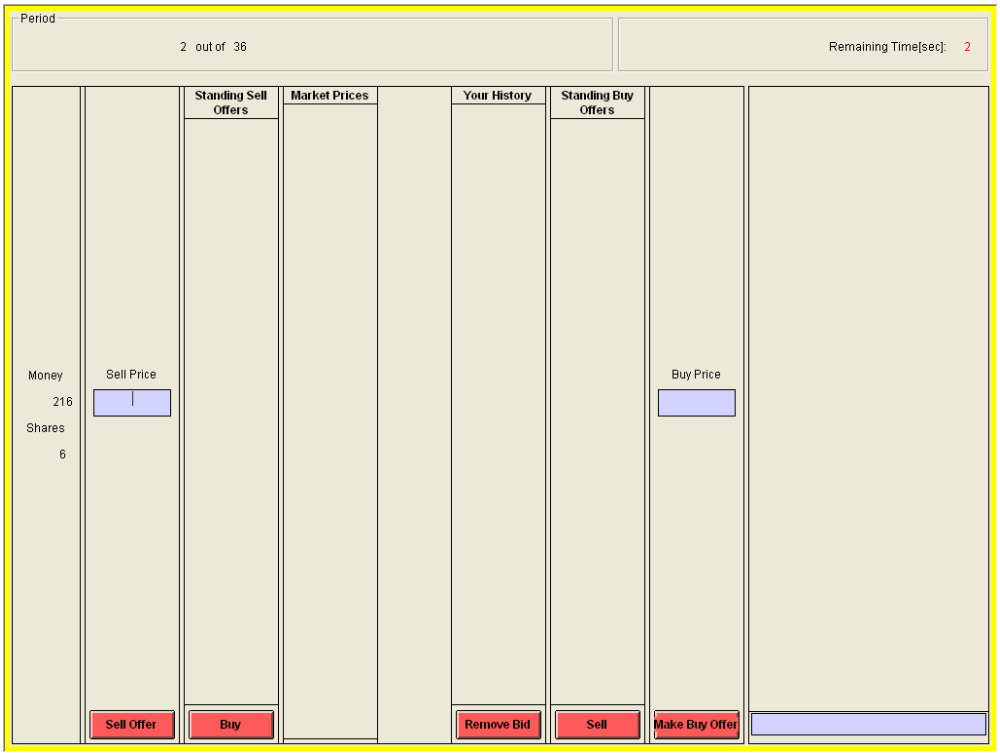
Shows all offers to buy stocks in ascending order with the highest price at the bottom.

Market Prices

Shows the history of the current trading period by listing all of the prices that stocks have been bought or sold for. These prices may not be available for trading.

Your History

Shows all the sell and buy offers you have made in this session.



You can sell a stock two ways: by specifying a sell price and releasing it to the market, or by selling directly to a buyer with an offer in the market

Sell Price

Type the amount, in cents, that you are willing to sell a unit of stock

The amount you type in the **Sell Price** box is your offer to sell one unit of stock at that price

Sell Offer

Pushing this red button releases your offer tothe market. Your offer will now be listed in the **Standing Sell Offers** and **Your History** columns

The sale will not be complete until your sell offer is accepted by a buyer.

Sell

Allows you to respond to an offer in the market and make an immediate sale.

Highlight the amount you wish to sell the stock for from the offers available in the **Standing Buy Offers**

Press the **Sell** button to complete the sale

You can buy a stock in two ways: by specifying a buy price and then releasing it to the market to attract a seller, or by buying it directly from a seller with an offer in the market.

Remove Bid

Press the "Remove Bid" button if you would like to remove the sell or buy offers you have made.

4. Value of stocks based on holding values

You can use the table in Section 4 to help you make decisions. There are 5 columns in the table:

Column1 – *Ending Period*: indicates the last trading period of the trading session.

Column 2 – *Current Period*: indicates the period for which the average holding value is calculated.

Column 3 – *Periods Remaining*: gives the number of holding periods from the *Current Period* until the end of the trading session.

Column 4 – *Average Dividend Value per Period*: gives the average (or expected) amount of the dividend that will be paid in that period for each unit of stock you hold. (Please note, although the actual dividend will either be 0 or 18 cents, the average for each period remains the same at 9 cents.)

Column 5 – *Average Holding Value/unit of stock*: gives the expected total dividend for each unit of stock in the periods remaining. That is, if you held one unit of stock and did not sell it in the periods remaining, on average the total dividends you would receive are listed in column 5. The number in column 5 is calculated by multiplying the numbers in columns 3 and 4.

For example, suppose that there is trading in the last 4 periods in a session. Since the dividend paid on a unit of stock has a 50% chance of being 0 and a 50% chance of being 18, the average dividend s therefore 9 cents for each unit of stock (as shown in column 4). If you hold a unit of stock for 4 periods, the expected total dividend for that single unit of stock over the 4 periods will be 4*9 = 36.

Final Period	***Current Period***	***Periods Remaining* x**	***Average Dividend per = Period***	***Average Holding Value/unit of stock***
12	**1**	**12**	**9**	**108**
12	**2**	**11**	**9**	**99**
12	**3**	**10**	**9**	**90**
12	**4**	**9**	**9**	**81**
12	**5**	**8**	**9**	**72**
12	**6**	**7**	**9**	**63**
12	**7**	**6**	**9**	**54**
12	**8**	**5**	**9**	**45**
12	**9**	**4**	**9**	**36**
12	**10**	**3**	**9**	**27**
12	**11**	**2**	**9**	**18**
12	**12**	**1**	**9**	**9**