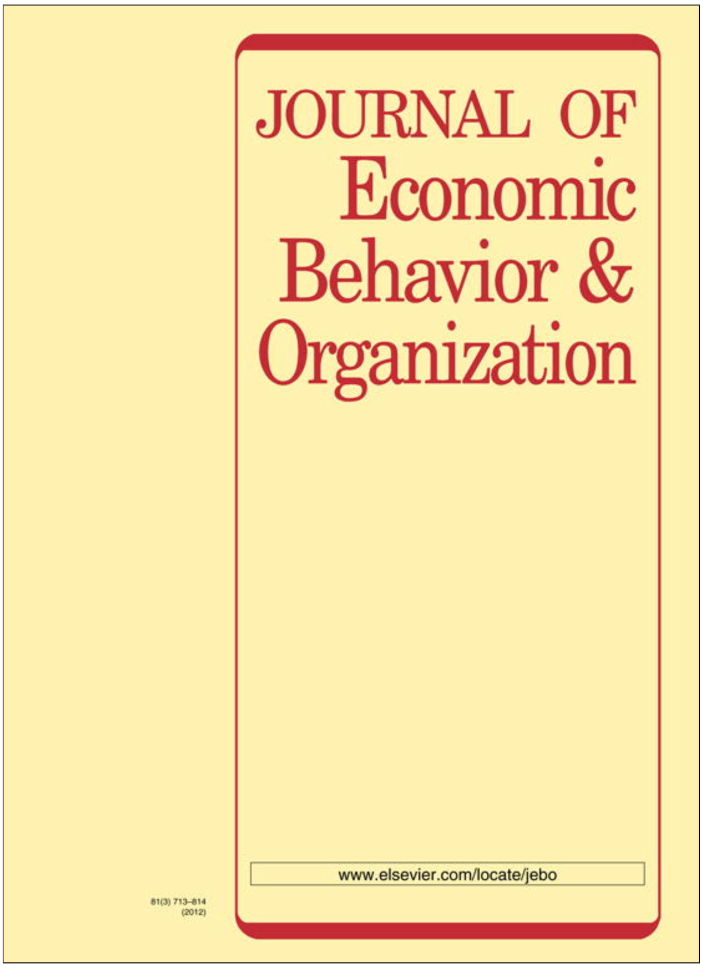
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# The house doesn't always win: Evidence of anchoring among Australian bookies[☆]

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ABSTRACT

We examine Australian horseracing bookmakers' responses to late scratches, instances in which a horse is abruptly withdrawn after betting has commenced. Our observed bookies exhibit anchoring on the original odds and fail to re-adjust odds fully on the remaining horses after a scratch, thereby earning lower profit margins and occasionally creating nominal arbitrage opportunities for bettors. We also examine which horses' odds bookies adjust after a scratch and demonstrate diminished profit margins even after controlling for these endogenous adjustments. Our results indicate that bookies' adjustments recover approximately 80% of lost profit margin but that bookies forgo the remaining 20% due to systematic under-adjustments.



Individuals often form an estimate by starting with an initial value which is then adjusted to yield a final answer. These judgments may be susceptible to *anchoring* effects, whereby individuals make insufficient adjustments from the initial value. Different initial values may therefore yield different final estimates, with final evaluations biased in the direction of the initial starting values. A substantial psychology literature has documented the existence of anchoring effects. Tversky and Kahneman (1974) employed a wheel of fortune that gave subjects random numbers before asking factual questions, demonstrating that subjects anchored on these obviously arbitrary and uninformative numbers. A more recent colorful example is Ariely et al. (2003), which asked subjects for their valuations of a bottle of wine after recalling the last two digits of their Social Security numbers.

The bulk of psychology research on the anchoring effect has employed laboratory experiments with inexperienced subjects. Many economists question whether individual anomalies identified in laboratory experiments would survive in a marketplace, given the opportunities for learning and expertise and the disciplining rigors of real financial stakes (Levitt and

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List, 2007). We address this question by considering how Australian bookmakers respond to changes in the field of horses shortly prior to races. In particular, late scratches, the withdrawal of horses after the posting of early odds but before the close of betting, offer a near-ideal natural experiment to shed light on the matter of anchoring and expertise. Though previous research in the economics literature has utilized horse wagering data (see Sauer, 1998, for an excellent survey of economics and gambling), most attention has been paid to the favorite-longshot bias, in which empirical losses increase as one wagers on less-favored outcomes (see Ottaviani and Sorensen, 2008). Neoclassical explanations for the favorite-longshot bias have focused on risk preferences (e.g., Weitzman, 1965; Ali, 1977) and partially informed bettors (Ottaviani and Sorensen, 2010), while behavioral explanations (e.g., Griffith, 1949; Snowberg and Wolfers, 2010) have considered issues such as probability misperception. Work in this vein has focused primarily, though not entirely, on the pari-mutuel system as found in the U.S., in which bookies are absent. Although there is a notable body of theoretical and empirical work on how bookmakers address potential insider trading (Shin, 1991, 1992, 1993; Cain et al., 2003), this paper is, to the best of our knowledge, the first to use bookmaker data to address the prevalence and persistence of anchoring.

A perfect data set for this application would include money wagered with each bookmaker on each horse at each set of odds, but we, like most of the literature, are limited to observe only odds (reciprocal prices).[2] It is nevertheless instructive to imagine what an ideal data set without quantities would contain. In a typical race, no late scratches occur and a racetime field of $K$ distinct horses generates equilibrium odds and the implied profit margin to the bookie. In scratching races, we would observe various original fields of $K+1$ horses, each of which includes the aforementioned $K$-horse field and an additional horse of varying ability. Bookmakers would set initial odds for the horses of this $K+1$-sized field. The $K+1$th horse would then be late-scratched at various times prior to race time, so that at race time all races have the original $K$-horse field, and the bookmaker would adjust odds for the remaining field of horses. The analyst could then compare racetime odds and see whether implied profit margins vary systematically with whether a late scratch occurs (and, if so, how many), the initial odds of the scratched horse(s), and the time between the late scratch and race time.

Our empirical strategy closely mimics the above, and we find systematic downward bias of races' profit margins consistent with anchoring, despite the potentially substantial financial stakes and bookmaker expertise. Australian bookmakers do not sufficiently adjust the odds on the remaining horses' odds after a late scratch. In fact, the odds adjustment is sometimes so insufficient as to permit arbitrage opportunities. In such cases, punters (as bettors are termed in Australia) who placed wagers on all remaining horses after a particularly poor odds re-adjustment to a late scratch could have earned a riskless profit. We address and rule out the alternative explanations of bookie risk aversion and bounded rationality. We also demonstrate that our results are not entirely due to partial adjustments, in which bookies adjust odds on only a portion of the field due to time pressure or costly adjustment. Finally, for each individual horse we calculate what the optimal updated odds should have been under the assumption that bookies should have proportionately re-distributed scratched horses' odds. We demonstrate that the odds on horses that were adjusted are significantly under-adjusted relative to these optimal odds, consistent with anchoring on the original odds. Our results indicate that bookies' adjustments recover approximately 80% of the profit margin lost by a scratch, but that bookies forgo the remaining 20% due to systematic under-adjustments.

The primary contribution of this paper is to provide evidence of the anchoring bias "in the wild." Previous research on anchoring has successfully demonstrated differences in laboratory experiments between the inexperienced and experienced for real estate evaluations (Northcraft and Neale, 1987) and stock return estimates (Kaustia et al., 2008). Other research has utilized real market data to document anchoring in online auctions (Dodonova and Khoroshilov, 2004), art auctions (Beggs and Graddy, 2009), and sportscards trading (Alevy et al., 2010), as well as to consider dissipation of anchoring effects over time for real estate purchases (Simonsohn and Loewenstein, 2006). The contribution of our paper is that, for the first time, we integrate all of these conditions and concerns within a single market. That is, we observe experienced market participants in their day-to-day profession where they face potentially substantial financial incentives as they make adjustments under time pressure.

In Section I, we describe bookmaking decisions and other horserace institutions in Australia. We specifically discuss assumptions under which observed odds can yield bookmakers' profit margin and then show how bookies must respond to late scratches if they wish to maintain their margins. We describe our data in Section II and our analysis and results in Section III. Section IV concludes and discusses the implications for the behavioral economics literature.

## 1. Fixed odds gambling in Australian racecourses

Fixed odds gambling in horse racing (as found in Australia, Ireland, the United Kingdom, and several other countries) offers to the empirical analyst several advantages over the pari-mutuel format. Under the pari-mutuel format (the only legal option for horserace wagering in the U.S. and Japan), odds are determined entirely by the relative allocation of wagers when wagering ends. Any pre-race odds are therefore preliminary, and final payouts are not determined until after the betting period is closed. The organization operating the pari-mutuel format garners revenue by deducting a fixed percentage (the takeout rate or take) of money wagered; payouts are calculated by subtracting the fixed take from the total betting pool and distributing the remainder to the winning punters. Fixed odds gambling differs from pari-mutuel gambling in several ways. The most prominent distinction is the existence of the bookmaker, an individual who actively sets odds. As the format's

[2] Coffey and Maloney (2010) is a notable exception.

name implies, odds offered to a punter are fixed, though these odds may be changed for subsequent punters. Foremost to this analysis, the take (the expected percentage of the last dollar bet that is kept by the bookie) is implicitly determined by the set of odds chosen by the bookmaker and thus can vary across time, racecourses and races. Under reasonable assumptions regarding demand and cost, the fixed odds take variable can reveal the impact of race characteristics that cannot otherwise be recovered without additional data.[3] Another obvious advantage enabled by the use of fixed odds races over pari-mutuel races is the potential to examine the bookmaker's behavior directly.

Australia, like its Imperial kin, allows gambling using both a fixed odds format and a pari-mutuel format. There are 379 racecourses in Australia, though only 17 are considered large. We observe Saturday data from the nine racecourses in metropolitan areas: two in Brisbane, three in Melbourne, and four in Sydney. These racecourses are roughly the largest in Australia. The horses that are slated to race are known in advance of race day. Independent bookmakers at these racecourses compete for punter business against one another, against the on-site pari-mutuel system, and against all off-site gambling options. There are approximately 12–15 bookies at the smaller racecourses and 25–30 at the larger racecourses. Bookies usually operate in multi-man teams. The typical bookie solicits business by standing in front of a chalkboard that displays his offered odds. Several assistants collect wagers, distribute receipts, and inform the bookie of how much has been wagered on each horse. Bookies adjust the odds on individual horses by simply writing the updated odds on the chalkboard. Initial (opening) odds from the bookmakers are posted approximately 30 min before race time, and changes to these odds are periodically made prior to the posting of the final (starting) odds.[4] Unlike the pari-mutuel format where punters receive the official final odds regardless of when they make their wagers, punters under the fixed odds format receive the odds that held when they made their wager. In the data and throughout this paper, a wager's gross odds is the amount for each dollar wagered that is returned to the punter in the event of his horse winning. For example, a $1 wager on a winning horse with listed odds of 4 would pay back $4 (the original $1 plus the $3 of winnings). Alternatively, the price of a wager is the reciprocal of those odds, and so the preceding wager would have a price of $0.25.

Two commonly used measures of bookies' profit potential are the margin and take. The margin $M$ is defined as the amount of a marginal dollar wagered that is retained by the bookie as a proportion of the amount returned to punters. The racecourse take-out rate (or take) $T$, a concept used explicitly in the pari-mutuel system, is defined as the amount of a marginal dollar wagered that is retained by the bookie as a fraction of the total amount wagered.[5] For example, a 25% margin corresponds to the bookie retaining 20% of the total amount wagered as take and paying out 80%. The connecting formulae between margin and take are thus $T = M/(M+1)$ and $M = T/(1-T)$. Both the margin and take should be weakly positive, else there exists an arbitrage opportunity. While bookie margin has instructive parallels with Arrow-Debreu prices that sum to more than one as bookies impose the equivalent of a tax, we prefer the implied take in order to facilitate comparisons with the competing pari-mutuel regimes. All of our empirical results are robust to employing bookie margin instead of implied takeout rates as the dependent variable.

We now detail assumptions under which the bookmaker's expected take for a race can be constructed from a set of observed odds, and we then illustrate both the baseline case and the consequences of a late scratch with a simple numerical example. We assume that punters obtain sufficiently high recreational utility from gambling as to always wager on a race, and decide on which horse to bet on the basis of the expected monetary payoff, assuming risk neutrality. Our model of punters is thus a special case of Ottaviani and Sorensen (2010) without private punter information so that punters share common beliefs about race outcomes. These assumptions then generate our identifying assumption that a late scratch of a horse in a race does not change the betting demand for that race. Price-setting bookmakers set odds $O_k$, the gross payout to a winner of a $1 wager on horse $k$ winning the race. Let $p_k$ denote the bookie's subjective probability of horse $k$ winning the race. The expected take on horse $k$ is then $t_k = 1 - p_k O_k$. In expectation, the bookie retains $t_k$ of every dollar wagered on horse $k$ and pays out $p_k O_k$. Letting $\rho_k$ denote a punter's subjective probability of horse $k$ winning the race, punter equilibrium conditions imply that a punter is indifferent between a wager on any two horses: $\rho_j O_j = \rho_k O_k \; \forall j, k$. When combined with the fact that subjective probabilities sum to one $\left(\sum_{k=1}^{K} \rho_k = 1\right)$, our system contains $K$ equations for $K$ horses. For a given set of observed equilibrium odds, one can uniquely determine the punter subjective probabilities that generated them:

$$\rho_k = \frac{1/O_k}{\sum_{k=1}^{K} 1/O_k}. \tag{1}$$

Note that the converse is not true, as punter subjective probabilities do not correspond to a unique set of odds. Punter subjective probabilities determine only the ratio of odds; for example, $O_1/O_2 = \rho_2/\rho_1$, $O_1/O_3 = \rho_3/\rho_1$ for a three-horse race. The bookie has the capacity to fix the magnitude of the odds and thus implicitly the level of take for the race.

[3] Employing this approach, Moul and Keller (2012) omit late-scratching horses and link the demand-side implications and a representative bettor to consider likely impacts of U.S. pari-mutuel reform.

[4] The initial and final odds are respectively referred to in the industry and our data as the opening and starting odds. We will differ from the official wagering terminology throughout this paper so as to minimize potential confusion between opening and starting odds.

[5] An alternative term for the margin is the overround, and alternative, more colorful terms for the take are the juice, the vig (short for vigorish), the edge, and the house edge.

Consider a three-horse race. Substituting $O_k = (1-t_k)/p_k$ into the consumer indifference conditions yields

$$\frac{(1-t_1)/p_1}{(1-t_2)/p_2} = \frac{\rho_2}{\rho_1}, \frac{(1-t_1)/p_1}{(1-t_3)/p_3} = \frac{\rho_3}{\rho_1} \tag{2}$$

which simplifies to $(1-t_1)/(1-t_2) = p_1\rho_2/p_2\rho_1$ and $(1-t_1)/(1-t_3) = p_1\rho_3/p_3\rho_1$. As before, we have more unknowns than equations, and horse-takes are not uniquely identified. Without loss of generality, assume the bookie sets the odds on horse 1 and thus implicitly determines $t_1$. The consumer indifference conditions then imply that $t_2 = 1-(1-t_1)\rho_1 p_2/\rho_2 p_1$, $t_3 = 1-(1-t_1)\rho_1 p_3/\rho_3 p_1$.

The above equations yield several implications. First, when bookie and punter probabilities coincide, such that $p_k = \rho_k \; \forall k$, then all horses should have a common take rate $t = T$. The bookie in such a scenario should set the odds on each horse such that $1 - p_k O_k = T$ for all $K$ horses. Second, the bookie cannot actually set individual horse-takes independently of each other, due to the inter-linking of odds imposed by the punter equilibrium conditions. Third, the expected race-take, the weighted summation of individual horse-takes, will apparently depend on $t_k$, $p_k$, and $\rho_k \; \forall k$.

The expected race-take is thus the sum of individual horse-takes, weighted by each horse's fraction of the total amount wagered. In the scenario in which bookie and punter probabilities coincide, $t_k$ is identical for all horses. For any distribution of relative wagers among the horses, race-take is equal to the constant take rate $t = T$. In the more general case in which bookie and punter probabilities do not coincide, we follow the literature on the pari-mutuel system and assume that the fraction wagered on a particular horse coincides with punter subjective probability for that horse: $T = \sum_{k=1}^{K} \rho_k t_k$. Substituting $t_k = 1 - p_k O_k$ and our prior expression for equilibrium subjective probabilities as the relative share of summed reciprocal odds yields

$$\begin{aligned}
T &= \sum_{k=1}^{K} \frac{1/O_k}{\sum_{k=1}^{K} 1/O_k}(1 - p_k O_k) \\
T &= \frac{1}{\sum_{k=1}^{K} 1/O_k} \sum_{k=1}^{K} \left(\frac{1}{O_k} - p_k\right) \\
T &= \frac{1}{\sum_{k=1}^{K} 1/O_k} \left(\sum_{k=1}^{K} \frac{1}{O_k} - \sum_{k=1}^{K} p_k\right) \\
T &= 1 - \frac{1}{\sum_{k=1}^{K} 1/O_k}
\end{aligned} \tag{3}$$

Alternatively, the race-margin under these assumptions is given by $M = \sum(1/O_k) - 1$, which coincides with the measure's conventional formula. Intuitively, the extent to which the reciprocal gross odds (i.e., the wagers' prices) sum to greater than one signifies the bookie's expected profit margin.

It is worthwhile to examine the relation of the race-take $T$ (and implicitly the margin) to the bookmaker's presumed objective function of expected profits. Let $b_k$ denote the number of dollars wagered on horse $k$, and let $B$ denote the total amount wagered on a race. Assuming that the bookie incurs no variable costs, the expected variable profit for the race will then be $E(\pi) = \sum b_k * t_k$. Using the prior assumption that the amount of money wagered on a particular horse as a share of the total amount wagered coincides with punter subjective probability on that horse $((b_k/B) = \rho_k)$, then $E(\pi) = B\sum \rho_k * t_k = B * T$. If the total amount wagered depends on the take $B(T)$, then the bookie chooses the level of odds and implicitly the take to maximize $B(T) * T$. The bookie's problem is thus quite analogous to a revenue-maximizing firm facing a downward-sloping residual demand curve.

Consider the following simple example of a three-horse race with horses A, B, and C with listed payout odds $(O_k)$ of 2.25, 1.5, and 4.5, respectively. Punter indifference conditions and the fact that the punter's subjective probabilities must sum to one imply that those subjective win probabilities are 1/3, 1/2, and 1/6. The take can be recovered as

$$T = 1 - \frac{1}{(1/2.25) + (1/1.5) + (1/4.5)} = 1 - \frac{9}{12} = \frac{1}{4}$$

Had the bookie magnanimously chosen to offer fair odds on each horse and retain nothing ($T = 0$), the comparable payout odds would have been 3, 2, and 6. If \$30 total is wagered on the race and shares of bets mimic the punter's subjective probabilities, then

$$E(\pi) = 10\left(1 - p_1 * \frac{9}{4}\right) + 15\left(1 - p_2 * \frac{3}{2}\right) + 5\left(1 - p_3 * \frac{9}{2}\right) = 30 * \frac{1}{4}$$

This shows that bookie's subjective probabilities do not enter into expected profits and also verifies our prior statement of the bookie's capacity to set the level of odds for a profit-maximization objective.

With our dependent variable of bookie take now described, we can turn to the exogenous shocks (i.e., scratched horses) on which we will focus. Horses may be withdrawn from races at two stages. Early scratches are horses that are withdrawn prior to the announcement of the initial odds. Late scratches are horses that are withdrawn after the announcement of the initial odds but prior to the announcement of the official final odds, a time period of approximately one-half hour. We have limited data regarding why late scratches occur; the primary causes appear to be veterinary advice and unruly horses (e.g., thrown jockeys, early breaking through the barriers, etc.). Punters who placed a straight wager on a single late-scratching horse receive a refund. For exotic multi-horse wagers involving a late-scratching horse, the bookie generally substitutes the next most favorable horse for the late-scratching horse. By state regulation, punters who wagered on a non-scratching horse before a late scratch occurs have their odds retroactively worsened to mitigate the economic loss to bookies from punters wagering on now-favorites at an effective discount. However, bets placed after a scratch occurs are binding at the current quoted odds, creating the need for the bookie to make odds adjustments if he wishes to maintain pre-scratch profit margins.

Updating the odds after a scratch is a straightforward task, requiring the bookie to allocate the scratched horse's probability among the remaining field. However, the existing pre-scratch odds may serve as an anchor. The anchoring literature distinguishes between two different types of anchors: externally-provided anchors and internally-generated anchors (Epley, 2004). External anchors occur when a subject first compares whether the true answer is greater or less than some externally provided value, and then provides a final estimate. By contrast, internal anchors occur when the nature of the problem suggests a natural starting value that must be adjusted. An important distinction is that internal anchors do not involve any explicit "more or less" comparison, as subjects already know that the starting value is incorrect and must require some adjustment.[6]

In our present context, the pre-scratch odds serve as an internal anchor. Bookies know that, at the time of the scratch, the quoted odds on the remaining field are too generous, since each remaining horse now has a higher probability of winning the race. As such, bookies must reduce the quoted odds to maintain pre-scratch take levels. A late scratch thus serves as a natural experiment, forcing bookies to re-perform their typical decision process, albeit under enhanced time pressure. Our data analysis is an attempt to measure how completely bookies respond to, and recover from, exactly these situations. If bookies anchor on the pre-scratch odds, then subsequent adjustments will be incomplete. Anchoring bookies will revise the odds on the remaining field in the appropriate direction (reducing quoted odds to reflect the higher win probabilities) but with too small of a magnitude, yielding observably lower take levels.

One potential complication with our empirical approach is that, in the absence of subsequently adjusted odds, bookie take necessarily declines following a scratch. In the above three-horse example with initial take $T = 0.25$, suppose relative longshot horse C listed at 4.5 odds scratches and is removed from the race. If the bookie does not adjust the odds to reflect the remaining horses' higher win probabilities, then the new take becomes $T = 1 - \frac{1}{(4/9)+(2/3)} = 0.1$. Horse C's removal from the race (and thus the removal of its 4.5 odds from the $\sum_{k=1}^{K} 1/O_k$ term in the denominator of the take calculation) decreases the race take from 25% to 10%. Take declines automatically after a scratch because the pre-scratch payout odds for the remaining field are now more favorable to punters given the new higher win probabilities of these remaining horses. Assume that the remaining horses' win probabilities are independent of each other, so that the scratched horse's probability is re-distributed among the remaining field in proportion to their prior probabilities and the updated post-scratch win probabilities become $\rho_A = 0.4$ and $\rho_B = 0.6$. The bookie should then lower the payout odds on A and B to 1.875 and 1.25 to maintain the original profit margin of 25%.

A reduction in take following a late scratch therefore does not by itself constitute evidence of anchoring or any other bookie error. Some scratches occur so immediately prior to the race start time that bookies have no time to re-adjust the odds, and the observed decrease in take is simply the natural consequence of the scratch. Fortunately, our data enable us to identify the timing of the scratch and subsequent odds adjustments after the scratch. We separate the races in which there were no odds adjustments after a scratch (and thus the decrease in take cannot be attributed to bookie error) from races in which there were subsequent odds adjustments after a scratch and demonstrate lower takes even after bookies have adjusted the post-scratch odds.

Updating the odds is not necessarily trivial, as bookies incur adjustment costs of both time and mental energy. Bookies may therefore selectively adjust odds on important horses, and only adjust odds on the remaining field if there is sufficient time before the race begins. If bookies only adjust odds on a portion of the field and decide to retain sub-optimal odds on the remaining field, this would also mimic anchoring's prediction of lower take. As a further robustness check, we control for the extent to which bookies adjust the odds on only a portion of the field before racetime.

## 2. Data

We observe, courtesy of the Australian Bookmakers Association, almost every Saturday race at metropolitan racecourses from November 2, 2002, to August 4, 2007, and the corresponding odds from the bookmaker who was randomly sampled that day.[7] After discarding six races for apparently erroneous data (e.g., all horses having same odds), we are left with 5218

[6] For example, Epley and Gilovich (2006) asked subjects, "What year was George Washington elected President of the United States?" Most adults will not recall the exact answer, but know that it must have occurred sometime after 1776. Subjects' average response was 1779, though the correct answer is 1789. Similarly, subjects typically estimated that vodka freezes at 1° F, rather than the correct value of −20°, suggesting incomplete adjustment from the commonly known freezing point of water of 32 °F.

[7] The data did not include 8 Saturdays, 5 of which occurred from November 2002 through January 2003. We thus observe 96.8% of Saturday races between November 2, 2002, and August 4, 2007.

**Table 1**
Description of data and summary statistics.

| | | All Races (1) | LS = 0 (2) | LS > 0 (3) | LS > 0 No Adjustment (4) | LS > 0 Any Adjustment (5) |
|---|---|---|---|---|---|---|
| Race number | Mean | 4.66 | 4.66 | 4.53 | 4.56 | 4.52 |
| | S.D. | 2.41 | 2.40 | 2.58 | 2.50 | 2.63 |
| Last race of the day | Mean | .12 | .12 | .16 | .12 | .17 |
| | S.D. | .33 | .32 | .36 | .33 | .38 |
| Number of horses | Mean | 11.02 | 11.04 | 10.45 | 10.98 | 10.16 |
| | S.D. | 2.87 | 2.87 | 2.75 | 2.73 | 2.73 |
| Gini | Mean | .41 | .41 | .41 | .42 | .41 |
| | S.D. | .09 | .09 | .08 | .08 | .09 |
| # Early scratches | Mean | 1.35 | 1.34 | 1.44 | 1.36 | 1.49 |
| | S.D. | 1.50 | 1.50 | 1.58 | 1.48 | 1.64 |
| LS time difference | < 1 min | 69 | – | 69 | 49 | 20 |
| (counts) | 1–3 min | 60 | – | 60 | 12 | 48 |
| | ≥ 3 min | 58 | – | 58 | 5 | 53 |
| Scratch time | Mean | | | 3.78 | 1.78 | 4.87 |
| (minutes until race) | S.D. | | | 6.19 | 5.40 | 6.35 |
| Late scratch | Mean | .128 | – | .128 | .140 | .122 |
| Reciprocal odds | S.D. | .12 | – | .12 | .12 | .13 |
| Initial take | Mean | 29.69 | 29.67 | 30.1 | 31.20 | 30.45 |
| | S.D. | 4.47 | 4.57 | 4.68 | 4.72 | 4.66 |
| Final take | Mean | 16.86 | 17.03 | 12.32 | 8.81 | 14.24 |
| | S.D | 5.61 | 5.13 | 12.13 | 14.18 | 10.42 |
| Observations | | 5218 | 5031 | 187 | 66 | 121 |

races. For each race, we observe the date, the racecourse, the number of horses that race, the ordinal placement of the race (e.g., second race of day), and whether the race is the last of the day. We observe the initial (opening) fixed odds of win bets for the entire field of horses, as well as the final (starting) odds. These initial odds enable us to construct a take measure that is a near-ideal proxy for several unobserved race-level variables (such as prestige or weather) that are likely to affect betting demand. We also observe each set of odds for all horses in the field, as well as the associated times of changes to these odds. Bookies adjust the set of odds on average 32.3 times per race, and adjust the odds on individual horses an average of 4.1 times per race. The set of odds that hold at any moment during the betting period then imply a race's time-specific marginal bookie take. We observe neither the competing pari-mutuel odds nor the odds from any off-track outlet. We also do not observe any betting volumes (i.e., $B$ in the preceding model's notation). From the final odds, we calculate a Gini coefficient that employs the implied subjective probabilities to measure the expectations of a race's even-ness (or lopsided-ness). A race with a Gini of 0 would have a perfectly even field of horses, and a race with an expected certain winner would have a Gini of 1.

Finally, we have information on scratches. In addition to the number of horses that scratched prior to the announcement of initial odds (early scratches), we observe the number of horses that scratch late as well as their odds preceding the scratch. When a horse scratches, an announcement is made over the racecourse loudspeaker. We observe the time of the scratch relative to the posting of the final odds; however, an unfortunate peculiarity of our data is that, while odds changes are listed to the nearest second, 78 out of the 197 scratch times are only reported at the minute level. For these instances recorded at the minute level, we cannot discern whether some of the remaining horses were adjusted before or after a scratch. For example, if we observe that horse A scratches at 1:23 and horse B's odds were adjusted at 1:23:45, we do not know whether horse B's odds were adjusted before or after the scratch. Our solution in these instances is to impute the timing of a late scratch as unfavorably toward our anchoring hypothesis as possible. For late scratches recorded at the minute level, we impute the scratch time as occurring at: 59 s within that scratching minute. Our imputation system therefore minimizes the number of horses which are counted as post-scratch adjustments and is therefore conservative against demonstrating anchoring.

Column (1) of Table 1 presents summary statistics for our entire sample of 5218 races. The systematic differences between initial odds and final odds reflect the competitive position of fixed odds wagering with respect to pari-mutuel wagering. Initial odds imply a much higher take and margin than that implied by final odds. In our sample, initial odds imply an average take of 29.7%. Bookies periodically adjust the odds favorably toward punters during the half-hour betting timeframe; final odds have an implied take of only 16.9%. This is supported by both demand and cost considerations. Knowledgeable punters may want to lock in their informational advantage, and they are willing to pay a premium to do so by betting early at (relatively) unfavorable odds. Conversely and consistent with Shin's theoretical model, bookies seek to protect themselves from punters exploiting inside information of which the bookies are unaware. As race time approaches, these differences against pari-mutuel wagering diminish. Bookies competing against one another (and the pari-mutuel system) may then drive the implied take to, or even below, the competing pari-mutuel system's take. This consistent downward trend in implied take suggests that punters who are unwilling to pay a sizable premium to secure odds will wait until closer to race time to do so. This incentive motivates our confidence that substantial wagering happens near race time, even though we have no data on wagering quantities.

Early scratches are a common occurrence (the typical race has one early scratch), but late scratches occur far less frequently. While the vast majority of races with late scratches involve a single horse scratch (178 of 187), there are eight races with two late scratches and one race with three late scratches. We observe 57,516 horses racing. Given the 197 horses that late-scratch, the data (197/(57,516 + 197)) imply a 0.34% unconditional probability of any one horse scratching. The importance of these late scratches varies widely across races. Using initial (reciprocal) odds, we construct the variable Late Scratch Odds (*LSO*) to capture the relevance of the late-scratching horse(s). Letting $LS(j)$ be the set of horses that late-scratched in race $j$, $\sum_{k \in LS(j)} 1/O_k$ and = 0 if $LS(j)$ is empty.[8] Conditioning on a race having at least one late scratch, we see that the typical outcome is equivalent to a horse with initial odds of 7.79 scratching. There is a great deal of variation in this variable, ranging from a longshot with initial odds of 200 to a heavy favorite with 1.62 odds.

Finally, late scratches appear to be plausibly exogenous. Column (2) of Table 1 summarizes the 5031 races without a late scratch, and Column (3) summarizes the 187 races with a late scratch. The two groups have similar Gini coefficients, race ordinal placements, and number of early scratches. One interesting point to note is that races that will have a late scratch have slightly higher initial takes than races that will not have a scratch. One insidious interpretation of this difference is that bookies may have inside information on the likely occurrence of scratches. If so, the odds posted before the scratch should already reflect the chance that the race is likely to have fewer competitors than initially announced. That is, bookies may set lower odds in anticipation of the scratch to minimize the need for later adjustments. While curious, it is worth noting that this take discrepancy no longer persists closer to the start of the race. At 5 min prior to the start of the race, the average take for races without a scratch is 17.7%, and for scratching races (which have not yet had their scratch) the average take is 17.8%.

Races with late scratches have significantly fewer horses (10.5 horses compared to 11). Though it is expected that we can reject that the field sizes of races without scratches and races with a late scratch are equal, it is superficially surprising that we can also reject that races with at least one horse that late-scratched do not have a field-size that is at least a full horse smaller. If, however, the probability of a scratch follows the horse rather than the race, one would expect that races with larger fields would incur more such scratches than races with smaller fields. Given our observed original field sizes and the probability of a horse scratching, one would expect means of 11 and 10.8. We cannot reject that our observed means are the same as those expectations. Regardless, this discrepancy should not be an issue in estimation as all specifications control for field size.

The fourth and fifth columns further break down the set of races with a late scratch into the 66 races in which there was a late scratch but no subsequent odds adjustment and the 121 races with a late scratch and any odds adjustment after the scratch. The most noteworthy figures here are a comparison of final takes across columns 2, 3, 4, and 5. Races with no late scratches (column 2) have a final take of 17.0 percentage points. By contrast, races in which there was at least one late scratch have a mean final take of 12.3 percentage points. As we have noted, however, some late scratches are not followed by any odds adjustments, and in such races lowered takes cannot necessarily be attributed to bookie error. The mean final take in column 4 (8.8 percentage points) thus illustrates the purely mechanical decline in take induced by a late scratch. Controlling for some adjustment after a late scratch (column 5), however, shows that mean take in those races (14.2 percentage points) still lags the control group.

The time between a late scratch and the start of the race also comports with the variables along this adjustment distinction. Races in which the bookie did not update odds after a scratch are disproportionately more likely to have a scratch occurring immediately prior to racetime. Of the 66 races in which the observed bookie made no adjustment after a scratch, 49 of these instances involve a scratch that occurred less than a minute prior to closing prices. By contrast, bookies did not subsequently adjust the odds in only 5 out of the 58 instances in which a horse scratched with more than 3 min until race time.[9] Of the races in which there was a late scratch and the bookies updated odds after the scratch, 16% (20 out of 121 cases) of the scratches occur less than 1 min prior to the announcement of final prices, 40% occur between 1 and 3 minutes prior to the final prices, and the remaining 44% occur more than 3 min prior to the final prices' announcement.

Proper identification of the anchoring hypothesis requires controlling for the amount of adjustments to the field. To quantify the amount of adjustment, we note for each individual horse whether there was any post-scratch adjustment in odds. We then calculate each horse's share of the race's probability mass using the implied equilibrium subjective probabilities by final odds in Eq. (1). We sum each adjusted horse's probability mass to create a measure of how much of the race's total probability mass was adjusted after a scratch. These race-level adjusted probability masses thus span the unit interval, with zero indicating that no adjustment was made after a late scratch and one indicating that odds on the entire field were changed. This measure is more informative than the number of horses adjusted, as adjusting one favorite may have a larger impact than adjusting several longshots.

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[8] We are therefore summing the opening prices (reciprocal odds) for any horses that late scratch.

[9] For the nine races with multiple late scratches, we considered both a simple average of horse-specific time difference and an odds-weighted time difference. The odds-weighted time difference has more intuitive appeal in that the impact of longshots late-scratching is mitigated, so we employ it throughout.

**Table 2**
Summary statistics by scratch time category.

| Scratch Time Category | | ≥ 3 min | 1–3 min | < 1 min |
|---|---|---|---|---|
| Race number | Mean | 4.09 | 5.18 | 4.35 |
| | S.D. | 2.50 | 2.56 | 2.59 |
| Last race of day | Mean | .09 | .22 | .16 |
| | S.D. | .28 | .42 | .37 |
| Number of horses | Mean | 10.6 | 10.1 | 10.6 |
| | S.D. | 3.17 | 2.55 | 2.54 |
| Gini | Mean | .41 | .41 | .42 |
| | S.D. | .07 | .10 | .08 |
| # Early scratches | Mean | 1.57 | 1.45 | 1.33 |
| | S.D. | 1.79 | 1.47 | 1.51 |
| Late scratch reciprocal odds | Mean | .133 | .125 | .127 |
| | S.D. | .14 | .12 | .11 |
| Initial take | Mean | 31.22 | 30.43 | 30.53 |
| | S.D. | 4.61 | 4.67 | 4.78 |
| Take at time of scratch | Mean | 20.78 | 17.12 | 18.09 |
| | S.D. | 6.36 | 5.90 | 5.28 |
| Number of horses adjusted | Mean | 6.19 | 3.62 | .46 |
| | S.D. | 3.32 | 3.67 | 1.29 |
| Any adjustment after late scratch | Mean | .91 | .80 | .29 |
| | S.D. | .28 | .40 | .46 |
| Adjusted probability mass | Mean | .71 | .42 | .06 |
| | S.D. | .33 | .38 | .15 |
| Final take | Mean | 16.22 | 11.76 | 9.54 |
| | S.D. | 8.98 | 12.18 | 13.60 |
| Observations | | 58 | 60 | 69 |

Given the importance of scratch timing on bookies' capacity to adjust the odds before the race start, Table 2 presents descriptive statistics by scratch time category. Race characteristics prior to a scratch are similar across all three scratch time categories. Adjustments to the field, however, differ dramatically across the scratch time categories. For races in which the scratch occurred more than 3 min prior to the race, bookies adjusted on average 6.2 horses' odds, representing 71% of the fields' probability mass, whereas in races with a scratch occurring within 1 min of the race start, bookies adjusted the odds on 0.5 horses representing only 6% of the probability mass.

Further casual evidence in favor of the anchoring hypothesis can be found by considering the 20 races in which the race-take is negative. Such situations yield a nominal arbitrage opportunity whereby a punter could wager on all horses and be guaranteed a positive return. The minimum take is −55.7 percentage points, which occurred in a race in which the heavy favorite ($O_k = 1.8$) withdrew with just under 1 min before the announcement of the official final odds. By placing relatively large wagers on the favorites and progressively smaller odds on the longer shots, a hyper-aware punter could have risklessly transformed \$100 into \$155.72.[10] All 20 instances of negative takes occur in races with at least one late scratch. Of these 20 races with negative takes and a late scratch, 13 occur in races with the scratch so immediately prior to racetime that bookies did not submit any updated odds. As such, the negative take is a natural consequence of the scratch and cannot be attributed to any bookie error. However, in 7 of these 20 races the bookie updated some odds after a scratch and still yielded a negative take.

## 3. Results

We begin by regressing marginal final (starting) take on the race's initial (opening) take, ordinal race placement, a binary variable for whether the race is the last of the day, the number of horses, and the Gini coefficient of subjective probability dispersion. Standard errors are clustered at the racecourse level. Table 3 displays the results. Specification (2) adds course fixed effects and specification (3) adds week fixed effects, greatly improving the fit. All coefficients remain stable across the differing specifications thereafter. Races with one percentage point higher initial takes have final takes approximately 0.30 percentage points higher, suggesting that any unobserved factor driving higher initial takes is still partially manifest in final takes. Take rises with the number of horses, consistent with Shin's story of bookies protecting themselves from insider trading but also consistent with Coffey and Maloney's (2010) finding that amounts wagered increase with field size. An additional horse in the field yields roughly a half-percentage point increase in final takes. The Gini coefficient of horse odds' dispersion is never statistically significant. Final take rises throughout the day, particularly for the last race of the day.

[10] We concede that these arbitrage opportunities are rare. In our sample, a race with a negative marginal take occurs on average once every 260 races. Given roughly eight races a day and limiting the analysis to Saturdays, this implies that such an opportunity could be expected to arise at any given track once every seven months. When it arises, the punter would typically have only a few minutes to identify and exploit the opportunity. The discipline and numerical skills required of such a punter are such that more lucrative career opportunities would almost certainly exist.

**Table 3**
Baseline impact of late scratches on take.

| Dependent Variable: final take (in percentage points) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Initial take | .25 | .31 | .28 | .28 | .30 | .30 | .30 | .30 |
| | (.07)** | (.09)** | (.07)** | (.07)** | (.06)** | (.06)** | (.07)** | (.07)** |
| Race number | −.10 | .17 | .18 | .17 | .17 | .17 | .17 | .18 |
| | (.07) | (.04)** | (.04)** | (.04)** | (.04)** | (.04)** | (.04)** | (.04)** |
| Last race of day | 1.24 | .66 | .68 | .64 | .69 | .75 | .67 | .76 |
| | (.20)** | (.19)** | (.19)** | (.19)** | (.18)** | (.15)** | (.17)** | (.12)** |
| Number of horses | .92 | .54 | .54 | .54 | .52 | .50 | .52 | .50 |
| | (.10)** | (.10)** | (.09)** | (.08)** | (.08)** | (.08)** | (.08)** | (.08)** |
| Gini | −4.83 | .45 | .75 | .84 | 1.13 | 1.04 | 1.15 | 1.21 |
| | (3.54) | (2.08) | (1.79) | (1.80) | (1.78) | (1.83) | (1.82) | (1.83) |
| # Early scratches | −− | −− | −− | .09 | .09 | .09 | .09 | .09 |
| | | | | (.03)** | (.03)** | (.03)* | (.03)** | (.03)* |
| # Late scratches | −− | −− | −− | −− | −4.70 | 2.29 | −8.55 | 4.11 |
| | | | | | (1.23)** | (.87)* | (1.99)** | (1.18)** |
| LSO | −− | −− | −− | −− | −− | −56.37 | −− | −93.24 |
| | | | | | | (11.56)** | | (11.90)** |
| # LS*anyadjustment | −− | −− | −− | −− | −− | −− | 5.63 | −3.32 |
| | | | | | | | (1.09)** | (1.20)* |
| LSO*anyadjustment | −− | −− | −− | −− | −− | −− | −− | 61.68 |
| | | | | | | | | (10.32)** |
| Course fixed effects | *No* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* |
| Week fixed effects | *No* | *No* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* |
| *R*-squared | .317 | .593 | .641 | .642 | .669 | .715 | .677 | .734 |
| Observations | 5218 | 5218 | 5218 | 5218 | 5218 | 5218 | 5218 | 5218 |

Constant included, not shown. Standard errors are in parentheses and clustered at the racecourse level.
* Indicates statistical significance at the 5% level.
** Indicates statistical significance at the 1% level.

Specification (4) adds the number of early scratches. An additional early scratch increases take by approximately 0.1 percentage points. Consistent with our model's assumptions, this result is presumably driven at least in part by captive punters, individuals who came to the racecourse to bet on a particular horse that scratched early. Bookies apparently exploit this additional demand by charging higher takes. Specification (5) adds the number of late-scratching horses and demonstrates that each late scratch reduces final take by 4.7 percentage points. Late scratches, however, are not equal. Specifically, a longshot scratching late causes little damage to take levels, whereas a favorite scratching late causes a large reduction. We therefore also include *LSO*, the reciprocal of the late scratching horse's initial odds (sum of the reciprocals for races with multiple late scratches), as specification (6). This variable's estimated coefficient is highly significant and confirms that late scratches' impacts on bookie take are larger when scratched horses are more heavily favored.

Specifications (5) and (6) demonstrate the large negative impact of late scratches on final take and bookies' profit margins. These specifications, though, do not necessarily indicate anchoring or any other bookie error in response to late scratches, as final take instantaneously declines following a late scratch if odds are not adjusted. The large negative impact of late scratches on final take may be due solely to late scratches which occurred so immediately prior to racetime that bookies had no chance to re-adjust odds. Specification (7) therefore extends specification (5) by interacting the number of late scratches with a binary variable indicating whether bookies updated any odds following a late scratch. Specification (7) reveals that a late scratch lowers final take by 8.6 percentage points. Bookies recover 5.6 percentage points of final take by re-adjusting odds after a late scratch. Evaluating the linear combination of these variables yields the net effect of late scratches after odds re-adjustment, a statistically significant 2.9 percentage point decrease in final take ($p$-value = 0.024). For every dollar wagered, insufficient adjustments after a scratch cause bookies to retain 2.9 cents less in takeout, an economically large effect relative to the mean final take of 17% for races without a scratch. Specification (8) extends specification (7) by including the late-scratching horse's reciprocal odds, as well as its interaction with the dummy indicating a post-scratch odds adjustment. A proper test of anchoring in this setting considers whether each variable's total and post-adjustment effects sum to zero. The $F$-statistic ($F = 6.58$, $p = 0.020$) is significant, indicating that post-scratch adjustments do not fully recover the damage from late scratches. Evaluated at the sample means for late-scratching races with post-scratch adjustments (1.05 late scratches and $LSO = 0.128$), the average net impact is a 3.2 percentage point decrease in final take ($p$-value=0.007).

These results reveal that bookies are somewhat successful in their attempts to recover from the negative shocks. Their odds adjustments, however, do not adequately return final take to pre-scratch levels. Given the punter incentives to delay wagering until the final minutes, bookies are directly and negatively affected by allowing a race's margin to fall after a late scratch. On their face, these estimates are quite surprising. Our observed bookmakers are presumably experts rather than novices, and the re-adjustment task bookies face after a late scratch is exactly the same as they would have faced had the horse scratched early. One potential mechanism for anchoring is that a typical bookie standing in a public betting area offering odds on a chalkboard does not have access to a spreadsheet that would automatically re-distribute the scratched horse's odds proportionately among the remaining field. Rather, bookies must replace the pre-scratch odds on the chalkboard with the updated odds, and these original odds may serve as a highly salient anchor when re-calculating the new optimal odds under time pressure.

One alternative explanation is that our findings are attributable to bookies setting odds in response to reduced demand after a late scratch. For example, punters who had a particular interest in betting on a horse that scratches may only wish to bet again if offered relatively generous odds on another horse. Though our data do not contain betting quantities and we cannot directly address this possibility, two facts suggest that the reduced takes are not attributable to demand effects. First, it is impossible to reconcile such a story with the observed negative final takes and their resulting arbitrage opportunities. Second, races with greater numbers of early scratches have higher takes, suggesting that captive punters are if anything less discerning about subsequent wagers' prices and bookies capitalize by charging higher takes.

Another alternative explanation for these findings other than an anchoring bias could be time-constrained bounded rationality: bookies do not have adequate time to perfectly re-optimize their odds listings, so they satisfice and update odds which are approximately profit-maximizing. The observed decrease in take after a scratch could simply be an acceptable consequence of satisficing rather than optimizing when re-adjusting odds. The bounded rationality explanation, however, is dubious because bookies' errors are systematic. For example, suppose that the new optimal profit-maximizing odds for a horse which was originally listed with odds of 10 would now be 8 after a scratch. Assuming symmetric costs of errors, bounded rationality without anchoring predicts that bookies are equally likely to re-adjust the odds to be too low at 7.5 as they are to re-adjust them to be too high at 8.5. Offering odds of 7.5 on a horse which should command odds of 8 implies an even higher take for bookies. Our observed bookies, though, are systematically more likely to re-adjust odds which are "too high" (i.e., too close to the original pre-scratch odds and thus more favorable to punters) than too low. Bounded rationality predicts that while bookies may not re-adjust odds perfectly, race take should be roughly unchanged after a scratch if overly stingy odds and higher take cancel out the diminished take from overly generous odds. That is, while both anchoring and bounded rationality imply lower profits, only anchoring predicts lower profit margins.

This refutation of bounded rationality as the complete explanation for our findings rests on the assumption that the costs of errors are roughly symmetric; that is, that the lost revenue from re-adjusting odds too high and thus earning a lower profit margin on the increased betting volume is roughly equal to the lost revenue from re-adjusting odds too low and earning a higher profit margin on decreased betting volume. We concede that verifying that these error costs are indeed symmetric would require calculating the betting volume elasticities, and we do not observe these data. We note two important points. First, unless a horse scratching fundamentally changes the betting demand curve for the remaining horses, the post-scratch profit-maximizing odds should simply be proportional to the scratched horse's probability and the remaining horses' pre-scratch odds. A large deviation in the profit-maximizing odds would require a seemingly implausible kink in the betting volume demand curve. Second, re-adjusting odds to be too favorable to punters can create arbitrage opportunities, which opens the potential for bookies to earn infinite losses, whereas the worst consequence for offering excessively stingy odds is simply zero sales. The greater potential for arbitrage losses predicts that bookies should err on the side of setting odds too low under a bounded rationality framework, precisely the opposite of what we observe.

Another potential concern is that our dummy variable indicating whether there was any adjustment after a scratch may be too blunt of a measure. Specifically, for late scratches occurring extremely close to race time, bookies may have insufficient opportunity to re-calculate and adjust the odds on the entire field of horses. Bookies may only have time to adjust the odds on particular horses, presumably the most heavily bet, and must accept the loss from the sub-optimal odds on the remaining field. Thus, while bookies may anchor and under-adjust the odds on important horses, unadjusted odds on the remaining field would also cause observably lower takes. As such, observably lower takes, even after controlling for races with some post-scratch odds adjustment, are not conclusive evidence of anchoring.

We explore whether this competing story has merit by focusing more closely on bookie actions after a late scratch. Bookies adjusted the odds on 610 of the 1961 horses in races that involve a late scratch. Specification (1) of Table 4 presents the results of a probit regression, at the individual horse level for the 187 scratching races, that models whether the odds on a horse were adjusted after a scratch. The results indicate that the likelihood of adjustment is decreasing in field size, suggesting that bookies face binding constraints reflecting computational complexity. Bookies are more likely to adjust a horse's odds in races with higher takes at the time of the scratch. The likelihood of adjustment is also increasing with the individual horse's reciprocal odds. That is, bookies are more likely to adjust the odds on favored horses, supporting the notion that bookies adjust favorites' odds first and adjust the odds on longshots only if there is sufficient time. Somewhat surprisingly, the positive coefficient of the scratching horse's reciprocal odds is not statistically significant, suggesting that bookies are only weakly more likely to update odds after a favorite scratches than after a longshot scratches. The estimated impact of time (in minutes) between the scratch and the race start is positive and statistically significant, indicating that bookies are more likely to adjust odds given greater time. Specifications (2) and (3) present the results of Tobit regressions at the race level on the respective dependent variables of adjusted probability mass and the percentage of the field which was adjusted. The race-level results confirm our previous findings that the amount of odds adjustments is decreasing in field size and increasing in the amount of time available for adjustment.

These results reveal that bookies prioritize adjustments of favored horses, and that our previous results of diminished post-scratch take may be at least partially attributable to adjustments on only a portion of the field. To address this concern, we repeat the analysis from Table 3 but now controlling for how much of the field a bookie adjusted after a scratch. We replace the binary indicator for whether there was any post-scratch adjustment with various measures quantifying the

**Table 4**
Bookies' decisions of which horses to adjust.

| Dependent variable: | Pr (Horse adjusted post-scratch) | Adjusted prob mass | Percent of field adjusted |
|---|---|---|---|
| Estimation method: | Probit | Tobit | Tobit |
| | (1) | (2) | (3) |
| Initial take | −.062 | −.005 | −.003 |
| | (.290) | (.010) | (.009) |
| Take immediately prior to scratch | .546 | .008 | .013 |
| | (.259)* | (0.11) | (.010) |
| Race number | .022 | .032 | .029 |
| | (.015) | (.025) | (.026) |
| Last race of day | .010 | .088 | .060 |
| | (.088) | (.169) | (.167) |
| Number of horses | −.034 | −.067 | −.074 |
| | (.006)** | (.022)** | (.021)** |
| Gini | −.197 | −.058 | −.298 |
| | (.214) | (.511) | (.528) |
| # Early scratches | −.019 | .000 | −.009 |
| | (.013) | (.032) | (.029) |
| # Late scratches | .187 | .472 | .424 |
| | (.142) | (.276) | (.275) |
| Late Scratch's reciprocal odds | .532 | −.246 | −.148 |
| | (.416) | (.408) | (.433) |
| Horse's reciprocal odds | .517 | – | – |
| | (.149)** | | |
| Minutes until race start | .024 | .054 | .049 |
| | (.009)* | (.023)* | (.021)* |
| Course fixed effects | *Yes* | *Yes* | *Yes* |
| Pseudo $R$-squared | .195 | .183 | .208 |
| Observations | 1961 | 187 | 187 |

Specification (1) is at the individual horse level and specifications (2) and (3) are at the race level. Standard errors are in parentheses and clustered at the racecourse level.
* Indicates statistical significance at the 5% level.
** Indicates statistical significance at the1% level.

**Table 5**
Impact of late scratches on take, controlling for amount of adjusted odds.

| Adjusted ProbMass | – | > 75% | > 80% | > 85% | > 90% | > 95% | Continuous |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| *Dependent variable: final take (in percentage points)* | | | | | | | |
| Minutes Until Race Start | .17 | .08 | .08 | .08 | .08 | .08 | .07 |
| | (.10) | (.07) | (.07) | (.07) | (.07) | (.07) | (.06) |
| # Late Scratches | 3.71 | 3.91 | 3.92 | 3.93 | 3.92 | 3.92 | 3.49 |
| | (1.07)** | (1.09)** | (1.10)** | (1.10)** | (1.11)** | (1.10)** | (0.97)** |
| LSO | −92.36 | −92.66 | −92.68 | −92.74 | −92.71 | −92.76 | −90.97 |
| | (11.82)** | (11.72)** | (11.73)** | (11.76)** | (11.76)** | (11.72)** | (13.75)** |
| # LS*any adjustment | −3.50 | −1.67 | −1.65 | −1.74 | −1.67 | −1.45 | – |
| | (1.27)* | (.89) | (.88) | (.88) | (.86) | (.81) | |
| LSO*any adjustment | 59.70 | 20.92 | 21.30 | 22.40 | 23.09 | 23.39 | – |
| | (9.90)** | (9.35) | (9.31) | (8.86)* | (8.59)* | (8.81)* | – |
| # LS*high adjustment | – | −2.47 | −2.48 | −2.04 | −2.06 | −2.63 | – |
| | | (2.25) | (2.47) | (2.16) | (2.29) | (2.22) | |
| LSO*high adjustment | – | 60.13 | 59.74 | 57.28 | 56.20 | 57.05 | – |
| | | (26.81) | (27.50) | (26.36) | (26.72) | (26.42) | |
| # LS * adjusted probability mass | – | – | – | – | – | – | −4.02 |
| | | | | | | | (2.05) |
| LSO * adjusted probability mass | – | – | – | – | – | – | 82.93 |
| | | | | | | | (22.60)** |
| $F$-stat | 6.29 | 7.01 | 5.27 | 4.17 | 4.46 | 5.01 | 3.63 |
| $p$-value | 0.023 | .017 | .035 | .057 | .050 | .039 | 0.076 |
| $R$-squared | .735 | .747 | .747 | .747 | .746 | .745 | .749 |
| Observations | 5218 | 5218 | 5218 | 5218 | 5218 | 5218 | 5218 |
| Races with high adjustment | – | 50 | 44 | 41 | 37 | 34 | – |

Standard errors are in parentheses and clustered at the racecourse level. * Indicates statistical significance at the 5% level. ** Indicates statistical significance at the 1% level. All specifications also include a constant, Initial Take, Race Number, Last Race of Day indicator, Number of Horses, Gini, # Early scratches, course fixed effects, and week fixed effects (results suppressed). The $F$-statistic tests whether the net effect of a scratch controlling for adjustments is zero.

amount of odds adjustments. To more fully address the role of time constraints, we also include the number of minutes between a scratch and the race's start as an additional regressor. Table 5 displays these results. All specifications include the non-late-scratch regressors from Table 3, but those coefficients are quite similar to the prior regression estimates and are not displayed for brevity. The number of minutes permitted for odds adjustments is not statistically significant after controlling for the amount of adjustments. Specification (1) is a baseline for comparison purposes and still employs the indicator for any adjustment. We next add an indicator variable denoting races with a high amount of adjustment. In specifications (2) through (6), we employ progressively stricter thresholds for this definition of high adjustment. For example, Specification (2) requires that races have adjusted probability mass of at least 75% to qualify as high adjustment, Specification (3) requires at least 80%, etc. The interaction of late-scratch odds and this high-adjustment indicator is always positive and statistically significant, indicating that bookies improve their recovery from late scratches as they make adjustments on more of the field. The $F$-statistics that test whether the total net effect of late-scratches with adjustment is zero, though, indicate that these bookie adjustments are on average insufficient. For example, consider Specification (6) in which our high-adjustment variable captures races in which bookies adjusted at least 95% of the race's probability mass. Interpreting these coefficients at the means for late-scratching races implies that even races with such high adjustment are still 1.7 percentage points below their non-scratch peers. No matter what threshold we employ, the $F$-statistics reveal that the net effect of post-scratch adjustment is non-zero with at least 90% confidence and at times 95% confidence.

Finally, specification (7) presents results using a continuous measure, replacing the indicator for any adjustment with the adjusted probability mass. Our F-test again sums up the coefficients but now implicitly tests the case of total adjustment against the case of no late scratch. Any observed lower take is therefore attributable to under-adjustment. Estimates are again consistent with the story of rational adjustment of only part of the field, in that the estimated coefficients are larger (in absolute value) than those of the model that considered any adjustment. Even these greater adjustment impacts, though, are insufficient to completely reverse the damage to take done by a late scratch. The specification yields an $F$-statistic ($F = 3.63$, $p = 0.076$) allowing us to reject the null at the 90% confidence level. Interpreting the coefficients in the continuous specification at the sample means for late-scratching races with post-scratch adjustments (1.05 late scratches and $LSO = 0.128$) implies that late scratches cause an immediate reduction in take of 8.0 percentage points. Even if a bookie were to adjust the odds on all of the remaining horses, he would only recover 6.4 percentage points, leaving a net gap of 1.6 percentage points ($p = 0.065$). That is, bookie adjustments are systematically insufficient and only recover 80% of the pre-scratch take.

It is important to note that anchoring may itself impact a bookie's decision to make any adjustment to a particular horse. Bookies may be sufficiently anchored on the original odds that they decide not to incur the costs of updating in circumstances that an unbiased bookie would have made an adjustment. To illustrate, consider a horse with pre-scratch odds of 10, which an unbiased bookie would adjust to post-scratch odds of 8 but an anchoring bookie would only adjust to 9. For intermediate costs of updating odds, an anchoring bookie may decide not to bother updating the odds and to accept the losses from the current sub-optimal odds, whereas an unbiased bookie would still find it worthwhile to make the adjustment. As such, controlling for a races' adjusted probability is a conservative test for anchoring as it utilizes only observed adjustments. Combining the recognition that anchoring can lead to deliberate non-adjustment with our conservative conditioning on post-scratch adjustments, these estimates provide a lower bound to the degree of anchoring. These results indicate that anchoring can be a real phenomenon among professionals in their day-to-day work.

As a final robustness check, we examine bookie adjustments at the individual horse level to test for anchoring. For the 178 races with only one late scratch, we construct what the optimal post-scratch adjusted odds would have been for each horse, under the assumption that bookies should have distributed the scratching horse's probability in proportion to the existing odds at the time of the scratch. We concede that this is a moderately strong assumption, though certainly a natural baseline for bookies' optimal strategy. For the 561 horses in these races that were adjusted, we perform a Wilcoxon signed rank test (the non-parametric analogue of a paired t-test) to examine whether the observed adjusted odds systematically differ from these constructed optimal odds. The observed final odds are significantly greater ($p < 0.001$) than the hypothetical optimal odds had bookies fully re-distributed the scratching horse's odds proportionately. To quantify the under-adjustment, horses that were ultimately adjusted had average odds of 7.63 just before the scratch. If bookies had re-distributed the scratching odds proportionately, bookies should have adjusted these horses' odds to 6.98; however, bookies ultimately adjusted these odds to 7.18. That is, bookie adjustments on individual horses' odds were only 70% as large as they should have been, roughly consistent with our previous findings of under-adjustment at the race-level.

## 4. Conclusion

We have examined fixed odds data from Australian gambling on horse races and found that bookies fail to update odds fully after a horse is withdrawn from a race before final odds are posted. Bookies experience a negative shock to profit margins whenever a horse scratches before a race, as the odds offered on remaining horses still reflect the pre-scratch probability distribution. Given that each remaining horse now has a higher win probability, bookies are offering relatively more generous wagers than before the scratch and thus face lower expected profits. Late scratches cause an immediate reduction in take of 8.6 percentage points, a large decrease relative to pre-scratch takes of approximately 17%. We examine the response of bookies to this natural experiment as they scramble to re-adjust odds to optimize to the new field of horses. Conditional on making odds adjustments after a scratch, bookies recover only 5.6 percentage points of lost take. A portion of the remaining gap is attributable to bookies adjusting odds on only a portion of the field, presumably due to time or cognitive constraints. Bookies prioritize by first adjusting the most favored horses and only adjusting the remaining horses if there is sufficient time. However, even after controlling for the number and importance of the adjusted horses, the adjustments are insufficient and do not fully recover expected race takes to the original pre-scratch level. Importantly, bookies are not simply erring randomly when re-calculating odds. Bookies systematically fail to adjust odds sufficiently, as the updated odds remain too close to the original pre-scratch odds. Even among races in which bookies adjusted greater than 95% of the fields' odds, average take levels are 1.7 percentage points lower than pre-scratch take levels, an economically significant bias relative to pre-scratch take levels.

We have utilized the novel opportunity induced by late scratches to demonstrate the existence of a behavioral anomaly in a real market setting with experienced agents. Our findings demonstrate that even professionals operating in their usual market can exhibit systematic biases. It is worth noting, though, how much bookies get correct. Our observed bookies perform (or at least approximate) relatively complex calculations, sometimes under extreme time pressure, and effectively restore 80% of the profit margin lost to a scratch. A natural question is why market forces are not sufficient to correct this bias. We suspect that, despite the potentially high stakes of mis-pricing wagering odds, this bias is not too costly in practice. Late scratches are sufficiently infrequent that bookies may decide to forgo the occasional percentage point of lost take after a scratch, rather than expending their full cognitive resources fine-tuning the quoted odds.

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