

Measuring the Extent of Inside Trading in Horse Betting Markets

by

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Abstract.

This paper develops a theoretical model that examines the optimal price setting by on-course bookmakers in the racetrack betting market. The model suggests that opening prices should include a premium that compensates bookmakers for the risk that insiders will account for private information and exploit any mis-pricing made by the bookmakers. The model is an extension of the model developed by Makropoulou and Markellos (2007) for football betting to the racetrack betting market. Using an extensive dataset and performing Monte Carlo simulations to calculate the potential value of new information, we measure insider trading in the Australian racetrack betting market.

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1. Introduction

This paper develops a theoretical model that examines the optimal price setting by bookmakers in the racetrack betting market and then uses it to measure the extent of insider trading in the market. Bookmakers are faced with the risk that insiders will account for information arriving after the opening odds have been set and will thus exploit any mis-pricing by the bookmaker by betting on horses whose price presents an expected profit for the bettor. The model is an extension of the model developed by Makropoulou and Markellos (2007) and applied to the European soccer betting market. The basic intuition underlying the model is that fixed odds¹ offered by bookmakers at the track are examples of call options and that, while bookmakers hope to offer only net of premium out-of-the-money options, when they err by underestimating a particular horse's true winning probability, they are liable to offer a net in-the-money option, which the insider (who is assumed to know her horse's true winning probability) will be glad to snap up.

This paper also builds on the pioneering papers of Shin (1991, 1992 and 1992) in presenting a model designed to estimate the extent of insider trading in a horse betting market. His approach differs from ours in that he focuses exclusively upon starting prices (SP) and makes two highly restrictive assumptions; namely, that the proportion of outsiders backing any horse is equal to its true winning probability and that inside traders always win. A possible consequence of these assumptions is that estimates using Shin's model are invariably low (for example, Shin (1993) obtains around 2 percent and Vaughan Williams, L. and Paton, D. (1997) slightly less), whereas we present estimates of 20 percent and over, depending upon the exact estimation procedure used. For an empirical test of the Shin model, see Schnytzer and Shilony (2003) and for further discussion and extensive bibliography, see Sung and Johnson (2007).

The other strand of research upon which we build is that which relates to the timing of inside trades. For a general discussion of this issue in the context of more general financial markets, see Foster and Vishwanath (1996), Jackson (1991) and Kyle (1989).

¹ For the purposes of this paper, by odds, we mean that odds of, say 5 to 1 represent a net profit of \$5 for every \$1 bet on the winning horse.

More specifically, we extend the analysis presented in Schnytzer and Shilony (2002), where the issue of timing trades is considered in the context of the Australian racetrack bookmaking market. At the opening of the betting, prices are determined by a loose cartel and incorporate profit margins so that prices exceed the perceived winning probabilities for all horses. These odds represent the most expert distillation of the public information available at the time that betting begins at the track, around 30 minutes before the start of the race. When betting begins, each bookmaker will accept different bets and since this implies different contingent debts for different bookmakers, the cartel collapses quickly. Thus, *ceteris paribus*, prices² tend to fall over time. However, as noted above, there are risk-neutral informed traders, whose estimates of winning probabilities for the horses with which they are associated are more accurate than those of the bookmakers. Should opening prices (OP) be less than the insiders' valuation of the corresponding horse's winning probability, the relevant insiders will place large amounts of money on the horse via a plunge (see Schnytzer and Shilony (1995)). This leads to an immediate increase in the price of that horse and a reduction in the prices of all, or nearly all, other horses in the race. Suppose, now, that there are two such groups of insiders, each wishing to plunge their own horse. Since a plunge reduces the prices of other horses, each group has an incentive to wait for the other to plunge first. On the other hand, since the information concerning any given horse is known to more than one person, the longer the insiders wait, the greater is the risk that the information will leak to a third party. The recipient of the leak will then plunge the horse and the group of insiders – except perhaps the one responsible for the leak – may be left with odds at which betting is no longer worthwhile. This conflicting set of incentives gives rise to a game of timing presented and tested empirically in Schnytzer and Shilony (2002). They conclude, first, that the higher the level of opening prices, the later will be any plunge activity. Second, that an increase in the number of horses which have insiders associated with them leads to an earlier optimal plunge time and, finally, that an increase in the number of horses in a race also leads to an earlier optimal plunge time.

² For the purposes of this paper, a horse's price is defined as the probability equivalent of its un-normalised odds; i.e. the odds as offered by the bookmaker.

On the basis of these findings, it is clear that obtaining an accurate measure of the extent of insider trading even in this relatively simple financial market would require price and quantity data that are simply unavailable. The data used in this paper are similar to those used by Schnytzer and Shilony (2002) and provide odds at three stages of betting: opening prices (OP), middle prices (MP) and starting prices (SP). Accordingly, we are restricted to considering plunges which occur at either OP, MP or the best between the two, from the viewpoint of the insider, (BP)³. On the other hand, a fully dynamic model of insider trading considered in terms of options pricing would be unnecessarily complex and possibly intractable. Accordingly, in section 2 of this paper, we present a simple model of bookmaker pricing in which all insiders are assumed to bet at OP. In section 3, the model is reformulated within an option pricing framework and in section 4 we present several measures of the extent of insider trading, one of which follows directly from the model. However, we also present results of simulations which take into account the fact that insider trading occurs at BP and not only at OP.

Further, we take into account that whereas our model is built from the viewpoint of the bookmaker, we have access to *ex-post* plunging information which the bookmaker cannot know and which sheds further light on the extent of insider trading. Thus, for example, when estimating the average extent of insider trading per race, we weight values of call options on individual horses first by the winning probabilities of horses implied by OP (and thus used by bookmakers in pricing). This approach, following the model directly, effectively supposes that bookmakers know the extent of insider trading in advance. Or, more reasonably, such a measure is of the bookmakers' expectations regarding insider trading and it should not be surprising to find that these are overestimates. In order to get closer to the true extent of insider trading, we also weight option values by the relative and absolute extents of plunges as well as winning probabilities as implied by BP.

Finally, our theoretical model assumes that the winning probabilities implied by OP are free of all biases and distortions. This is, however, untrue because all bookmakers'

³ Thus, the best price, BP, is simply the lower of the two, OP and MP. Plunges cannot occur in the Australian market at SP, since SP betting is illegal in Australia and thus SP are the ruling prices at the end of betting. For a comparison of the role SP in the Australian and UK horse betting markets, see Schnytzer and Snir (2008a).

odds are known to beset by the favorite-longshot bias and in the Shin model this bias is even a consequence of the presence of insiders in the market. Accordingly, in order to avoid possible biases in our estimates, we use a simple econometric technique to generate unbiased estimates of winning probabilities based on both OP and BP, respectively. We present these results together with those obtained by using the original biased probability estimates. Since analytical solutions are not available for these methods, Monte Carlo simulations are used.

The results of our Monte Carlo simulations are presented in section 5 and range from mean estimates of around 20 through 33 percent insider trading over a sample of nearly 4000 races simulated 1000 times, depending upon the assumptions underlying the specific method employed. It is found that the presence of the favorite-longshot bias in prices increases the estimates considerably if no correction to implied winning probabilities is made. Taking all factors into consideration we consider that the actual extent of insider trading in this market to be somewhere in the range of 20 to 22 percent. Our conclusions are presented in section 6.

2. The Model

Assume there are n horses in a race and that a bookmaker sells contingent claims on each horse. The contingent claim on horse j costs ϕ_j and pays 1 if horse j wins, and zero otherwise. A price ϕ_j implies odds $\theta_j = \frac{1-\phi_j}{\phi_j}$. There are two populations of bettors on the race: outsiders and insiders.

The assumptions regarding the information arrival process can be described as follows: Suppose that the horses' true winning probabilities are given by P_1, P_2, \dots, P_n , where $\sum_{j=1}^n P_j = 1$. These true winning probabilities reflect both public and private information. Moreover, we assume that the true probability of a certain outcome evolves according to the information flow throughout the betting period until the race starts and is

therefore stochastic. The stochastic process for the true probability could be either continuous or discontinuous, i.e. a jump process, or a mixture of the two. Strictly speaking, the process that affects the true probability should be seen as discontinuous, since the flow of information from small events that may affect the outcome does not happen continuously. However, these events are numerous and diverse in nature. Moreover, the arrival rate of such events is highly unlikely to be known. Therefore, the information arrival process may be proxied by a continuous stochastic process.

Assume that nobody, not even an insider, knows in advance which horse is going to win the race, in contrast to Shin (1991,1992 and 1993), who assumed that insiders know which horse will win the race. At time zero the bookie declares the opening prices (OP). At this time all market participants, i.e. outsiders, insiders and the bookie have the same information set. This means that they all know the true winning probability of horse j at time 0, $P_j(0)$. Obviously, if no inside information hits the market, there is no reason for this initial true winning probability to change. Suppose instead that at a subsequent time $t > 0$ a private signal is revealed to the insiders, which makes the true winning probability equal to $P_j(t)$. This is observed only by the insiders. Thus, an insider knows the true winning probabilities, $P_j(t)$, at any $0 \leq t \leq T$ while the bookie and the outsiders know only what is now the mistaken estimate at $t = 0$. A risk-neutral insider would wager on horse j if $P_j(t) > \phi_j(t)$. We do not make any assumptions concerning the likelihood of inside traders *vis-à-vis* either favorites or longshots. Since we assume that the bookmaker and the outsiders do not observe any private information, we expect the outsiders to support the horses in proportion to their perceived winning probabilities at time zero. These probabilities may be thought of as the winning probabilities implied by “public information”.

The bookmaker declares his initial odds according to the public information set that exists today. Since any private information is conveyed to the bookmaker only after an informed trade takes place, the latter should include a premium in the OP to compensate him for this risk. We further assume that the variance of public information is very small,

in other words we do not expect any public information to be revealed after time zero. This assumption makes sense especially if one considers the nature of racetrack betting and the small betting period (about 30 minutes).⁴ Therefore, any changes in the quoted odds should be related to observed insider behavior.

In reality, the sum of opening prices is always greater in any race than the sum of starting prices even in the apparent⁵ absence of insider trading. The reason is that opening prices tend to have a "cartel" level of profit built in since they are recommended to individual bookies by the bookmakers' association. Once betting begins, there is competition among bookies and thus the sum of prices will tend to decrease. However, in our model it is implicitly assumed that the only reason for OP to be higher than SP (which incorporate all available information, both public and private) is the risk that bookies run due to the existence of insiders. Thus, the model does not take into account the fact that OP would anyway be higher because of this "cartel" level of profit. This practically means that the estimates of insider trading obtained may overestimate its true extent if the premium included in OP is due to this "cartel" profit rather than to the risk that bookmakers face in the presence of insiders. On the other hand, it may be that the expected profit margins built into OP are designed just to compensate the bookies for inside trades.

Trading proceeds in a number of stages, the first and the last of which we consider in our formal model. At stage 1, a proportion of the outsiders bet in the market at the OP set by the bookie. Also, all insiders may bet should the opportunity arise. At the other stages, the rest of the outsiders bet at new updated prices set by the bookie after having observed the insider trading pattern. It should be noted that insiders must utilize any special information they have during the betting, since it loses all value once the race starts. Furthermore, since insider trading is both legal -- only jockeys are forbidden to bet -- and

⁴ We thus exclude such phenomena as late scratchings from consideration in our analysis.

⁵ Races in which there are no plunges visible in the data (odds at no point fall for any horse during the betting) are races in which inside trades are not observed. Of course, it could be that an insider has placed a discreet bet with a single bookie and that this bet cannot be discerned in the average odds that rule in the market and are published. The greater the extent of this phenomenon, the more will our estimates of insider trading underestimate its true extent.

takes place at fixed prices, insiders have no incentive to hide their trading behavior from outsiders. Moreover, such information may no longer be valuable since the odds available about a particular horse would be lower after a plunge. Finally, we make the assumption, for the purposes of the formal model, that all insiders bet simultaneously. We relax this assumption in section 4 when estimating the extent of insider trading.

Price updating effectively continues until the last stage at which starting prices are determined as the equilibrium prices observed in the market at the end of betting. Since in contrast to the British market there is no legal *SP* betting in the Australian market, these prices may be assumed to embody all the available useful information regarding the race's outcome.

A set of additional assumptions is necessary to proceed:

- a) There are no transaction costs.
- b) The bookmaker can accurately predict the expectations of outsiders, i.e., the amount of money that will be bet by them on each possible outcome is known with certainty.
- c) The true probabilities of race outcomes evolve according to the private information flow throughout the betting period until the event takes place. Moreover, the true probability of outcome j occurring, $P_j(t)$, follows a driftless continuous stochastic process such that:

$$E_t [P_j(t^*)] = P_j(t) \text{ for any } 0 \leq t < t^* \leq T$$

where T denotes the end of the betting period. Hereafter, whenever the time subscript is dropped from the expectation it is assumed that $t=0$.

- d) The bookmaker is assumed to be risk-neutral, (i.e. an expected profit maximizer) and there is free entry in the market. This assumption is necessary, for if the bookmaker were a monopolist, he could capture rents. Under the free entry assumption however, the long-run competitive equilibrium will be established when

all bookmakers earn zero expected profits. Throughout the analysis we assume that bookmakers make zero expected profits in the market corresponding to each race. Moreover, assuming perfect competition allows for the demand of outsiders to be totally inelastic^{6,7}

e) The expectations of outsiders fully reflect all available information at time zero and hence are unbiased expectations of the true winning probabilities at time zero. This amounts to the assumption that outsiders are rational and thus do not suffer from any behavioral biases. This turns out to be an unrealistic assumption which we relax, and whose implications we investigate, in sections 4 and 5.

Outsiders

Assume for the moment that only outsiders exist in the market, W is the total amount of money bet by them at stage 1 on the n horses and w_j is the amount bet on horse j , where $j=1, 2, \dots, n$. Assume also that the bookmaker gives (opening) odds of $(1+\theta_j)$ for each one of the horses and that the betting period is T periods of time, where $T>0$. Then, ignoring the time-value of money and making use of assumption (b), the expected profit of the bookmaker at time zero is:

$$E(\Pi) = W - \sum_{j=1}^n E[P_j(T)] w_j (1 + \theta_j) \quad (1)$$

or, equivalently, using assumption (c):

⁶ If the bookmaker were a monopolist and demand was totally inelastic, maximizing profits would lead to unbounded prices

⁷ Shin (1991, 1992) makes the assumption of *ex ante* competition among bookmakers. At the first stage of the game, the bidding stage, the bookmakers issue their bids. The expected profit of the bookmakers at this stage is zero. At the second stage, the price-setting, the bookmaker who has won the bid, sets prices that maximize his expected profit at this stage, given the winning bid at the first stage. On the other hand, Ottaviani and Sørensen (2005) consider *ex post* competition among bookmakers and assume that each bookmaker is assumed to make zero expected profit in the market corresponding to each horse.

$$E(\Pi) = W - \sum_{j=1}^n P_j(0)w_j(1 + \theta_j) \quad (2)$$

where $P_j(0)$ and $P_j(T)$ are initial and terminal values (time T) for the realized true winning probability of horse j , respectively.

Given that $\sum_{j=1}^n P_j(t) = 1$ for each $t \in [0, T]$, then for the bookmaker to have a zero expected profit, it is sufficient that for each j :

$$OP = \phi_j = \frac{w_j}{W}, \quad \text{where, } \phi_j = \frac{1}{1 + \theta_j} \quad (3)$$

Therefore, if only outsiders exist in the market and, as assumed earlier, the bookmaker can accurately predict their expectations, then for the latter to have zero expected profit on each horse, it is sufficient that opening prices are set equal to the expectation of the bookmaker about the proportion of money bet on each horse i.e., $\phi_j = p_j$, where $p_j = w_{j,n}/W_n$. Therefore, in this case, the price set by the bookmaker for a certain horse might deviate from the efficient market price due to “false expectations” on the part of bettors, which induces the bookmaker to distort prices in order to preserve the zero-profit condition. Note that the efficient market price is equal to the true probability of a certain outcome occurring.

Now, equations (1), (2) and (3) hold at any t . Hence:

$$E_t(\Pi) = W_t - \sum_{j=1}^n E_t [P_j(T)] w_{j,t} (1 + \theta_{j,t}) \quad (4)$$

$$E_t(\Pi) = W_t - \sum_{j=1}^n P_j(t) w_{j,t} (1 + \theta_{j,t}) \quad (5)$$

This means that at all times the bookmaker tries to quote odds so that his book is balanced. In the absence of insiders, given our assumptions, there can be no change in prices over time.

Insiders

If insiders also exist in the market, then the final distribution of bets will depend upon both the expectations of outsiders and insiders. As noted above, the bookmaker can predict with accuracy the expectations of outsiders but not those of insiders, since the latter are shaped according to the private signal they receive and this is not revealed to the bookie. It is assumed that at each point in time, the expectations of insiders fully reflect all information, and, hence, are an unbiased estimator of the true winning probability of horse j .

Consider an insider who bets only if she expects a positive return; i.e., if her subjective probability is greater than the quoted prices. The subjective probability of the insider at any time t is equal to the true probability of outcome j being realized. Therefore, the bookmaker is expected to lose from informed bettors. If we assume that the time value of money is negligible over this small period, the bookmaker's expected loss at time zero to an informed bettor on a one unit bet (placed at time zero) is:

$$E(\Pi)|_i = -E\left\{\max\left(-1 + P_j(T)(1 + \theta_j), 0\right)\right\} \quad (6)$$

We assume further that insiders bet $w_{j,i}$ on the outcome(s) with favorable odds. The expected profit of the bookmaker is therefore:

$$E(\Pi) = W_n - \sum_{j=1}^n E\left[P_j(T)\right]w_{j,n}(1 + \theta_j) - \sum_{j=1}^n w_{j,i}E\left\{\max\left(-1 + P_j(T)(1 + \theta_j), 0\right)\right\} \quad (7)$$

For the bookmaker to have zero expected profit, the following condition must be met:

$$W_n = \sum_{j=1}^n w_{j,n} P_j(0)(1 + \theta_j) + \sum_{j=1}^n w_{j,i} E \left\{ \max \left(-1 + P_j(T)(1 + \theta_j), 0 \right) \right\} \quad (8)$$

Rearranging the terms in the above equation we obtain:

$$1 = \sum_{j=1}^n P_j(0) \left\{ \frac{w_{j,n}}{W_n} (1 + \theta_j) + \frac{w_{j,i}}{P_j(0)W_n} E \left\{ \max \left(-1 + P_j(T)(1 + \theta_j), 0 \right) \right\} \right\} \quad (9)$$

For this equation to hold it is sufficient that for each j :

$$1 = \frac{w_{j,n}}{W_n} (1 + \theta_j) + \frac{w_{j,i}}{P_j(0)W_n} E \left\{ \max \left(-1 + P_j(T)(1 + \theta_j), 0 \right) \right\} \quad (10)$$

The second part of the right-hand side of this equation is greater than or equal to zero. Therefore, the first part should be lower than unity implying that:

$$OP = \phi_j \geq \frac{w_{j,n}}{W_n} = P_j(0) \quad (11)$$

Therefore, if insiders also exist in the market, then prices should be set greater than the true probability of winning at time zero, in order for the bookmaker to have zero expected profit. Thus, the competitive price set by the bookmaker includes a premium that reflects the uncertainty of new information. Rearranging the terms in equation (10), we derive the competitive price the bookmaker should set as:

$$OP = \phi_j = P_j(0) + qE \left\{ \max \left(P_j(T) - \phi_j, 0 \right) \right\} \quad (12)$$

where q is the ratio of informed to noise betting, i.e. $q = \frac{w_{j,i}}{w_{j,n}}$.

3. The Model in an Option-Pricing Framework

The basic idea we propose is that the commitment made by bookmakers to sell at fixed prices, the quoted odds, can be analyzed as a call option. The bookmaker gives a prospective bettor a call option, i.e., the right to buy at the asking price $\phi > P_0$, where P_0 is the initial true probability of a certain outcome occurring. Note that in order for the bookmaker to be compensated for the uncertainty of information, this option is issued out-of-the money and is similar to an American call option on a stock that pays no dividends. Informed bettors wait for updated information and place their bets only if the true probability at maturity, $P(T)$, is greater than the initial price, ϕ . This is consistent with the option pricing theory for American options on a stock that pays no dividends, according to which it is never optimal to exercise the option before the expiration date. Assuming that the bookmaker is risk-neutral, then today's option price can be determined by discounting the expected value of the terminal option price by the riskless rate of interest. Therefore, neglecting the time-value of money, the value of the call option is:

$$C = E \left\{ \max \left(P_j(T) - \phi_j, 0 \right) \right\} \quad (13)$$

Equation (13) says that the value of the option at maturity will be either $P_j(T) - \phi_j$, or, zero, whichever is greater. If the true probability at time T is greater than the exercise price, the option will expire in-the-money. This means that the informed bettor will exercise it by placing her bet. Otherwise, the option expires unexercised. In an option-pricing framework, equation (12) can now be transformed into the following equation:

$$\phi_j = P_j(0) + qC \quad (14)$$

In order to derive the value of the option we need to know the stochastic process followed by the true probability. This could be a jump process or a continuous one or even a mixture of the two. Here, it is assumed that the true probability follows a continuous process. Given that the probability can take values only in the range $[0, 1]$,

assuming a Geometric Brownian Motion would be inappropriate, since this would imply that true probabilities can take values in the range $[0, \infty]$. Consider instead that the true probability evolves according to the following stochastic equation:

$$\frac{dP_j(t)}{P_j(t)} = (1 - P_j(t)) \sigma dz \quad (15)$$

where σ is the instantaneous standard deviation of the change in the random variable, $P_j(t)$, and dz is a standard Wiener process. It is readily shown that $P_j(t)$ takes values in the range $[0, 1]$. Furthermore, given that this process is driftless, the expected value of $P_j(t)$ at any $t > 0$ is equal to the initial value $P_j(0)$ and hence any deviations from this value are white noise. Knowing the stochastic process followed by $P_j(t)$, the value of the call option can be calculated numerically via Monte Carlo simulation. The competitive price ϕ_j can be found from equation (14) by solving the underlying optimization problem.

4. A Measure of Insider Trading

We use the above model to derive a measure of the extent of insider trading. Our measure is applied to a dataset of the 1998 Australian Horse Racing season, covering 4017 races with 45296 runners.⁸ For each of these horses, an option value is generated by Monte-Carlo simulation.

To generate the option values, several input variables are required. Firstly, the time during which betting takes place, T , is set at 30 minutes. Second, the volatility is derived from the bookmakers' odds as follows: As the dataset includes prices at three moments (OP, MP and SP), prices are available roughly every 10 minutes. The ten minute volatility may thus be calculated by defining:

$$u_i = \frac{\varphi_i - \varphi_{i-1}}{\varphi_{i-1} \cdot (1 - \varphi_{i-1})}, i = 1, 2 \quad (16)$$

and then computing

⁸ The data were obtained from the CD-Rom, *Australasian Racing Encyclopedia '98*, presented by John Russell.

$$s^2 = \frac{1}{m-1} \left[(u_1 - \bar{u})^2 + (u_2 - \bar{u})^2 \right] \quad (17)$$

where $\bar{u} = \frac{1}{m}(u_1 + u_2)$, $m = 2$.

Consequently, the one-minute volatility equals:

$$\sigma = \sqrt{\frac{s^2}{T/3}} \quad (18)$$

Finally, the initial true winning probability at time 0, $P(0)$, is generated in two different ways. According to the first, we simply normalize OP as suggested by Dowie (1976). This is shown below to yield estimates with a favorite-longshot bias. The second method involves regressing a dummy variable, equal to 1 when the horse wins the race and 0 otherwise, on OP. The predictions arising from this regression are unbiased estimates of the winning probabilities but since some emerge negative, these are set to 0.0001, a value lower than the lowest positive predicted probability. The set of $P(0)$ thus obtained were checked and found also to be free of any bias. The results are presented below.

The true winning probability for each horse is simulated in 1000 steps using the standard Wiener Process. When the simulated price is larger than the strike price at the 1000th and final step, the option value is this positive difference; otherwise, the option value is zero.

In total, four specifications of Monte-Carlo simulation are run. The first and second specifications use OP as a strike price. In first specification, the true winning probability is OP modified so as to remove the favorite-longshot bias precisely as described above⁹ and this specification thus follows the theoretical model directly. The second specification uses the normalized OP as estimates of $P(0)$. The third and fourth specifications use the longest odds available at OP or MP as the point at which insiders trade. More specifically, the odds at which the insider bets is max (opening odds, middle odds), the best odds available to her, as this would give the insider the highest expected

⁹ See page 14.

payoffs.¹⁰ These odds are transformed into the best price, BP, which is used as the strike price. In the third specification, as in the first, the BP has any favorite-longshot bias removed by regression to form our estimate of the true winning probability at the time of insider betting. The fourth specification follows the second in that normalized BP are used. Since trades at BP occur, on average, later than those at OP, the time of betting is no longer 30 minutes, but lies between 30 and 15 minutes, and so we set the time of betting at 20 minutes for the whole dataset. All specifications are repeated 1000 times and the option values are averaged to form the option value for each specific price.

Once the option values are generated, the extent of insider trading may be calculated as follows for the first two specifications:

$$a_j = \frac{q_j}{1+q_j} = \frac{(OP_j - P_j(0))}{C_j + (OP_j - P_j(0))}. \quad (19)$$

And for the thirds and fourth specifications, the extent of insider trading may be calculated as:

$$a_j = \frac{q_j}{1+q_j} = \frac{(BP_j - P_{j,BP}(0))}{C_j + (BP_j - P_{j,BP}(0))}. \quad (20)$$

where $P_{j,BP}(0)$ is one or other of the two estimated sets of BP, or the true winning probability at time of insider betting.

The extent of insider trading per horse is weighted using the estimated initial true winning probability, $P(0)$, for each specification. Moreover, for the third and fourth specifications, the initial true winning probability estimates at the time of betting, based on BP, are also used as weights. Finally, two additional weights are calculated. The first is the relative size of a plunge, called PW: $\max((MP-OP)/OP,0) + \max((SP-MP)/MP,0)$.

¹⁰ We thereby assimilate, as well as possible, given the data, the fact that insiders trade not only at OP (Schnytzer and Shilony (2002)).

The second weight is the absolute size of the plunge called PW2: $\max(\text{MP}-\text{OP},0) + \max(\text{SP}-\text{MP},0)$.

Using these four weights, the weighted average degree of insider trading for each of the races in the sample is calculated. The simple average of these values is the extent of insider trading in the dataset.¹¹

As already noted, when using winning probabilities derived from prices at which insiders are assumed to bet, as weights, we are actually measuring the expected extent of insider trading as implicit in the bookmakers' pricing. Clearly, bookmakers expect the greatest losses from insider trading on the most favored horses. The favorite in a race is such precisely because his true winning probability is considered to be higher than that for any other horse and, to the extent that this remains true over the course of betting time, more insider trading may be expected to occur on this horse. On the other hand, using the two different measures of plunge activity as weights should yield a more accurate estimate of the extent of insider trading, since it only via plunges that insider trading may be detected in the absence of explicit quantity data. In other words, when weighting by price (OP or BP) it is implicitly assumed that insiders bet according to price, Shin's (1991, 1992 and 1993) assumption, albeit not applied to SP. Whereas, when we weight either absolute or relative plunges sizes, we are weighting on those horses where insiders were observed to have bet more heavily in accordance with plunge size.

5. Results

Table I displays descriptive statistics for the sums of opening, best and starting prices for the races in our sample. The table shows clearly that the average sum of prices decreases as between OP and SP. If bettors were to bet strictly in proportion to prices, allowing bookmakers to balance their books, then the excess of sums of prices per race above unity would represent the bookmakers' profit margins.

¹¹ The sample size differs for the two procedures since there were some cases in which the sum of OP in a race was less than one, and some in which the sum of BP was less than one, and these races were dropped from the sample. This left us with 3999 and 3992 races, respectively, out of an initial sample of 4017 races.

Table I: Descriptive statistics on the sum of prices per race

	Sum of prices per race		Standard deviation
	Average	Maximum	
OP	1.4326	2.0631	0.1138
BP	1.2456	1.7476	0.0981
SP	1.2477	1.7646	0.0940

Note: OP are the opening prices, BP are the best prices available prior to SP and SP are the starting prices.

At the opening of betting this margin is 43 percent, but by the start of the race the margin has decreased to 24 percent. The decrease in the margin indicates competition among bookmakers, forcing them to decrease prices and leading to decreased profits. Note that the margin on BP is very close to the margin on SP. So we should bear in mind that OP apparently contains some excess profits. Since the OP are above the competitive level, this could deter insiders from trading at these prices, leading to a lower degree of insider trading. This “cartel” level of profit does not hold for the set of BP, which have the same margin as on SP, and can be considered to be competitive prices. Hence, the insider is faced with lower prices at BP, and we might expect the extent of insider trading to be higher at BP than at OP.

Table II displays the extent of plunges in the data set, where an early plunge is defined as a positive percentage price change from OP to MP and a late plunge is defined as a positive percentage price change from MP to SP. A sustained plunge is defined in the case where the horse in question receives both early and late plunges; the extent of the sustained plunge is then the percentage change from OP to SP. It can be seen in Table II that the majority of the 13852 plunges in the dataset are late plunges, suggesting insider

trading at MP. This confirms our intuition that insiders bet at the longest price available to them at either OP or MP.

Table II: The extent of plunges in the dataset

Plunges	Number	Average extent
Early Plunge	1281	21.25%
Late Plunge	9783	15.72%
Sustained Plunge	2788	26.33%
All	13852	18.37%

Note: An early plunge is defined as a positive percentage change from OP to MP. A late plunge is defined as a positive percentage change from MP to SP. When there are both early and late plunges, this forms a sustained plunge.

It is interesting to note that most plunges are, indeed, late, justifying the incorporation of insider trading at BP into our empirical procedures. On the other hand, it must be borne in mind that many of the BP likely to be close to OP in size¹² and that the average extent of early plunges exceeds that of late plunges.

Table III displays the returns on betting at OP, BP and SP for a specified range of prices. As shown by Dowie (1976) and Crafts (1985), this table demonstrates the presence of a favorite-longshot bias in the data. The table shows that returns are, as expected, on average always negative, although for bets on horses at higher prices (lower odds), the returns are higher than for lower prices (higher odds). It is clear that the extent of the favorite-longshot bias is greater at OP than at SP.

¹² When a horse is plunged at OP, there is certainly a decrease in the prices of most if not all of the other horses in the race, but the extent of the decrease will be quite small per horse unless the plunge was really larger. Thus, in an eleven-horse race, if the price of the plunged horse increases by 10 percent, the prices of the other horses will fall, on average, by only one percent if the sum of prices is to stay the same. Since, however, from Table 1, the sum of BP are around 20 percent below OP, there would occur another 2 percent drop in the prices of the unplunged horses, yielding a total of 3 percent per horse.

Table III: Favorite-longshot bias at OP, BP and SP

Range of prices	Returns		
	OP	BP	SP
<0.05	-63.57%	-53.06%	-50.51%
0.05 - 0.2	-37.32%	-25.92%	-23.70%
0.2 - 0.35	-20.15%	-6.45%	-11.44%
0.35 - 0.5	-18.10%	-5.14%	-10.22%
>0.5	-10.01%	-0.46%	-3.76%

Table IV uses the same methodology as that employed in, for example, Schnytzer, Shilony and Thorne (2003), of grouping the horses by odds and then performing weighted regressions, the weights being the number observations per group, on the normalized winning probabilities derived from OP, BP and SP. The null hypothesis of no favorite-longshot bias, which requires a zero intercept and a slope of 1 jointly, is clearly refuted at any reasonable levels of significance. It is also clear from the results in Table IV that the extent of the bias falls, but is not eradicated, as the betting proceeds.

Table IV: Econometric Tests for Favorite-Longshot Bias

Dependent variable	Constant	Dummy Win	N	R2
NOP	-0.0184 (-8.47)*	1.2124 (63.89)*	40	0.9908
NBP	-0.0155 (-7.92)*	1.1796 (70.27)*	40	0.9924
NSP	-0.0125 (-6.87)*	1.1456 (74.93)*	40	0.9933

Notes: NOP, NBP and NSP are the OP, BP and SP, respectively, normalized to sum to 1 in each race. t-statistics are in parentheses.

* indicates a significance level of 1% level or better.

Owing to the presence of a significant favorite-longshot bias in both NOP and NBP, we ran the following regressions (Table V) and used the predicted values of winning probabilities as our estimates in the simulations, except where the predictions were negative, in which case the values were set to 0.0001.¹³ The resultant estimates are free of any significant favorite-longshot bias.¹⁴

Table V: Regressions of Win on OP and BP

Dependent variable	Constant	OP	BP	N	R2
Win	-0.0211 (70.18)*	0.8751 (-10.48)*		45296	0.0981
Win	-0.0178 (71.42)*		0.9764 (-9.11)*	45296	0.1012

Notes: Win is the dummy variable indicating a winning horse in the race. t-statistics are in parentheses.

* indicates a significance level of 1% level or better.

The measures of insider trading for each specification are reported in Table VI. Depending upon the weights employed, the prices at which insiders are assumed to bet and whether or not biased or unbiased estimates of winning probabilities are used in the simulations, the measures range between 20 and 33 percent.

Table VI: Measures of degree of insider trading for each specification

Weight	Biased		Unbiased	
	OP	BP	OP	BP
P(0) - OP	32.68%	31.67%	32.51%	32.34%
PW	26.38%	28.54%	22.64%	30.97%
PW2	26.48%	27.56%	20.40%	22.73%
P(0) - BP		30.61%		20.90%

¹³ In no case was the predicted probability greater than 1.

¹⁴ Results of tests for the bias are available upon request.

Notes: $P(0) - OP$ is true winning probability at time 0. PW is the $[\max((MP-OP)/OP,0) + \max((SP-MP)/MP,0)]$. $PW2$ is $[\max(MP-OP,0) + \max(SP-MP,0)]$. $P(0) - BP$, is the true winning probability at time of insider betting. The size of the sample is 3992 races for the BP specifications and 3999 races for the OP specifications.

Now, we assumed above that there are no behavioral biases in the bookmakers' estimates of "true" winning probabilities. The question therefore arises: how has the fact of a favorite-longshot bias influenced our measure of the extent of insider trading? From Table 4, it may be concluded that the favorite-longshot bias seems to have yielded overstated estimates and this is dramatically the case when winning probabilities derived from BP are used in the estimation (30.61% as against 20.9%) and when the absolute levels ($PW2$) of plunges are used in both the OP (26.38% as against 22.64%) and the BP (27.56% versus 22.73%) estimates. Other than that, there seems little difference between the respective estimates, none reaching a difference of 4%. Given that the differences in estimates are not consistent in size or direction, it is difficult to explain why the bias impacts as it does.

When comparing the OP measures and BP measures, it is clear that the BP measures are equal or slightly higher than the OP measures when plunge weights are used. One possible reason is that we allow the insider to bet at the most favorable moment, either at OP or MP. The values of the options will be higher as the strike price is lowest on BP, as compared to OP. The considerably higher option values at BP may also explain the far greater number of plunges occurring at BP than at OP (Table 1).

Another reason why the degree of insider trading at OP is lower in these estimates than at BP is the possibility of herding. The general betting public may see which horses are plunged, and thus backed by insiders, and may follow suit. If we allow the insider to bet at BP, this may have already included some outsiders following insiders. If the insider is assumed to bet only at OP, any herding by the public cannot be taken into account in the simulations and thus this degree of insider trading figures to be lower than when using BP¹⁵.

On the other hand, when using prices as weights in the estimations, there is almost no difference between the estimates at OP and BP. But it should be recalled that these

¹⁵ See Schnytzer and Snir (2008b) for empirical evidence of herding in this market.

estimates are bookmaker's expectation of insider trading and thus there is no reason to expect a difference. From the bookmaker's point of view, all that matters is that his estimates be higher, rather than lower, than the realization as seen through the plunges, and this is certainly the case when probabilities derived from OP are used in the estimations.

This relationship between the values generated options for the OP and BP simulations, using biased and unbiased estimates of true winning probabilities, is displayed in Table VII. The mean and maximum option values are consistently higher for estimates using unbiased rather than biased measures of true winning probabilities. Now, from equation (13), we have the option values calculates as $C = E\{\max(P_j(T) - \phi_j, 0)\}$. Since the respective prices remain the same as between the two sets of estimates, it is clear that the results are due, on average, higher estimates of true winning probabilities. But why this should be so - for example, whether the favorite-longshot bias under-prices favorites relatively more than it over-prices longshots and why this might be so – is unclear.

Table VII: Values of the generated options

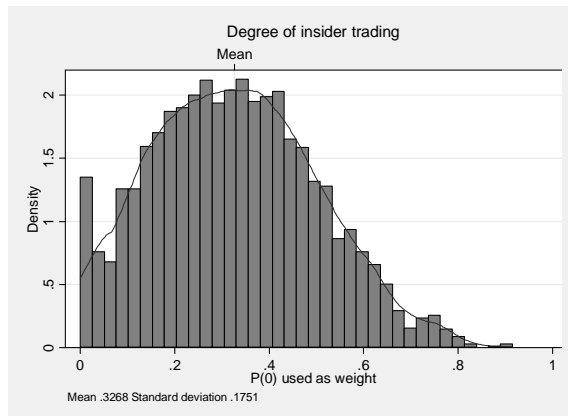
Option values	Biased		Unbiased	
	OP	BP	OP	BP
Mean	0.00197	0.00293	0.00230	0.00307
Standard deviation	0.00530	0.00732	0.00680	0.00828
Maximum	0.15435	0.12714	0.18402	0.14439

Table VIII displays the distribution of the four specifications. The specifications with unbiased estimates of true winning probabilities have a larger tail to the right compared to the specifications with biased estimates. As Table VII indicates, the reason is that the option values generated for the unbiased set of true winning probabilities are on average higher and also have a higher standard deviation. This leads to the larger tail for the unbiased specifications as compared with the biased specifications.

On the basis of the forgoing discussion, it seems reasonable to conclude that the extent of insider trading in the Australian bookmakers' horse betting market is at least 20 percent of all bets in this market. This is considerably higher than the level of 2 percent or so obtained by Shin (1993), a result doubtless owing to the significant differences in our basic assumptions.

Table VIII: Distribution of insider trading for four specifications

Specification 1: Unbiased - OP



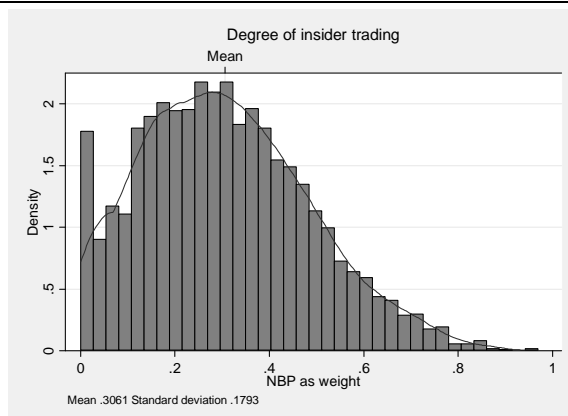
Note: P(0) – OP is used as weight

Specification 2: Biased - OP



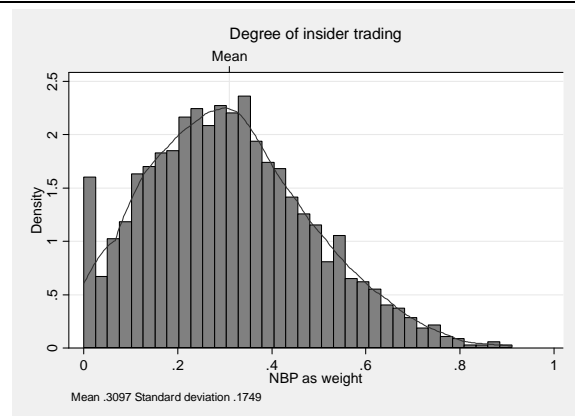
Note: P(0) – OP is used as weight

Specification 3: Unbiased – BP



Note: P(0) – BP is used as weight

Specification 4: Biased - BP



Note: P(0) – BP is used as weight

6. Conclusions

In this paper, we have presented a theoretical model that examines the optimal price setting by bookmakers in the racetrack betting market and then used the model to measure the extent of insider trading in the Australian bookmakers' racetrack betting market. Bookmakers are faced with the risk that insiders will account for information arriving after the opening odds have been set and will thus exploit any mis-pricing by the bookmaker by betting on horses whose price presents an expected profit for the bettor. The basic intuition underlying the model is that the odds offered by bookmakers at the track may be viewed as call options and that, while bookmakers hope to offer only net of premium out-of-the-money options, when they err by underestimating a particular horse's true winning probability, they are liable to offer a net in-the-money option, which the insider (who is assumed to know her horse's true winning probability) will buy. Using Monte Carlo simulations to estimate horses' winning probabilities, we have derived the values of the call options offered for each horse using both opening and best prices and obtained measures of the extent of insider trading in this market in the 20 to 33 percent range.

By using different sets of winning probability estimates in accordance with whether or not the estimates contain a favorite-longshot bias, we have shown that the biased estimates gives rise to upward biases in the estimates of the extent of insider trading. Finally, since herding does not affect our measure when estimated at opening prices, we are confident that 20 percent represents a clear lower bound on the extent of insider trading in the Australian racetrack betting market.

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