Herding in Imperfect Betting Markets with Inside Traders

by

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Abstract

Herding is often considered as a phenomenon that drives prices of risky assets away from their equilibrium levels. In this paper we study the on-course UK and Australian horse betting markets. These are simple examples of imperfect markets for state-contingent assets. We provide strong evidence of herding behavior and show that the effects of herding are occasionally sufficient to render the markets inefficient even in the weak sense. Furthermore, the results demonstrate that traders with inside information are not always able to arbitrage away the effects of herding.

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"Financial institutions have been adopting… [a trend chasing] investment strategy… [so] it is perhaps not surprising that they have exhibited mediocre or bad performance… A gambler is doomed to lose… if he constantly plays with unfavorable odds." (Mei and Saunders,1997, p. 255).

A. Introduction

Herding in financial markets occurs when traders overestimate the information contained in the actions of others.[1] Such behavior is inconsistent with the assumption that markets are efficient and frictionless (Tirole, 1982), but empirical evidence suggests that herding may have significant effect nevertheless even in relatively sophisticated markets (Shiller, 1995, 2003, Mei and Saunders, 1997).

In this paper we study the behavior of traders in simple but large markets for state contingent claims:[2] the on-course markets for horse betting in the UK and Australia. Our evidence suggests that the herding effect may be of the same level of magnitude as the favorite-long-shot bias. Thus, using a betting rule that takes this effect into consideration can greatly reduce expected losses. Moreover, at least for the betting market in Australia and in the period we study, the results suggest that there may be a betting rule that is based on the herding effect and that allows modest positive expected earnings. Previous evidence suggests that the UK betting market is probably less similar to assets markets than the Australian betting market because the UK betting market seems to be influenced by the actions of bettors who use their market power to influence prices, an activity which is forbidden by law in most asset markets.[3] We therefore interpret the different findings in the two markets as strengthening the assumption that herding may have important effect on asset markets (Von Norden 1996, Shiller, 2003).

In order to explain our findings we develop a simple model of betting markets where some traders have inside information and all traders have cash constraints. Shiller (2003) argues that imperfect credit markets may play an important role in the pricing of assets. Thus, our model may be relevant to markets other than horse betting markets.

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[1] Some models that capture this Keynesian "beauty contest" aspect of assets markets are Abbel (1990), Froot et al. (1992) and Hirshleifer et al. (1994).

[2] In Australia, for example, around US$10 billions are wagered every year on horse racing (Coleman, 2006).

[3] For evidence on the UK market See, for example: Gabriel and Marsden (1990), Johnson and Sung (2006) and Schnytzer and Snir (2006).

Beside cash constraints, one other possibility is that herding takes place because when many traders act similarly this generates a misleading signal that influences even informed traders (Shiller, 1995, Mei and Saunders, 1997). We do not capture this effect in our model, but to the extent that such an effect exists, it may exacerbate the herding effect in real world markets.

Our results are in line with findings reported in the literature on other asset markets (Shiller, 1983, 1990, 1995, 2003, Von Norden, 1997, Mei and Saunders, 1997 and Edison et al. 2000). However, the simpler structure of the on-course horse betting market enables us to identify the existence and extent of herding with greater certainty and precision than is possible in other, more complicated markets.

In particular, since betting markets are bounded in time and the outcomes are known with certainty, the search for a herding effect is not complicated by the possibility that traders may change their preferences or expectation-generating process (Flood and Hodrick, 1986, 1990). Further, profits in betting markets can be made only while the market is open, and thus any deviations of the final set of prices from predicted equilibrium levels must be the outcome of some inefficiency.[4]

Several authors have taken advantage of the simple structure of betting markets to try and look for the effects of herding. Law and Peel (2002) study occasions when the final odds offered by bookmakers on runners are significantly shorter than the initial odds.[5] They find evidence supporting the hypotheses that "herd behavior… exist[s] in horse racing" (Law and Peel, 2002, p. 327). Shing (2006), however, claims that the evidence does not support the herding hypothesis, and argues that when odds offered on runners change significantly, it is normally associated with genuine information.

Our approach is to focus on the dynamics of changes in the odds offered on runners during the betting period. As we show, the odds offered on most runners change monotonically or remain unchanged throughout the betting period. However, the odds on certain runners change in a non-monotonic way. In these cases, bookmakers either first lower the odds and then lengthen them or vice versa. It is generally assumed that the goal of bookmakers is to ensure that they profit

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[4] Hurley and McDonough (1995) indeed show that in frictionless betting markets, a small number of bettors with inside information can ensure that prices are efficient even if most traders have no information at all.

[5] This implies that the bookmakers increased the winning probability they assign to those runners. Such changes in the odds usually occur in response to relatively large bets only.

independently of which runners win (Craft, 1985). It follows that bookmakers normally shorten the odds of runners when large bets are placed on them and lengthen the odds when large bets are placed on other runners. Thus, cases where odds first shorten and then lengthen are typically cases where traders place relatively large bets on runners in the early stages of the betting period but stop doing so at later stages. Most of the large bets at the later stages of the betting are placed on other runners. Large early bets on runners are often associated with the actions of insiders (Crafts, 1985, Gabriel and Marsden, 1990, Law and Peel, 2002, Shilony and Schnytzer, 2005).[6]

Early contraction in the odds therefore suggests that there are traders with inside information who believe that the runners they backed have a greater winning probability than that implied by the odds initially offered about them. However, a short time later, when the odds on those runners are lengthened again, those insiders are either unable or unwilling to place bets of sufficient significance to affect prices, even when the odds on those runners have drifted back to initial levels or even further.[7] This suggests that the effect of herding is strong enough to make insiders unable to change the final pattern of prices, even though they have information suggesting that the available set of prices is inefficient. It is likely that this occurs because betting markets are effectively cash-only and insiders are likely to spend their entire cash budget during the initial plunges. It also implies that when herding occurs, the less informed bettors discard the information contained in the early changes in prices and overestimate the weight they give to information contained in the behavior of others, which is the inefficiency in herding suggested by Banerjee (1992, 1993). This leads to the prediction that runners whose odds first contract and then lengthen will be under-priced. The opposite should be the case for runners whose odds first lengthen and then contract.

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[6] For example, consider the following quote from Gabriel and Marsden (1990, p. 878): "we would expect … [insiders] to place early fixed odds bets with bookmakers." Consistent with this argument, Law and Peel (2002) use the Shin (1993) procedure to estimate the share of insiders' trading in the early and final stages of the betting period. They report that the share of trading by insiders in the early stages is almost double the share of insiders' trading at later stages. We used a similar measure to check the share of insiders' betting in the two markets we study. We find that the share of insider trading in the UK in the early stages was larger than the share of insider trading in the later stages (2.5% compared with 2.3%). In Australia we find that the share of trades by insiders is about 2.1% in both the early and later stages of trading, a result that is consistent with the findings of Coleman (2006).

[7] In our two data sets, occasions when the odds on runners where lengthened beyond (or to the same level) of their opening values after initial contraction account for over one-third of the observations in the UK data set and about 70% of the cases in Australia.

Testing this hypothesis on data from the UK and Australian horse betting markets suggests that herding has a significant effect on market outcomes and market efficiency.

The rest of the paper is organized as follows: The next section presents a simple theoretical model. Section C describes the market and the data sets. In sections D we test some of the model's hypotheses. We conclude in section E.

B. Model

To see how herding may affect horse betting markets, consider the following stylized model, that is based on Banerjee (1989, 1992) and Shin (1991).

In horse race j there are N_j runners ($N_j \geq 2$) and N_j assets, indexed by 1,2…*n*. The market opens at time 1 and remains open for *T* periods. Each asset $i \in \{1,2...n\}$ costs $0 < p_{ijt} < 1$ and represents a contingent claim to 1 in the event that runner i wins race j . The winning probability of each runner is π_{ij} and its predicted winning probability - as given by public information - at each period is $\hat{\pi}_{ijt}$. Thus, bets on the winning runner earn $1 - p_{ijt} > 0$ and bets on all other assets yield negative returns of $- p_{kjt}$, $k \neq i$.

As in Banerjee (1989 and 1992), the goal of the bettors is to buy the asset that yields positive returns (i.e. to bet on the winning runner). However, as also in Banerjee (1989 and 1992), the identity of the winner is known only ex-post. Further, most of the bettors are *Outsiders*. As such, they have no information on the winning probabilities other than that captured by the prices. Outsiders can also observe the actions of all the bettors who placed bets before them. Another and smaller class of bettors is composed by *Insiders*. We assume that there are N_j *Insiders*. Each insider i , has private information that gives him the true winning probability of runner i , π_{ij} .

We follow Shin (1991) and Banerjee (1989, 1992) and assume that outsiders always bet when they have the opportunity, and they bet on the runner that they believe is the likely winner. Since when betting begins the only information at their disposal is that captured by the set of prices, they always bet on the runner whose asset has the highest price (the favorite). Thus, as in Banerjee (1989, 1992), in the absence of other information, outsiders bet on one asset and this makes deviations observable. In order to maintain the similarity with Banerjee's 1989 model, we denote (without loss of generality) the shortest-priced runner as runner *n*.

Insiders, who have private information, use it to bet on their own horses if its winning probability exceeds its price; i.e. an insider i bets at period t on runner i if $p_{ijt} < \pi_{ij}$. We assume, for simplicity, that at any given time during the betting only one runner at most may be under-priced.

All bettors (both insiders and outsiders) can bet only once and when they bet they buy one unit of some asset. Thus, once a bettor has placed a bet he cannot bet again. This assumption captures the liquidity constraint in betting markets where transactions are mostly made in cash and credit is rare. Thus, even large bettors can normally place bets only a limited number of times.

As in Shin (1991, 1992) prices are set by a single bookmaker whose goal is to maximize expected profits subject to the constraint that the total sum of prices does not exceed a given maximum, $\overline{sum} \geq 1$.[8] The bookmaker is risk neutral. He therefore sets the initial set of prices such that: $\hat{\pi}_{ij1} \leq p_{ij1},\ i = 1,2...n$ and $\sum_{i=1}^{n} \hat{\pi}_{ij1} = \overline{sum}$. Because the bookmaker knows that at OP, outsiders always support the shortest priced favorite, they price it above its likely winning probability. That is, by assumption $\pi_{nj1} \leq p_{nj1}$.[9]

As in Banerjee (1989, 1992), betting takes place sequentially, and one bettor (either insider or outsider) places a bet at each period. At the beginning of each period $t \in \{1,2...T\}$, insiders choose whether to bet. If they choose not to bet, then one outsider (who knows the actions of all his predecessors) places a bet on the runner that he believes to be the most likely winner.

Under these assumptions, the behavior of prices and bettors continue as following: In period 1, if $\pi_{ij} \leq p_{ij1}$ for all runners, then no insider bets. The first bettor is therefore an outsider who only observes prices and thus deduces that the highest winning probability is that of the shortest-priced favorite, runner n. He thus bets on that

[8] This is a simplifying assumption that captures the competitive nature of on-course bookmaking markets, allowing bookmakers only minimum margins.

[9] Changing this assumption so that $\hat{\pi}_{nj1} \leq p_{nj1}$ instead of $\pi_{nj1} \leq p_{nj1}$ would not change the model, as long as such mistakes by bookmakers are not common. As we show below, if we change the model in this way, it may be that insider *n* bets on runner *n* in the first round. However, since his action can not be distinguished from that of outsiders, the other insiders and the outsiders behave in the same way as in the case where none of the runners is undervalued.

runner, as do all other bettors. By assumption, $\pi_{nj1} \leq p_{nj1}$ and thus, the risk neutral bookmaker has no incentive to change prices. As a consequence, only outsiders bet on runner n and prices do not change.[10] On the other hand, if for some runner i, $p_{ij1} < \pi_{ij}$, then insider i bets on runner i in period 1. Observing the action of bettor 1, all other agents learn that bettor 1 is an insider who knows that runner i is undervalued, so that $p_{ij1} < \pi_{ij}$. The outsiders (and the bookmaker) therefore update their expectations, so that $\hat{\pi}_{ij2} > \hat{\pi}_{ij1}$. After updating expectations, it may be that

$$\hat{\pi}_{ij2} \overset{>}{\underset{<}{=}} \hat{\pi}_{nj2} \quad (1).$$

The direction of the inequality in (1) depends on the distribution of probabilities and on the initial difference between the prices of runners i and n. If, after calculating the contingent probabilities, outsiders still believe that the winning probability of n is greater, they will continue to bet on it. Knowing this, and knowing that there are no more insiders who have private information on runner i, the bookmaker would maintain prices unchanged, and take advantage of the fact that $\pi_{nj1} \leq p_{nj1}$. Since prices do not change, other insiders have no incentive to place bets. Thus, after period 1, only outsiders bet and they all bet on runner n.

If, on the other hand, bettors decide that the value of (1) is such that the winning probability of runner i is greater than that of n, then outsiders switch to betting on runner i. In anticipation, the bookmaker increases the price of runner i so that the price of runner i exceeds its expected probability. Thus, following the bet by the insider, prices change so that: $p_{ij2} \geq \hat{\pi}_{ij2}$. In the process of raising the price of runner i the bookmaker must also reduce the prices of other runners because he is constrained by: $\sum_{i=1}^{N_j} \hat{\pi}_{ij1} = \overline{sum}$. It may therefore be that the price of some other runner now drops below its true winning probability. We first consider the case where this does not happen. In that case, all bettors place bets on runner i and the bookmaker profits in expectation because $p_{ij2} \geq \hat{\pi}_{ij2}$.

In the case where the change in prices leads to some other runner, k, being under-

[10] Assuming that the bookmaker is risk neutral and that he maximizes profits by taking advantage of bettors favoring an over-priced runner is similar to the behavior found by Levitt (2004). If bookmakers rather try to ”balance the books”, then they may minimize exposure by changing prices slightly to make other runners more attractive.

priced then the relevant insider k bets at period 2. Outsiders then learn that runner k's new price under-estimates its true winning probability. Outsiders then have to decide whether (given the initial set of prices) the winning probability of runner k is greater than that of runner i. This is a similar problem to the one given in (1) with k replacing i and i replacing n. Where outsiders assume that $\hat{\pi}_{kj2} < \hat{\pi}_{ij2}$, they will keep backing runner i. The bookmaker would therefore maintain prices unchanged and profit in expectation because $p_{ij2} \geq \hat{\pi}_{ij2}$. However, if $\hat{\pi}_{kj2} \geq \hat{\pi}_{ij2}$ then outsiders would prefer to bet on runner k. The bookmaker would therefore have to increase the price of k and reduce the price of some other assets. Since he loses in expectation to any insider,[11] he would prefer not to give the opportunity of betting to insiders who have not yet bet. Thus, the bookmaker prefers to reduce the price of runner i (because the insider who has information on runner i has already placed his bet) and not the price of any other runner. He therefore increases the price of k and reduces the price of i. Since $p_{kj3} \geq \hat{\pi}_{kj3}$ it may be that $p_{ij3} < \hat{\pi}_{ij3}$ (indeed, if $\overline{sum}$ is close to 1 then this is even likely). However this does not influence betting on runner k since, by assumption, the insider who has this information cannot bet again, and outsiders, as in Banerjee (1989), prefer to go with the herd.

The important conclusions from this simple model are that when a herd forms on some runner i, the price of that runner is likely to over-estimate its winning probability, since bookmakers profit in expectation. Thus, in all the scenarios of this model, runners who enjoy high demand (are being herded) are likely to be over-priced. On the other hand, the price of runners whose price increases and then decreases has some likelihood of underestimating their winning probability, because bookmakers take advantage of the budget constraint that limits the actions of insiders. Although it is extremely simple, the results of the model may be extended to more complicated situations so long as the assumptions that insiders are cash-constrained and outsiders are interested in picking winners hold. This implies that, as predicted by Banerjee (1989, 1991), herding leads to a situation where ordinary bettors place too few bets on some runners, leading to an unequal share of the profits between bookmakers and bettors. If we were to assume with Banerjee (1989) that all agents have similar utility functions, this would imply that herding leads to an inefficient

[11] This follows from the assumption that insider i bets only if $p_{ijt} < \pi_{ij}$.

allocation of resources. This result may also be aggravated in environments where insiders may be uncertain about the quality of their information and thus look on herds as signaling information which they do not posses. At such times, herding may cause even insiders to ignore their private information. Another similarity with Banerjee's (1989) model is that, as in his model, when there are gains for originality (i.e. for being the first to pick a winner) herding still occurs but people with inside information normally bet according to their signals. This suggests that our results may also be relevant to other markets where there are credit constraints and investors try to pick the most profitable investment.

C. Methodology and data

Our model implies that demand and prices of assets may change in response to spot changes in prices. As a consequence, a one-time change in the price of an asset may lead to herding, and prices may overshoot their value. The goal of this and the next section is to test for the effects of herding on equilibrium prices in on-course bookmakers' horse betting markets in the UK and Australia.

Each data set covers one full season of betting on flat races with on-course bookmakers. In both markets, the on-course bookmakers' market is considered to be highly competitive with normally between 10 – 50 bookmakers operating at each race track (Shin, 1991, 1992, Bruce and Johnson, 2005). The market for bets usually opens 20 – 30 minutes before each race is run and the bookmakers offer bets at fixed odds.[12] The first set of odds they post at the time they open for bets are known as *Opening Prices* (*OP*). As the market progresses, bookmakers often change odds in order to manage their exposure.[13] The last set of prices that the bookmakers post before the market closes (and the race starts) are known as the *Starting Prices* (*SP*).

The first data set we employ contains observations on all the races with six runners or more that took place in the UK in 1995. The data set was provided by Timeform and it contains information on 39,098 runners that took part in 3,562 races.

[12] Fixed odds are a commitment by on-course bookmakers to pay bettors the quoted odds in the event that the runner they back wins. Thus, bettors who bet at fixed odds know their contingent outcomes at the time they place the bets. This feature makes betting with bookmakers different from pari-mutuel markets where the outcomes are proportional to the final share of the bets placed on each runner. (For more on pari-mutuel markets see for example: Thaler and Ziemba, 1988 and Gandar et al., 2001).

[13] In over 42,000 observations that we have in our UK data set, fewer than 8.5% of the runners maintained a constant price from the time the market opened and until it closed.

The second data set contains observations on all the flat races run at Metropolitan race tracks in Australia in the 1997/8 season. It includes data on 43,056 runners that took part in 3,654 races.[14] Since Metropolitan races tend to attract large audiences, offer large prizes and attract considerable media attention, this data set may be expected to exhibit a relatively small degree of any biases that might be associated with insider activity (Vaughan Williams and Paton, 1997 and Bruce and Johnson, 2005).

Both data sets include information on opening and starting prices offered on each runner and on its actual finishing place in the race. For some runners, the data sets also include information on their price at some mid-point in the betting. This information is apparently made available, in general, for runners whose price did not change monotonically during the betting period. That is, this information is given for runners whose prices decreased in the first stages of the betting period and then increased or vice versa.[15] Observations on middle prices are provided for 18,107 runners in the UK data set and for 10,803 runners in the Australian Metropolitan races.

Table 1 summarizes some of the key information on the two markets.

Table 1: Summary Statistics

	Number of horses	Number of races	Median Number of Runners
UK	39,098	3,562	12
Metropolitan	43,056	3,654	12

Table 1: Number of horses is the total number of starters. The first row is for observations on races run in the UK in the 1995 season. The second row is for observations on Metropolitan races run in Australia in the 1997/8 season.

[14] The data come from the CD version of the "Australasian Racing Encyclopedia '98".

[15] In the full data set that includes information on the UK, Victorian and Metropolitan meetings throughout Australia, there were only 164 cases where the middle price was given for horses whose middle price was between their OP and SP.

D. Tests

If betting markets are efficient, then the final set of prices posted by the bookmakers before the market closes should represent equilibrium prices that summarize all the available information. It follows that in efficient betting markets, the final sets of prices should be the best unbiased estimator of winning probabilities. Standard tests for market efficiency therefore check whether any other information can improve winning probabilities when controlling for the closing odds (*SP*), and whether this information permits positive profits to be made. It has been found that, in most betting markets, odds are not an unbiased predictor of probabilities. The closing odds tend to overestimate the probabilities of low-probability runners and underestimate the probability of high-probability runners.[16] This implies that in most betting markets, betting on low-probability runners (long-shots) leads to greater expected losses than betting on favorites, although the *favorite- longshot bias* is normally not sufficiently pronounced to allow for positive net expected profits (Crafts, 1985, Sauer, 1998, Gandar et al. 2001, Johnson and Sung, 2006). Testing for a bias in the pricing that is the result of herding should therefore show that there is a bias in the pricing that can be associated with herding, and that this bias may be distinguished from the favorite-longshot bias. Our theoretical model implies that runners whose odds shortened and then lengthened during the betting period should be under-priced whereas runners whose odds lengthened and then contracted should be overpriced.

To test this hypothesis we define the following variables:

$oodds_{ij}$ - The opening odds of runner i in race j.

$modds_{ij}$ - The middle odds of runner i in race j (where provided in the data set).

$sodds_{ij}$ - The starting price (final odds) of runner i in race j.

$sreturns_{ij}$ - The returns to betting 1 on runner i in race j at starting prices. The returns equal $sodds_{ij}$ if the runner won the race and -1 otherwise.

$oprice_{ij}$ - The price of a contingent claim to 1 in the event that runner i wins race j at its opening odds.

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[16] The favorite-longshot bias has been found in most betting markets, including the horse betting markets in the US, Australia, the UK and New Zealand. See, for example: Thaler and Ziemba (1988), Vaughan-Williams (1997), Sauer (1998), Gandar et al. (2001), Bruce and Johnson (2005) and Coleman (2006). One market which seems to be free from such a bias is the Hong Kong market, in which a reverse bias has been found (Busche and Hall, 1988).

$sprice_{ij}$ - The price of a contingent claim to 1 in the event that runner i wins race j at its starting price.

$mprice_{ij}$ - The price of a contingent claim to 1 in the event that runner i wins race j at its middle odds (where provided in the data set).

The prices ($oprice_{ij}$, $mprice_{ij}$ and $sprice_{ij}$) are calculated by finding the price that solves:

$$odds_{ij} = \frac{1 - price_{ij}}{price_{ij}} \qquad (4)$$

where $price_{ij}$ is either $oprice_{ij}$, $mprice_{ij}$ or $sprice_{ij}$ and *odds* is either $oodds_{ij}$, $modds_{ij}$ or $sodds_{ij}$, respectively.

To capture the effect of changes in prices during betting on the subjective winning probabilities, we define three more variables:

$$osp_{ij} = \ln\left(\frac{1 - sprice_{ij}}{1 - oprice_{ij}}\right)$$

$$mop_{ij} = \ln\left(\frac{1 - oprice_{ij}}{1 - mprice_{ij}}\right)$$

$$msp_{ij} = \ln\left(\frac{1 - sprice_{ij}}{1 - mprice_{ij}}\right)$$

These three variables capture the magnitude of the change in the price between the opening and closing odds, the opening and middle odds and between the middle and the closing odds, respectively. They are positive in the event that the starting price is smaller than the middle or opening price and if the opening price is lower than the middle price (in which case there has been an early plunge), and negative otherwise. Measuring the changes in logarithms has the advantage that it gives more weight to observations with shorter odds (higher implied probabilities).[17] Finally, we define two dummy variables:

[17] See: Law and Peel (2001) and Shing (2006).

$mp\_sp\_up\_down$, that receives the value of 1 if the middle odds are shorter than both the opening and starting odds and 0 otherwise, and $mp\_sp\_down\_up$, that receives the value of 1 in the event that the middle odds are longer than both the opening and starting odds.

Gandar et al (2001) show that estimating a regression on the returns from a bet of 1 on each runner as a function of its starting price measures the extent of the favorite – longshot bias in a market. We therefore estimate such a regression for the UK and Australian markets. We add to the regression our measure of movement in the prices between the Opening Prices and Starting Prices and for movements between Middle Prices and Starting Prices. If our hypothesis that herding significantly affects outcome is correct, then we should find that the returns on runners whose odds shortened between the Middle Price and Starting Prices should be lower (ceteris paribus) than the returns on other runners, since the reduction in the odds is associated with herding. On the other hand, we should expect that the returns on runners whose odds lengthened between the Middle Prices and Starting Prices to be greater than the return on other runners. We estimate the regression using a Tobit model, since the dependent variable is censored at -1. We also cluster the observations by race to control for possible heteroscedasticity. The results for the two markets are given in Table 2.

Table 2: The effect of change in prices between Middle Prices and Starting Prices

Variables	UK	Australia
sodds	-0.68***	-0.47***
	(0.025)	(0.02)
osp	-0.85	11.01***
	(2.79)	(3.64)
$mp\_sp\_up\_down \times msp$	47.29***	71.26***
	(12.65)	(16.21)
$mp\_sp\_down\_up \times msp$	-36.99***	-59.17***
	(5.02)	(7.3)
Constant	-15.05***	-21.62***
	(0.375)	(0.43)
$\chi^2_{(4)}$	2,103***	1,699***
Observations	39,098	43,056

Table 2: Dependent variable: The returns to a bet of 1 on each runner (*sreturns*). Robust (clustered by race) standard deviations are reported in parenthesis.
***- The coefficient is Significant at the 1% level.

The results strongly support the hypothesis that herding plays a significant role in driving prices in both markets. The negative and significant coefficient of *sodds* shows the expected effect of the favorite – longshot bias in the two markets. The negative coefficient implies that when the odds on a runner shorten, the expected returns from a bet on it increase by more than suggested by the reduction in the odds. The positive coefficient on *osp* in Australia suggests that runners whose odds contract during the betting tend to have higher winning probabilities (the insignificant coefficient in the UK suggests that this information is captured fully in the final set of odds). Both those results are common in betting markets (Shing, 2006), but the positive and significant coefficient in Australia suggests that plunges contain more information there, perhaps due to some institutional differences. Schnytzer and Snir (2006), for example, suggest that at the time these data sets were collected, off-course *SP* bookmakers in the UK may have used their market power to influence prices, a phenomenon that did not exist in Australia.

Most importantly, the coefficients on the interactions between non-monotonic changes in prices during the betting period and the magnitude of the change are significant and have the signs as predicted by our model. Thus, the coefficient on runners whose odds fell between the middle of the betting period and the closing of the market is positive and significant. This implies that the odds on those runners were too long despite the fact that the initial contraction in the price suggested that those runners had higher than initially expected winning probabilities. Nevertheless, this information did not affect trading at the later stages of the betting period, which implies that bettors discounted the early information too much, an indirect feature of herding.

The coefficient on the interaction between runners whose odds contracted after they initially lengthened is negative and significant. This implies that the odds on those runners contracted too far, suggesting that bettors kept on backing them even when their price over-estimated their true winning probabilities, which is a direct indication of herding behavior. The magnitude of the herding effect can be interpreted by calculating the elasticity of the probability with regard to the different variables. According to the results, at the mean, a contraction in the odds between the middle of the betting and the closing of the market for runners whose odds initially lengthened that led to a fall in msp by 1% leads to a fall of 0.34% in the expected profits in

Australia and 0.4% in the UK. When *msp* increases by 1%, the expected profits increase by 0.07% in Australia and 0.05% in the UK.[18] The sharp drop in expected profits when *msp* decreases is an indication of the strength of the herding effect: Although the expected profits drop, the demand for the runners that are being herded does not seem to drop in the same proportion.. The modest increase in expected profits when *msp* increases is probably a consequence of the fact that bookmakers hedge themselves against possible losses when they decrease prices.

Thus, the results testify to the existence of a herding effect. To test its practical significance, we simulate betting on different classes of runners according to their *mop* and *msp* values.[19] Since Starting Prices should represent equilibrium prices (Dowie, 1976 and Crafts, 1985), then in markets that are efficient in the weak sense it should be impossible to generate expected positive profits on any class of runners by using only information on prices (Fama, 1970, Sauer, 1998). On the other hand, if our hypothesis is correct and herding leads to significant pricing biases, then runners whose price initially shortened and then lengthened (mop>0 and msp>0) should be undervalued and thus may provide profitable betting opportunities. At the same time, runners whose odds initially lengthened and then contracted (mop<0 and msp>0) are likely to be overpriced, and are therefore may be expected to yield smaller than normal profits, where by normal profits we mean the expected profits (losses) from betting on all runners. Since bookmakers profit from the margin they set between the price and their perception of the actual winning probability, only large biases should permit finding profitable betting rules. We therefore differentiate between runners

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[18] The greater drop in expected profits as a result of a fall in *msp* in the UK when compared with Australia and the greater responsiveness in Australia to an increase in *msp* may be explained by the different interests of some of the larger bettors in the two markets. See: Schnytzer and Snir (2006).

[19] Simulating betting on runners in those markets may not be considered as an out-of-sample test because we use the same information sources for our regressions analyses. However, the results are highly suggestive and the discovery of a profitable wagering rule provides strong support for our hypothesis.

whose *mop* and *msp* are both greater than 0.1 and those of other runners.[20] For such runners, the large changes between their initial, middle and final odds suggest that a large amount of herding occurred on other runners despite the fact that insiders placed relative large bets on these horses in the early stages of the betting. This class of runners is therefore the most likely to be undervalued.

We simulate betting a sum of $\frac{10}{1+sodds}$ on each runner. We choose this rule because it ensures that we bet a sum that is proportional to the odds, thus rendering our results relatively robust to spurious successful bets on low probability runners. The results are given in Table 3, and they generally support our theory. Runners whose odds contracted and then lengthened (the bottom two rows) always offer better returns than the general population of runners (the middle row), which implies that bettors do not stop herding on other runners even when runners in this group are priced below their winning probabilities. Moreover, the bottom two rows imply that the herding effect is sometimes large enough to offer profit opportunities in both markets. On the other hand, when the odds of runners first lengthen and then shorten, the results indicate that the relevant runners are indeed overpriced with respect to their true winning probabilities.

One prominent feature of our findings is that for the UK, profits seem to be smaller and are obtained only when the herding effect is more extreme than in the Australian metropolitan market. As we argue in the introduction, previous studies have shown that the betting market in the UK seems to be less efficient than other betting markets (Bruce and Johnson, 2005, Johnson and Sung, 2006). Schnytzer and Snir (2006) argue that some of those inefficiencies may be explained by the presence

[20] The values of *omp*>0.1 and *msp*>0.1 are similar to those used by Law and Peel (2002) to define large plunges.

of off-course SP bookmakers in the UK who participate in the on-course betting with the goal of affecting prices. Schnytzer and Snir (2006) explore this issue in detail. On the other hand, SP betting is illegal in Australia and off-course bettors have sufficient scope for betting to ensure that any SP bookmakers which do exist have no impact on the on-course market. We therefore expect the Australian Metropolitan market to exhibit patterns that are more similar to other asset markets. We also expect the herding effect in Australia to be stronger because prices in the UK may be influenced by off-course SP bookmakers who may intervene in the market when the prices of runners fall. To check this hypothesis, we simulated betting £1 on every runner in both Australia and the UK for which mop>0.1 and msp>0. In other words, we simulated betting on a runner if there was an early plunge on this runner and the effect of the plunge did not last until the end of the betting period (i.e. the bettors moved to bet on other runners). Under the hypothesis that in Australia there are fewer traders with market power, we expect that betting on such runners would yield higher returns there. As expected, we find that in using this rule on the Australian database yields 4.73% profit from betting on 73 runners belonging to that category. At the same time, following the same rule yields a negative profit of -13% in the UK (343 runners).

Table 3: Returns to bets on runners according to their *msp* and *mop* values.

Mop / *Msp*	UK				Australia			
	Runners	Total bet	Winners	Profits	Runners	Total bet	Winners	Profits
$mop < -0.1$ $msp < -0.1$	152	736.1	38%	-21.2%	74	344.6	33%	-27.2%
$mop < 0$ $msp < 0$	16,812	23,524.3	12%	-.13.3%	9,113	13,868.4	13.1%	-14.0%
All Runners	39,098	4,4204.6	9.1%	-19.4%	43,056	45,422.3	8.5%	-19.2
$mop > 0$ $msp > 0$	1,284	2,575.4	17.7%	-11.5%	1,207	2104.4	14.6%	-15%
$mop > 0.1$ $msp > 0.1$	30	118.9	30%	-10.3	15	51.98	40%	15.3%
$mop > 0.1$ [21] $msp > 0.15$	10	36.83	50%	8.5%	0	---	---	---

Table 3: Returns from betting a sum of $\frac{10}{1+sodds}$ on runners according to their *mop* and *msp* values. The Total bet columns gives the total sum bet on runners in each category. The winner columns give the percentage of winners belonging to that category. The Profits columns give the share of the returns for betting on runners in that category.

E. Conclusions

[21] It is possible to generate positive profits for *mop*>0.07 and *msp*>0.07 in Australia and *mop*>0.1 and *msp*>0.12 in the UK. In this case the number of runners belonging to the profitable category in Australia is 35 and the generated profit is 2.5%. In the UK, the number of runners in the profitable category is 18 and profit rate of 7.8%.

Understanding traders' behavior in asset markets is an important issue for understanding market behavior and efficiency. Some authors suggest that herding may be a factor that affects traders and biases their actions so that prices are not set efficiently (Banerjee, 1992, Shiller, 2003). In this paper, we study the on-course two bookmakers' horse betting markets, simple markets for state contingent assets. We find that, using information on non-monotonic movements of prices during the trading period, we can identify a significant herding effect in both markets. This herding effect seems to be strong enough to bias prices away from equilibrium values even when there is evidence that traders with inside information are present in the market place. Thus, our findings suggest the existence of a significant herding effect. We show that the effect is occasionally strong enough to allow profitable betting rules, and thus breach even weak-form market efficiency. We find that our results are especially strong in the Australian Metropolitan races where there are no off-course SP bookmakers, thus making them more similar to other asset markets.

Thus we find that contrary to the predictions of the efficient market theory, the existence of better informed traders is not a sufficient condition for ensuring market efficiency. In particular, one important constraint on the activity of traders in these markets is that most transactions are made in cash, and therefore inside traders may find themselves credit constrained. These results are consistent with the predictions of models that view credit constraints as important in asset markets (Shiller, 2003), and they therefore suggest that our results may be extended to such markets as well.

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