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# Information and Attitudes to Risk at the Track

by

Adi Schnytzer and Sara Westreich<sup>1</sup>

## Abstract

There have been many attempts, theoretical and empirical, to explain the persistence of a favorite-longshot bias in various horse betting markets. Most recently, Snowberg and Wolfers (2010) have shown that the data for the US markets support a misperceptions of probability approach in line with prospect theory over a neoclassical approach of the Quandt (1986) type. However, their paper suffers from two basic difficulties which beset much of this literature. First, the theoretical model used fails to allow for the existence of horse betting markets which either display no such bias (or a reverse bias) as in Hong Kong and at least one large Australian market (Busche and Hall, 1988, Schnytzer, Shilony and Thorne, 2003 and Luppi and Schnytzer, 2008). Second, econometric testing and theoretical modeling are facilitated by the highly unrealistic assumption that the betting population is homogeneous with respect to either information or attitude to risk or (usually) both. Our purpose is to show that allowing for heterogeneous betting populations (in terms of both attitude to risk and access to information) permits the explanation for the different biases (or their absence) observed in different markets within a strictly neoclassical framework of rational bettors. We conclude with empirical support for our model.

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# 1 Introduction

What causes the favorite-longshot (hereafter f/l) bias? This is a question which has fascinated and frustrated economists and psychologists since Griffith first published a paper demonstrating its existence at the Churchill Downs track in 1949<sup>2</sup>. The puzzle deepened when Busche and Hall (1988) demonstrated the existence of a reverse f/l bias at the track in Hong Kong and Busche (1994) showed that the Japanese horse betting market also displayed a reverse f/l bias<sup>3</sup>. Subsequently, Schnytzer and Luppi (2008) showed that not only is there no longer any bias at the close of betting in Hong Kong but that there isn't even a bias at different times prior to the close of betting. Finally, there is a large betting market in Australia where a bias appears at the opening of betting and is steadily eliminated as the betting proceeds. What is more, the same population of bettors does not eliminate the bias when betting in a different market, the only difference between the two markets being access to information (Schnytzer, Shilony and Thorne, 2003). In sum, there are pari-mutuel (tote) horse betting markets with an f/l bias (the vast majority), and there are small numbers with a reverse bias or with no bias at all.

The purpose of this paper is to present a unified model whereby rational bettors with differing attitudes to risk and different access to information may give rise to any of these outcomes in betting markets. In order to capture exclusively demand side influences on the betting markets, we restrict our attention to tote markets only, although fixed-odds markets may be operating in the same given environment.<sup>4</sup> Thus, our major concern is to check whether, in contrast with psychological models of bettor behavior, we are able to explain the wide range of observed outcomes based solely upon considerations of attitude towards risk and access to information, without needing to invoke psychological biases on the kind to be found in papers in behavioral economics. An excellent, very recent example of such studies is that of Snowberg and Wolfers (2010), who show that the data for the US markets support a misperceptions of probability approach in line with prospect theory<sup>5</sup> over a neoclassical approach of our kind or of the Quandt (1986) type. Our problem with the Snowberg and Wolfers approach is that, in order to explain a reverse f/l bias (which is not in evidence in their data, but known to be or have been in evidence elsewhere) they would need to argue, *a priori*, that bettors in, say, the Japanese market are afflicted by a misperception of probabilities problem opposite to that of American bettors, whereas Australian bettors in a market with no bias suffer from no such afflictions whatsoever! The conceptual confusion implied by such an approach requires no further elaboration.

The real difficulty is that econometric testing and theoretical modeling are facilitated by the highly unrealistic assumption that the betting population at a given track (which is the source of the data) is homogeneous with respect to either information or attitude to risk or (usually) both. Indeed it is difficult to imagine how one might proceed otherwise in the absence of further data sets. Accordingly,

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<sup>2</sup> For a substantial, if incomplete, sample of the literature on the bias, see <http://favourite-longshot-bias.behaviouralfinance.net/>

<sup>3</sup> Lest one suspect, albeit politically incorrectly, that perhaps Asian bettors differ from those in Western markets, it should be pointed out that a regular f/l bias has been measured in the Singapore and Malaysian horse betting markets (Leong and Lim, 1994).

<sup>4</sup> In this paper, we focus exclusively upon tote markets because we are interested in whether bettors, by themselves, behave rationally or irrationally in the generation of any observed bias. In the case of fixed-odds bookmakers' markets, a f/l bias is uniformly observed (see, for example, Shin, 1991, 1992 and 1993, Vaughan Williams and Paton 1997 and Schnytzer and Shilony, 2003 and 2005).

<sup>5</sup> See Kahneman and Tversky (1979) for the pioneering exposition and <http://prospect-theory.behaviouralfinance.net/> for a rich sample of the subsequent literature.

when we have built our theoretical model, we draw on empirical evidence from different source for support. This evidence is provided in Section 4.

Our conceptual approach considers first bets and then bettors. To bet on a horse to win a race is to purchase a binary gamble (a specific kind of contingent commodity) which returns the tote payout for \$1 bet if the horse wins and returns nothing if it loses. We develop a measure of the inherent riskiness of such a bet for each horse in the race. Inherent riskiness is the riskiness of a gamble defined independently of either the utility or the wealth of the individual contemplating taking the gamble. In other words, the index is unconcerned with the attitude of the individual towards risk, but attempts to capture that risk which is inherent to the gamble itself. The first such index was presented by Aumann and Serrano (2007) (hereafter [AS]), but it is restricted to gambles which risk-averse agents would accept. Thus, while it is an index of inherent risk, it is restricted in its applicability to a particular type of agent and does not even cater to a risk-averse investor who wishes to sprinkle his portfolio with some potentially high return, high risk gambles. For [AS], risk aversion applies to every component of a portfolio and is not an "on average" notion. For our purposes, given that many if not most horse bettors are generally viewed as risk lovers, the index must be expanded to account for all possible kinds of gamblers. This expansion, in general terms, appears in Schnytzer and Westreich (2009) (hereafter [SW]).

The [AS] index has one feature which should be true of any index of risk and yet is surprisingly hard to find among other measure of risk. It turns out to be critical for our analysis of the f/l bias. It is what [AS] term the Duality Axiom: As they put it, "Duality says that if the more risk-averse of two agents accepts the riskier of two gambles, then a fortiori the less risk-averse agent accepts the less risky gamble." We present the relevant features of the [SW] extended index as developed for our current purposes in Section 2. We show there that if the less risk loving agent accepts the riskier of two gambles then a fortiori the more risk loving agent accepts the more risky gamble.

As we shall see, the over- and under-betting of favorites and longshots turns on the nature of the bets of different inherent riskiness available to bettors and the attitudes to risk and available information which leads bettors to rationally engage in biased betting behavior.

Which brings us to bettors, whose behavior in interaction with the riskiness of bets is discussed in Section 3. The bettors may either accept, in principle, gambles with perceived negative and positive returns (risk lovers), or accept only perceived positive return gambles (risk averse bettors). There is also the group of risk neutral bettors but, for ease of exposition and without loss of generality, we group these with the risk averse bettors and do not deal with them explicitly in Section 3.<sup>6</sup> Now, in contrast to the simplifying assumptions of Quandt (1986), (hereafter [Q]), we do not assume that all risk lovers will back all horses. It will be shown that if a bet on a horse is of sufficiently high inherent riskiness, there will be even risk lovers whose utility functions reflect insufficient risk "lovingness" to encourage them to bet on that horse. For a parallel reason, not every risk averse bettor will necessarily back every horse offering a positive expectation.

With respect to information access, we make the simple assumption that all bettors range between complete knowledge of all horses' objective winning probabilities and complete ignorance as reflected by the assignment of equal winning probabilities to all horses participating in any given race. This assumption leads immediately to the well-known observation that a regular f/l bias, as observed in most horse betting markets, follows, *ceteris paribus*, if bettors are unaware of the horses' true winning probabilities.<sup>7</sup> They need only bet in accordance with their subjective winning probabilities. Note further,

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<sup>6</sup> Where necessary, results are presented for risk neutral bettors in Section 3.

<sup>7</sup> See Thaler and Ziemba (1988).

that an increase in transaction costs (the track take) simply increases the extent of the bias.<sup>8</sup> No recourse to either prospect theory or any other form of irrationality is required. Hence, if there is to be either a reverse bias or no bias in a betting market, it must be the case that some bettors, at least, have full information vis a vis the winning probabilities of all horses in the race. We further show that some bettors must be risk averse in such markets. Finally we investigate the impact of transaction costs on the f/l bias. Some conclusions are provided in Section 5.

## 2 The Inherent Riskiness of Horse Bets

In this section, following [AS] and [SW], we present those features of a *generalized index of inherent riskiness* necessary for our analysis of the f/l bias. Given that horse bettors make have a wide range of attitudes towards risk, we make no a priori assumptions about such attitudes.

A *utility function* is a strictly monotonic twice continuously differentiable function  $u$  defined over the entire line. We normalize  $u$  so that:

$$u(0) = 0 \quad \text{and} \quad u'(0) = 1.$$

If  $u$  is concave then an agent with a utility function  $u$  is risk averse, while if  $u$  is convex, then an agent with a utility function  $u$  is risk lover.

**Definition 2.1** An agent is said to have *Constant Absolute Risk (CAR)* utility function if his normalized utility function  $u(x)$  is given by

$$u_{\alpha}(x) = \begin{cases} \alpha^{-1}(1 - e^{-\alpha x}), & \alpha \neq 0 \\ x & \alpha = 0 \end{cases}$$

If  $\alpha > 0$  then the agent is risk-averse with a CARA utility function, while if  $\alpha < 0$  then the agent is risk-loving with a CARL - Constant Absolute Risk-Loving - utility function. If  $\alpha = 0$  then the agent is risk neutral.

The next theorem appears in [SW] extending the original idea of [AS]. It verifies the existence of the general index for the following class of gambles. A gamble  $g$  is *gameable* if it results in possible losses and possible gains. If  $g$  has a continuous distribution function, then it is gameable if it is bounded from above and below, that is, its distribution function is truncated.

**Theorem 2.2** [AS,SW] Let  $g$  be a *gameable* gamble and let  $\alpha$  be the unique nonzero root of the equation

$$Ee^{-\alpha g} - 1 = 0$$

Then for any wealth, a person with utility function  $u_{\alpha}$  is indifferent between taking and not taking  $g$ . In other words, the CAR utility function  $u_{\alpha}$  satisfies for all  $x$ ,

$$Eu_{\alpha}(g + x) = u_{\alpha}(x).$$

Moreover,  $\alpha$  is positive (negative) if and only if  $Eg$  is positive (resp. negative).

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<sup>8</sup> See, for example Hurley and McDonough (1996) on the impact of transaction costs.

**Definition 2.3** Given a gamble  $g$ , denote the number  $\alpha$  obtained in Th.2.2 by the upper limit of taking  $g$ .

The notation upper limit is justified by the following:

**Theorem 2.4** Let  $\alpha$  be the upper limit of taking a gamble  $g$ . Then:

1. If  $Eg > 0$  then all CARL accept  $g$  and a CARA person with a utility function  $u_\beta$  accepts  $g$  if and only if

$$0 < \beta < \alpha$$

2. If  $Eg < 0$  then all CARA reject  $g$  and a CARL person with a utility function  $u_\beta$  accepts  $g$  if and only if

$$\beta < \alpha < 0$$

3. If  $E(g) = 0$  then all CARA people reject  $g$  while all CARL people accept  $g$ .

Given a gamble  $g$  and its upper limit  $\alpha$  define its index  $Q(g)$  by

$$Q(g) = e^{-\alpha} \quad (1)$$

Th. 2.4 and the fact that  $Q$  is a monotonic decreasing function of  $\alpha$ , imply that:

**Corollary 2.5** An increase in riskiness corresponds to a decrease in the set of constant risk-attitude agents that will accept the gamble.

**Caution:** The corollary above does not say that constant risk-attitude agents prefer less risky gambles. It says that they are more likely to accept them.

It is straightforward to check the following properties:

**Corollary 2.6** The generalized index  $Q(g)$  given in (6) satisfies:

2.  $Q(g) > 0$  for all  $g$ .

2. If  $Eg > 0$  then  $Q(g) < 1$  and if  $Eg < 0$  then  $Q(g) > 1$ . When  $Eg = 0$  then  $Q(g) = 1$ .

3.  $Q(Ng) = Q(g)^{1/N}$ . In particular

$$Q(-g) = Q(g)^{-1}$$

**Remark 2.7** Unlike the case of the [AS]- index, homogeneity of degree 1 does not hold. However, when  $E(g) > 0$  then it is replaced by (increasing) monotonicity. This follows since in this case  $Q(g) < 1$ .

Hence if  $t < 1$  then  $Q(tg) = (Q(q))^{1/t} < Q(g)$ , while if  $t > 1$  then  $(Q(q))^{1/t} > Q(g)$ .

If  $E(g) < 0$  then  $Q(g) > 1$  and  $Q$  is monotonically decreasing with respect to multiplication by  $t$ . This follows by the same argument as above, with the reverse inequalities.

An intuitive explanation for higher and lower values of riskiness for negative expectation

gambles could be as follows. Following Cor. 2.6, consider the suggested index of riskiness as the opposite of the number of constant risk attitude gamblers who will accept it. Now, gamblers who put money on gambles with negative expectations are all risk lovers, which means that they get thrills from higher values of money, and by their utility functions, they make better use of larger gain. Such a gambler gets more thrills when doubling his bet, that is, he enjoys the gamble and the possible outcomes more, and so it is more attractive for him to take it. As a result, more risk-lovers will take the double betting gamble, which means by the above that the gamble is less risky.

The results derived thus far are true for all gameable gambles, but since a win bet on a horse is a binary gamble, we now proceed to derive some necessary results for such simple gambles. In what follows we prove that for binary gambles the generalized index is a monotonic function of  $Var(g)$ , which is increasing for gambles with  $Eg > 0$  and decreasing otherwise.

Let  $g$  be a gamble that results in a gain of  $M$  with probability  $p$  and a loss of  $L$  with probability  $q = 1 - p$ . We assume  $M$  and  $L$  are positive real numbers. The following lemmas are a natural observation; we prove it here for completeness. Note that:

$$Eg = p(M + L) - L \quad \sigma^2(g) = p(1 - p)(M + L)^2 \quad (2)$$

**Lemma 2.10** *Given two binary gambles that result in loss of  $L$  and have the same expectation, then a risk lover agent will always prefer the gamble with the greater variance, while a risk averse gambler will prefer the smaller variance.*

Proof: Define a function  $F$  by  $F(p) = Eu(g)$ . Set  $E = Eg$ , then by (2)

$$F(p) = (1 - p)u(-L) + pu(M) = (1 - p)u(-L) + pu\left(\frac{E + L}{p} - L\right). \quad (3)$$

Hence

$$F'(p) = u\left(\frac{E + L}{p} - L\right) + u'\left(\frac{E + L}{p} - L\right) \frac{-(E + L)}{p} - u(-L).$$

The first two terms give the value obtained by substituting  $-L$  in the tangent equation to the function  $u$  at the point  $\frac{E + L}{p} - L$ . If  $u$  is a concave function, then this value is necessarily smaller than  $u(-L)$  and thus  $F'(p) < 0$ . If  $u$  is convex then  $F'(p) > 0$ .

Since by (2),  $V(g) = (E + L)^2(1 - p)/p$ , we have

$$\frac{\partial V(g)}{\partial p} = \frac{-(E + L)^2}{p^2} < 0 \Rightarrow \frac{\partial Eu(g)}{\partial V(g)} = \frac{\partial Eu(g)}{\partial p} \frac{\partial p}{\partial V(g)} = -\frac{\partial Eu(g)}{\partial p}.$$

The desired result follows now by both parts.

**Lemma 2.11** Let  $g$  be a gamble that results in a loss  $L$  and a gain  $M$ . If  $Eg \geq 0$  then all risk lovers accept

it. If  $Eg \leq 0$  then no risk averse gambler will accept it.

Proof: If  $Eg = 0$  then by (2),  $p = \frac{L}{M+L}$ . Substituting in (3) we obtain that when  $Eg=0$  then  $Eu(g)$

satisfies:

$$F\left(\frac{M}{M+L}\right) = \frac{M}{M+L}u(-L) + \frac{L}{M+L}u(M).$$

Now, if  $u(x)$  is concave then the above value is less than  $u(0) = 0$ ; that is, it is negative. By Lemma 2.10,

in this case  $F'(p) < 0$  hence  $F(p)$  is negative for  $p \geq \frac{L}{M+L}$  and risk averse agents will not accept it. The

reverse argument works for a convex utility function,  $u(x)$ .

**Theorem 2.12** *Let  $g$  be a gamble that results in a gain  $M$  with probability  $p$  and a loss  $L$  otherwise. Consider  $Q(g)$  as a function of the independent variables  $L$ ,  $M$  and  $Eg$ . Then we have:*

*If  $Eg < 0$  then  $\frac{\partial Q(g)}{\partial M} < 0$  and if  $Eg > 0$  then  $\frac{\partial Q(g)}{\partial M} > 0$ . Finally if  $Eg = 0$  then  $\frac{\partial Q(g)}{\partial M} = 0$ .*

**Proof.** Assume  $M_1 < M_2$ . Let  $g_1$  be the gamble resulting in  $M_1$  and  $g_2$  resulting in  $M_2$ . Let  $u_{\alpha}(g)$  be a CAR utility function as in Definition 2.1. Assume  $\alpha_1$  satisfies  $Eu_{\alpha_1}(g_1) = 0$ . By Th.2.4, if  $Eg < 0$  then  $\alpha_1 < 0$  which imply that  $u_{\alpha_1}(g)$  is concave. Since  $M_1 < M_2$  it follows that  $p_1 > p_2$ , and by Lemma 2.10 we have  $0 = Eu_{\alpha_1}(g_1) < Eu_{\alpha_1}(g_2)$ . Hence an agent with utility function  $u_{\alpha_1}$  accepts  $g_2$ . This implies by Th.2.4 that  $\alpha_1 < \alpha_2$ , where  $\alpha_2 < 0$  is the upper limit of taking  $g_2$ . Since  $Q = e^{-\alpha}$  we have  $Q(g_1) > Q(g_2)$  and we are done. When  $Eg > 0$  then  $\alpha_1 > 0$ , and by Lemma 2.10,  $0 = Eu_{\alpha_1}(g_1) > Eu_{\alpha_1}(g_2)$ . Hence  $\alpha_1$  rejects  $g_2$  and thus  $\alpha_2 < \alpha_1$  and  $Q(g_1) < Q(g_2)$ . If  $Eg = 0$  then  $Q(g) = 1$  and the result follows. QED

As a corollary we obtain:

**Corollary 2.13** *If  $Eg$  is fixed, then an increase in riskiness corresponds to a decrease in the set of agents that will accept the gamble.*

Proof: If  $Eg > 0$ , then by Lemma 2.11, risk lovers always accept the gamble, no matter how risky it is. By

Theorem 2.12,  $\frac{\partial Q(g)}{\partial M} > 0$ , hence by Lemma 2.10 less risk averse gamblers accept it. If  $Eg < 0$  then by

Lemma 2.11 no risk averse will accept it. By Theorem 2.12,  $\frac{\partial Q(g)}{\partial M} < 0$ , hence by Lemma 2.10 less risk lovers accept it.

For binary gambles, fixing  $Eg$  and increasing  $M$ , means increasing  $V(g)$ . Thus Theorem 2.11 implies that for fix  $Eg > 0$ ,  $\frac{\partial Q(g)}{\partial Vg} > 0$  and for  $Eg < 0$ ,  $\frac{\partial Q(g)}{\partial Vg} < 0$ .

### 3 A Model of Betting Behavior

Horse race betting is a complex example of a binary bet. Payouts are more-or-less known, when the betting is via pari-mutuel, but the probabilities of different race outcomes must be estimated. Assume that in a given race we have  $n$  horses  $h$  with prospective probabilities of winning given by  $p_h$ . Assume further that at a certain moment an amount  $\tilde{b}_h$  is bet on a horse  $h$ . We define the subjective probability that horse  $h$  will win as

$$b_h = \frac{\tilde{b}_h}{\sum_{i=1}^n \tilde{b}_i}$$

Following [Q], if the racetrack retains a fraction  $t$  of all money bet for taxes, expenses, and profit then the payoff per dollar invested on horse  $h$  is given by:

$$O_h = \begin{cases} \frac{1-t}{b_h} - 1 & \text{if the horse wins} \\ 0 & \text{otherwise} \end{cases}$$

The mean (expectation) and variance of the outcomes are given by:

$$\begin{aligned} \mu_h &= p_h O_h - (1 - p_h) = \frac{p_h(1-t)}{b_h} - 1 \\ \sigma_h^2 &= p_h O_h^2 + (1 - p_h) - \mu_h^2 = p_h(1 - p_h) \left( \frac{1-t}{b_h} \right)^2 \end{aligned} \quad (3)$$

We suggest here the following model. Our assumptions are that:

- Some of the bettors know the true probabilities of winning and some know them only with certain errors;
- the bettors may be either risk lovers or risk averse. Thus their utility functions may be either concave or convex;
- bettors are rational in the sense that they want to maximize their expected utility functions; and

- even risk lovers are subject to risk constraint. They do not accept gambles that are too risky (in the sense that the expected return according to their utility functions is negative).

We discuss first the effect of errors in information on true probabilities of winning.

Claim 1: A lack of information about the true probabilities of winning implies that the prospective winning probabilities are estimated with an f/l bias.

Proof of claim 1: Assume the true probabilities are given by the set  $\{q_h\}$  and there is an error in the estimation of these values. We assume that the error distributes equally among the horses and it is weighted by some coefficient  $\alpha$ ,  $0 \leq \alpha \leq 1$ . Thus,  $\alpha = 0$  means no error, while  $\alpha = 1$  means no prior information on the horses. Since we have  $n$  horses in the race, no information means that the winning probabilities of each horse are estimated as  $1/n$ . If a bettor has an error of weight  $\alpha$ , then he estimates the winning probabilities of a horse  $h$  by:

$$p_h = \alpha \frac{1}{n} + (1 - \alpha)q_h, \quad 0 \leq \alpha \leq 1.$$

Now, if the true probabilities satisfy  $q_1 \leq q_2 \dots \leq q_n$ , where at least one strict inequality holds, then necessarily  $q_1 < 1/n$  and  $q_n > 1/n$ . In this case  $p_1 > q_1$  and  $p_n < q_n$ . Thus the winning probabilities are estimated with an f/l bias.

Based on this result, we present four different groups of gamblers:

- A – Risk-lovers who do not know the exact objective winning probabilities.
- B – Risk-averse gamblers who do not know the exact objective winning probabilities. A representative of this type is one who is ready to spend a certain amount of money for entertainment. For this bettor, a bet on horse  $h$  is a gamble that results in either 0 or  $O_{h+1} = (1-t)/b_h$ .
- C – Risk lovers who know the exact objective probabilities. This group may contain addicted gamblers and its behavior is described in [Q].
- D – Risk-averse gamblers who know the exact objective probabilities. A representative of this type is an insider that (on the average) makes a profit from the track.

Our hypothesis is that groups A and B represent the majority of bettors at the opening and early on in most, though not necessarily all, betting markets, while groups C and D join in towards the end. To test this we discuss below how each type contributes to the bias.

Group A: By Claim 1, they use a set of probabilities  $\{p_h\}$ , which they believe is the set of true probabilities. This set is either biased or equal to the set of true probabilities  $\{q_h\}$ .

If  $p_h = b_h$  for all  $h$ , then by (3)

$$\mu_h = -t \quad \text{and} \quad \sigma_h^2 = (1-t)^2(1-b_h)/b_h \quad \text{for all } h.$$

Since all bets have the same expectation, and since bettors of group A are risk lovers, they maximize their utility functions when they bet on the horse with maximal variance. By the formula above, maximal variance is obtained for the horse with the smallest  $b_h$ , hence those bettors will increase

the amount of money bet on the horse  $h$  with the lower  $b_h$ , and so they will push the odds towards equality, that is  $b_h=1/n$  for all  $h$ . As was shown previously, any weight given to  $b_h=1/n$  is necessarily f/l biased.

If the prospective probabilities are different from  $b_h$  then we are in the situation described in [Q]'s model. As is proved there, in this situation we necessarily have a f/l bias with respect to the set  $\{p_h\}$ , which is already biased. As a result, they may increase the f/l bias.

Yet, we have some minor restrictions to [Q]. He claims that the market cannot reach an equilibrium if  $p_h = b_h$  for all  $h$ . We wish to indicate that betting on the smallest  $b_h$  may yield a gamble which is too risky even for risk lovers. This may happen for two independent reasons. The first reason could be if the utility functions of the risk lovers are not steeply concave, that is, if they are close to risk neutral. Another possible reason is if the track tax  $t$  is higher. In this case both  $Eg$  and its variance are smaller, which imply that less risk lovers accept it.

For both reasons, unlike in [Q], we may have an equilibrium even with  $p_h = b_h$ . But by Claim 1, the set  $\{p_h\}$  is already f/l biased, hence we conclude:

**Group A will contribute to the f/l bias. The bias increases if there is a lake of information. It is smaller if the track tax  $t$  is higher.**

Group B: If  $p_h = b_h$  for all  $h$ , then again all betting have the same expectation. Risk aversive agents maximize their utility functions when choosing the minimal odds, that is, the maximal  $b_h$ . In this case, we have a reverse bias. Once a horse  $h$  is overpricing, they will not bet on it and thus reduce again  $b_h$ . As a result, as a group they cannot reach equilibrium. On the other hand, recall their prospective probabilities are already biased depending on the error in estimation. We conclude:

**Group B can generate any result, even a reverse bias.**

Group C: Members of group C act according to the true winning probabilities. Here we can adopt [Q]'s model with one restriction mentioned above – they do not bet if the betting it too risky. As a result, the market can be stable also if  $p_h = b_h$ . To sum up:

**Group C contributes to f/l bias providing they are large enough risk lovers and the tax is not too high. Their contribution is smaller than that of group A since they do not have the error effect.**

Group D: Members of group D are not risk lovers, hence they bet on a horse  $h$  only if its expected return

is positive. Since  $\mu_h = \frac{p_h(1-t)}{b_h} - 1$  it follows that they will bet on a horse  $h$  only if

$b_h < p_h(1-t)$ . However, they may avoid the betting if it is too risky. This would happen if  $p_h$  is close to  $b_h$  or if  $t$  is high. As a result, when there is a big gap in mispricing the horse  $h$ , they will bet and reduce the gap. If  $t$  is high, or if there is only little mispricing, they will not act. So members of group D reduce big gaps between subjective and true probabilities. In particular they also reduce any kind of bias.

They never generate bias. To sum up:

**Group D reduces mispricing. Its members do not act when there is no mispricing. They will bet less if  $t$  is higher.**

#### **4 The F/I Bias: Empirical Evidence**

We have shown that, on the basis of remarkably simple assumptions vis a vis attitude to risk and access to information, it is possible to explain how regular, reverse and no f/I bias may arise as a result of rational bettor behavior. In particular, since the average return to betting with the tote is negative, it is reasonable to assume that most bettors at most tracks will be risk lovers and that, further, at most tracks, many of these bettors will not be fully informed as to horses winning probabilities. It is thus not surprising that most studies have found that horse betting markets are beset by a f/I bias. And yet anomalies have been found, although our model permits us to explain them.

In this section we provide further details on two of the more unexpected outcomes in betting markets and discuss them in terms of our model. The first, based on results derived by Luppi and Schnytzer (2008), deals with the Hong Kong horse betting market where, in recent years, there has been no statistically significant bias of any kind either at the start or the end of betting. The following regressions are run on a data set of 4258 Hong Kong races in which 54,335 horses took part between the 3rd of September 2000 and the 18th of October 2006. The test for a favourite-longshot bias is conducted for the probability equivalents of the prospective tote odds overnight, 5 minutes before the race and at the close of betting. As Tables I and II indicate, there is no favourite-longshot at any reasonable levels of statistical significance at any stage of the betting. Further, the information contained in the three sets of odds is different at each stage of the betting. This is evident in Table III, which shows the result of a linear probability model explaining winning probabilities as a function of the odds at the three stages of betting. All three sets of odds are statistically significant at far better than the 1% level of significance, which shows that information relevant to explaining the horses' real winning probabilities is changing as the betting proceeds and that while bettors may have errors in their probability estimates, these errors are fairly evenly distributed. It may be noted in passing that, if we examine the coefficients and standard errors in the tables more carefully than is really necessary, bettors' estimates of horses' winning probabilities become more accurate as betting proceeds.

In terms of our model, the implications are that many bettors in Hong Kong - as already suggested by Busche and Hall (1988) - must be risk averse and, further, that if there is inside or expert information that is not available to many bettors, it must be spread over horses more or less equally on average and not concentrated on favourites or longshots and that the extent of such information is not large. Some evidence in this direction is provided by the fact that most horses in Hong Kong train at either of the two tracks (owing to the cost of land in Hong Kong, which would make private training tracks prohibitively costly) and thus their training behaviour is readily observable by interested observers. Finally, the Hong Kong Jockey Club (which controls horse racing) web page (<http://www.hkjc.com/home/english/index.asp>) provides more information than is available elsewhere in the world where horses race. Thus, for example, videos of the three previous starts of all horses entered in the coming race may be viewed from various camera angles with expert commentary available in a choice of languages. Direct telecasts of barrier trials are also available free of charge on the web (<http://www.hkjc.com/english/press/btrs.asp>).

**Table I**  
*The presence of Favourite-longshot Bias and different types of bettors*

Variables	Overnight bettors	Betting 5 minutes before race start	Betting at the close
<i>Prob_00</i>	1.024971*** (.0187403)		
<i>Prob_05</i>		.9968372*** (.0127564)	
<i>Prob_fo</i>			1.000875*** (.0122404)
<i>Constant</i>	-.0017853 (.0019371)	.0004127 (.0013713)	.0000972 (.0013326)
<i>Observation</i>	20	20	20
<i>Adjusted R<sup>2</sup> (%)</i>	99.37	99.69	99.72

**Table II:** Dependent variable: Win, a dummy which receives 1 for the winning horse in the race and zero otherwise. Standard errors corrected for heteroskedasticity as required by the linear probability model are reported in parenthesis.

\*\*\* The coefficient is significant at the 0,1% level.

In order to test the presence of favourite-longshot bias, we perform an F- test on the joint hypothesis:

$$\begin{aligned}
 \text{prob}_i &= 1 \quad i = 00, 05, fo \\
 \text{Constant} &= 0
 \end{aligned}$$

**Table II**

*F-test results for the presence of Favourite -longshot Bias*

Variables	<b>Overnight bettors</b>	<b>Betting 5 minutes before race start</b>	<b>Betting at the close</b>
<i>F-test</i>	0.90	0.05	0.02
<i>(Prob&gt;F)</i>	(0.4255)	(0.9550)	(0.9817)

**Table III**  
*The role of different information sets*

Explanatory Variables	
<i>Odds open</i>	-.0030464*** (.0002629)
<i>Odds_05</i>	.0020522*** (.0003918)
<i>Odds final</i>	-.0047497*** (.0003488)
<i>Observations</i>	54,335
<i>Adjusted R<sup>2</sup> (%)</i>	3.54

**Table III:** Dependent variable: Win, a dummy which receives 1 for the winning horse in the race and zero otherwise. In addition to the explanatory variables shown in the table, the regression also contains horse-jockey interactions. Standard errors corrected for heteroskedasticity as required by the linear probability model are reported in parenthesis. \*\*\* The coefficient is significant at the 1% level.

The second example provides a direct measure of the impact of access to information on a particular betting population. It is based upon the results obtained by Schnytzer, Shilony and Thorne (2003). The data set (3430 harness races with 33233 horses starting from June 1997 to the end of February 1998 in Australia at tracks covered by the Victorian tote operator, TABCORP) covers a population of Victorian bettors who may bet on races run both inside and outside Victoria. The difference between these two race types is that the pool on betting on the races outside Victoria contains money bet by the Victorians only and thus represents an exclusively off-course population. On the other hand, when bettors bet on Victorian races, their money is pooled with on-course tote bettors in Victoria. This means

that, in this case, inside information contained in plunges with on-course Victorian bookmakers reaches the pool via the tote bets of on-course bettors (see Schnytzer and Shilony (1995)). In other words, the bettors betting on Victorian races receive more information updates as the betting proceeds than those betting on interstate races. Victorian bookmakers also bet on races being run outside Victoria but they generally rely on odds ruling at the interstate track and this information arrives in Victoria in sporadic bundles only and generally not in the last few minutes of betting.

Assuming that the mix of Victorian tote bettors as regards attitude to risk is unlikely to be affected by which race the bettor is betting on, differences in the extent of and change in the f/l bias between these betting sub-populations may be attributed to the difference in their access to information. Table IV shows the results of a regression described by Schnytzer, Shilony and Thorne (2003):

The horses were sorted by the closing payouts and the sample then divided into 30 groups of as nearly as possible equal size. In addition to the payouts at the close of betting, data were available in viable quantities for the projected payouts 1, 2, 3, 5, 7, 9, 10 and 15 minutes before the actual start of the race, and 30 minutes before the official start time of the race. The latter case was chosen to obtain a set of payouts reflecting bettor behaviour *before* bookmakers had begun to offer fixed odds on-course. These data were also sorted according to the closing payouts. Thus the payouts for these time periods in each group reflect changing bettor evaluation of the same horses over time. The same procedure was adopted for races being run in Victoria as for those being run outside the state.

...Table [IV] shows the regression results consolidated as one regression for each market, with dummy [and interaction] variables for the intercepts and slopes of the different time periods. These results indicate the more discrete nature of the interstate market, with all variables significant except the dummies for 1 minute before the close. The latter lends support to the hypothesis that, in this market, any important late changes in the bookmakers' market interstate are not transmitted. On the other hand, in the Victorian market, there is a smooth, significant change in the regression line until around the 5 minute mark, at which point the market has appeared to reach something very close to its final equilibrium. The fact that the regression constant is generally greater in the interstate market may indicate that Victorian bettors are, on average, less knowledgeable about interstate markets than their own. This would lead to more uninformed betting, a known cause of a favourite-longshot bias.<sup>9</sup> Indeed, although the bias is not removed in this market, it appears that the presence of bookmakers, as conveyors of information, is more important in this market than the domestic market.

It is clear that the elimination of a bias at least five minutes before the end of betting on Victorian races has been facilitated by the information provided to tote bettors via betting with Victorian bookmakers. It seems also reasonable to argue that the reduction in the extent of the bias in both markets is due to the entry of informed risk averse bettors into the market subsequent to the opening of the bookmakers market. Indeed, it may be the case that the persistence of a f/l bias in markets outside Australia where the tote has a monopoly on betting is due to the absence of on-course bookmakers.<sup>10</sup>

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<sup>9</sup> See Thaler and Ziemba (1988).

<sup>10</sup> The case of the UK is complicated by the presence of both on- and off-course bookmakers, a discussion of which is beyond the scope of this paper.

**Table IV**  
*Regression of Mean Win Frequency against Mean Subjective Probability*

Variable	Coefficient in Victoria	t-statistic	P>t	Coefficient in Other Markets	t-statistic	P>t
Slope	1.019355	32.164	0.000	1.107853	41.001	0.000
Slope_1	.0245735	0.542	0.589	.0650679	1.654	0.099
Slope_2	.0427793	0.934	0.351	.117948	2.928	0.004
Slope_3	.0604486	1.308	0.192	.1649855	4.011	0.000
Slope_5	.0785061	1.683	0.094	.2534352	5.922	0.000
Slope_7	.0939413	1.997	0.047	.312916	7.121	0.000
Slope_9	.1007083	2.133	0.034	.3560262	7.947	0.000
Slope_10	.1018986	2.156	0.032	.3796904	8.386	0.000
Slope_15	.1093001	2.301	0.022	.4467271	9.581	0.000
Slope_30	.3021055	5.791	0.000	.8822636	15.739	0.000
Constant	-.0020021	-0.411	0.681	-.0111775	-2.708	0.007
Dummy_1	-.0025288	-0.365	0.715	-.0066958	-1.132	0.259
Dummy_2	-.0044023	-0.633	0.527	-.0121376	-2.029	0.043
Dummy_3	-.0062212	-0.890	0.374	-.016978	-2.809	0.005
Dummy_5	-.0080795	-1.151	0.251	-.02608	-4.230	0.000
Dummy_7	-.0096684	-1.372	0.171	-.0322008	-5.152	0.000
Dummy_9	-.0103649	-1.468	0.143	-.0366371	-5.802	0.000
Dummy_10	-.0104871	-1.485	0.139	-.0390722	-6.153	0.000
Dummy_15	-.0112486	-1.589	0.113	-.0459706	-7.124	0.000
Dummy_30	-.0311057	-4.193	0.000	-.0907896	-12.604	0.000
Adjusted R <sup>2</sup>	0.9717			0.9825		
No. of obs.	300			300		

**Table IV:** **Dummy\_x** is a dummy variable for the regression constant **x** minutes before the actual start of the race (except **x = 30**, which is 30 minutes before the official race start time) and **Slope\_x** is the interaction between the slope of the regression and **Dummy\_x**.

## 5 Conclusions

In this paper we have presented a simple model which explains the presence of either an f/l, a reverse f/l bias or no bias at all in different horse betting markets. We have shown that different attitudes to risk combined with different access to information may explain all observed outcomes as being the result of rational behavior. In particular, the greater the risk lovingness and the greater the ignorance of the betting population, the greater the extent of an f/l bias. If the betting population is largely risk averse but to some extent uninformed a reverse bias may be observed. A risk averse, fully informed betting population will display no bias. By information we refer to the extent to which the winning probabilities of horses in the race are known. Finally, since the measurement of a bias is a statistical, and not deterministic, issue it is not necessary that all bettors be of a similar kind for a given outcome to be observed. In a tote market, the outcome will be determined by the type of betting population which bets the relatively greater amounts; in most horse betting markets the weight of money would appear to be risk loving and/or uninformed while Hong Kong bettors appear to be, by and large, risk averse and knowledgeable.

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